

Can citizen science complement official data sources? Case study of Luxembourg surface water quality

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Based on a joint research project with Karl Pickar*

Overview

1. Challenges and opportunities for evidence-based environmental governance in the 21st century
2. The potential of citizen science for environmental governance
3. Case study: What contribution from citizen science to water governance?
4. Conclusions and outlook

Hier steht Thema/Title der Präsentation

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1. Challenges and opportunities for evidence-based environmental governance in the 21st century

Hier steht Thema/Title der Präsentation

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Challenges of the 21st Century are...

- situated where society meets the environment and technology
- interconnected
- subject to accelerating change as population growth and our socio-industrial metabolism are exceeding the biophysical carrying capacity of the planet



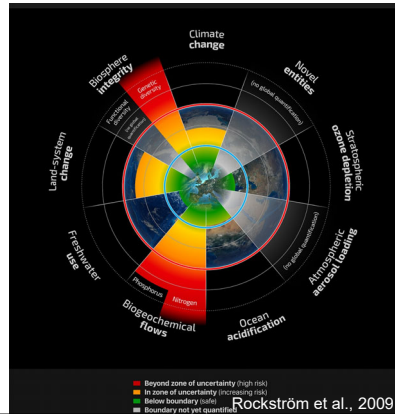
What are planetary boundaries?

Towards a safe operating space for humanity

- A framework for analysis and integration of scientific research on critical processes for an accommodating earth system.
- Developed to frame policy-making.

Critics voices:

- Relies on experts 'preaching truths to power' for a top-down sustainability. Is expert knowledge enough for societal transformation? (Castree, 2015).
- A reductionist view of human agency (O'Brien, 2015).



Sustainability in the anthropocene

Fundamental assumptions:

- Earth is conceived as a complex dynamic social-ecological-technological system
- The societal metabolism and land-use practices exceed the earth's carrying capacity
- Fundamental changes in social practices relating to production, consumption, and life-style decisions are required for sustainability transformation of our civilisation.

Resilience – from participatory sensing learning feedback loop... Holling

→ We need to better understand **how ecological, social and technological systems interact and co-produce** each other. **THIS OFTEN IS CONTINGENT ON TIME AND PLACE**



Design principles of local common resource management

- High levels of face to face communication
- Physical, technological and social infrastructures to support institutionalisation of self-governance processes
- Platforms for analytic deliberation to deal with value conflicts
- Monitoring and clear information on stocks, flows and use of scarce resources and changes therein
- Information should also address: uncertainties in assessments, changes in behaviour, values of individuals and groups

Elinor Ostroem. (1990). Governing the Commons: The Evolution of Institutions for Collective Action

Community monitoring projects as a way of natural resource management

Participatory monitoring involves multiple participants with diverse interests and forms of expertise in design and implementation of monitoring.

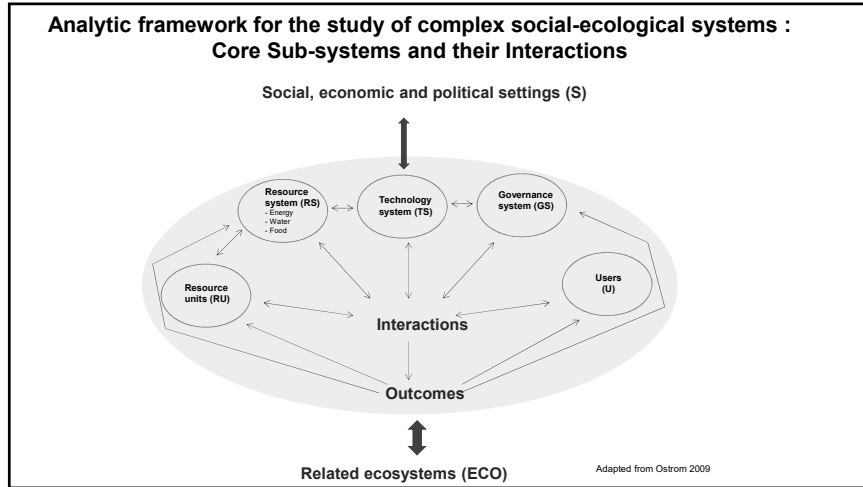
Common examples: forest-management, water quality management.

It challenges traditional stance of science located as objective knowledge outside of society.

Results:

- Transform relationship of ecosystems, local communities and economies
- Reconnect people to the land scape and to each other
- Double and at times triple loop learning were evidenced
- Appreciation of complexity, renegotiation of what is valued how in the community

Fernandez Gimenez et al, 2008



Monitoring of users and the resource: Clear information on stocks, flows, uses and changes therein (... and uncertainties)

Table 1. Examples of second-level variables under first-level core subsystems (S, RS, GS, RU, U, I, O and ECO) in a framework for analyzing social-ecological systems. The framework does not list variables in an order of importance, because their importance varies in different studies. [Adapted from (12)]

Social, economic, and political settings (S)	
S1 Economic development	S2 Demographic trends
S3 Political stability	S4 Government resource policies
S5 Market incentives	S6 Media organization
Resource systems (RS)	
RS1 Sector (e.g., water, forests, pasture, fish)	RS2 Clarity of system boundaries
RS3 Size of resource system*	RS4 Human-constructed facilities
RS5 Productivity of system*	RS6 Equilibrium properties
RS7 Predictability of system dynamics*	RS8 Storage characteristics
RS9 Location	
Governance systems (GS)	
GS1 Government organizations	GS2 Nongovernment organizations
GS3 Network structure	GS4 Property-rights systems
GS5 Operational rules	GS6 Collective-choice rules*
GS7 Constitutional rules	GS8 Monitoring and sanctioning processes
Resource units (RU)	
RU1 Resource unit mobility*	RU2 Growth or replacement rate
RU3 Interaction among resource units	RU4 Economic value
RU5 Number of units	RU6 Distinctive markings
RU7 Spatial and temporal distribution	
Users (U)	
U1 Number of users*	U2 Socioeconomic attributes of users
U3 History of use	U4 Location
U5 Leadership/entrepreneurship*	U6 Norms/social capital*
U7 Knowledge of SES/mental models*	U8 Importance of resource*
U9 Technology used	
Interactions (I) → outcomes (O)	
I1 Harvesting levels of diverse users	I2 Information sharing among users
I3 Deliberation processes	I4 Conflicts among users
I5 Investment activities	I6 Lobbying activities
I7 Self-organizing activities	I8 Networking activities
I9 Social performance measures (e.g., efficiency, equity, accountability, sustainability)	I10 Ecological performance measures (e.g., overharvested, resilience, bio-diversity, sustainability)
I11 Externalities to other SES	
Related ecosystems (ECO)	
ECO1 Climate patterns	ECO2 Pollution patterns
ECO3 Flows into and out of focal SES	

*Subset of variables found to be associated with self-organization.

Requirements of science for environmental governance

Requisites include to take account of

- Complexity
- Uncertainty and ignorance
- Contingency
- Contradictions

Resulting attributes

- Interdisciplinarity
- Connection to practice
- Local diverse forms of knowledge count

Procedural implications:
Need a new approach to combining research, governance, monitoring and social learning
From scientific analysis for prediction and control
to monitoring for analytical deliberation in multi-stakeholder processes

Opportunity:
Tap into the potential of distributed knowledge co-creation in a networked knowledge society.

On science, method, and social learning

Scientific inquiry is a planned, systematic, structured, self-critical process to create new knowledge that relies on iterative learning process from action and reflection in practice..

The purpose of inquiry...:

- ...is to achieve agreement of what to do, with what end, by what means to make life better -- other inquiry is just word play...
- Science can serve to manage but not represent realities
- The quality of science is revealed in its predictive power on how to make life better

The diagram shows a circular process of scientific inquiry. It is divided into four quadrants: 'Developing ideas for (shared) hypothesis', 'Testing Hypotheses through Action', 'Observation of consequences', and 'Following ideas, observations and reflections'. A portrait of John Dewey is in the top right corner.

2. The potential of citizen science

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Citizen Science



Maricopa Audubon Society



Wikipedia

A litany of terms have been coined describing ways that groups of non-scientists participate in research or environmental monitoring

Most definitions describe citizen science as a process of scientific inquiry involving a cooperation between members of the public and professional scientists.

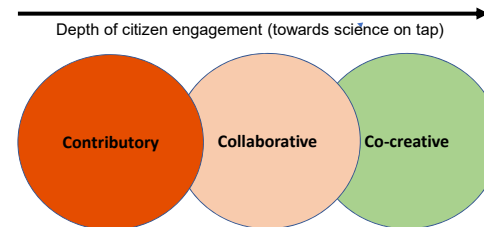
Different forms of citizen science can be distinguished based on level and stage of volunteer engagement.
More info: Haklay, 2015; Fritz et al 2019

- Volunteer monitoring
- Participatory sensing
- Citizen science
- Collaborative or multi-party monitoring
- Civic science
- Community science



Challenge traditional stance of science as objective knowledge situated outside of society.

A simpler representation of diverse forms citizen science



Adapted from Ballard 2014

EU FP7 project -- EveryAware: A participatory sensing platform for monitoring the environment and behavioural change

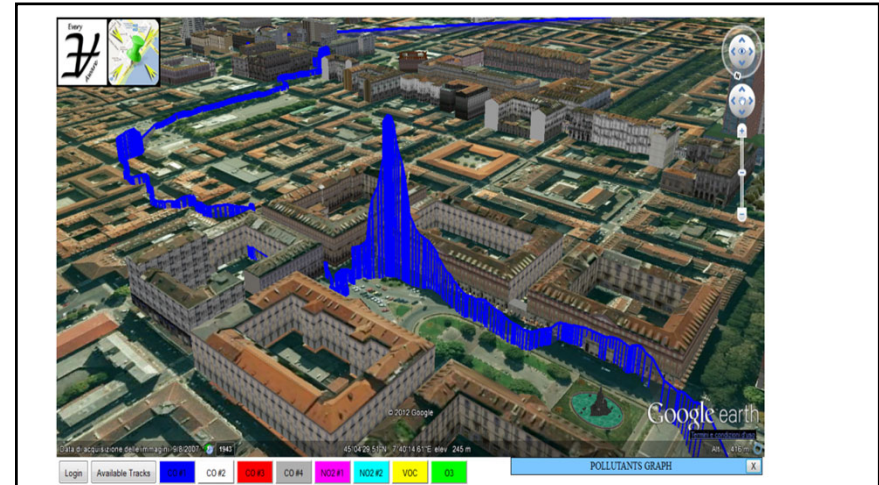
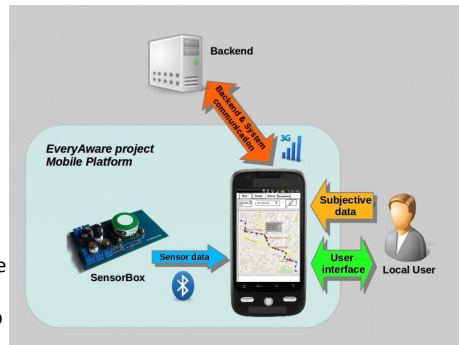
Goals:

-To Engage citizens in a techno-social integrated process

-To Enhance our collective understanding of our environment and how better to adapt to it.

Requirements:

- A SensorBox
- Networking applications: A smartphone with the free app *AirProbe*;
- Data processing tools: A dedicated web server with self-organizing data base.




A social learning process based on citizen science

- Pervasive computing and participatory sensing
- Empirical data on social, technological and environmental change and how they might interrelate
- Science looks at available data and suggests corrections of conceptions and remedial action
- Joint deliberations inspire new management strategies, which in turn can be monitored and refined.

Evolving tools of citizen science:

Tools for the co-creation of citizen science projects

<http://naturelocator.org/>




Evidence on progress towards the UN Sustainable Development Goals

SDGs are a vision for a sustainable future, and require statistical performance indicators to trace their progress.

Study of potential of Citizen Science (Fraisl et al., 2020) found it contributes to very few SDG indicators, yet has the potential to make an impact to approximately one-third of them.

Indicators within SDG 6 (Clean Water and Sanitation) are among those which could benefit the most from citizen science.

Overview of EU-27 progress towards the SDGs over the past 5 years, 2020 (Data mainly refer to 2015-2018 or 2014-2019)



Goals for which trends cannot be calculated (*)

(*) The trend information is available for member states of the EU.

3. Case study:


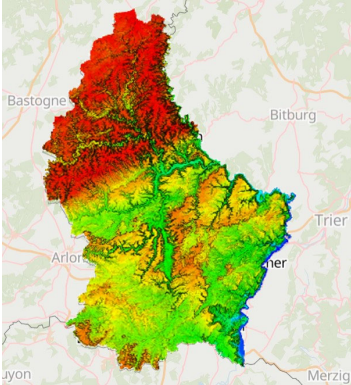
What potential for citizen science for water governance in Luxembourg?

Can Citizen Science purposefully complement official data collection on water pollution in Luxembourg – focus – nutrient content?

1. Can volunteers be engaged to get any data at all?
2. What are issues with data quality?
3. Who can and will use this data – for what purpose?

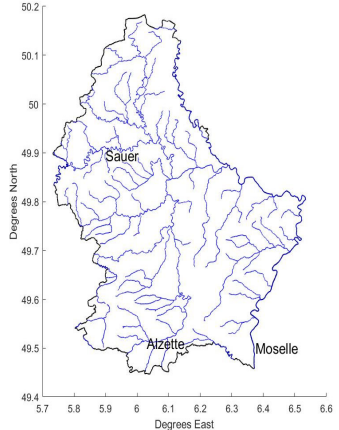
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Luxembourg

Luxembourg

- Surface area: 2,586 km²
- Landlocked
- 98% of the area inside the Rhine basin
- management of water systems is the responsibility of the Water Management Agency (AGE)
- Country's small size often causes it to be overlooked in international reports, or dismissed as a statistical anomaly



Different data types

Large scale global/national databases:

- These cover large area and usually have regular spacing. This spacing, however, is often too coarse for detailed local studies.
- For some parameters, their evolution with time is not sufficiently frequent.
- As data collection is often automated, systematic errors can be present.
- Manual data collection by experts is very expensive and thus scant in comparison to ideal data sets with sufficient sampling points in space and time.

Local datasets:

- Concentrated on points of interest, with potentially dense coverage at these points.
- Sampling is usually irregular, and includes gaps.
- These data often differ among themselves, making comparisons difficult.

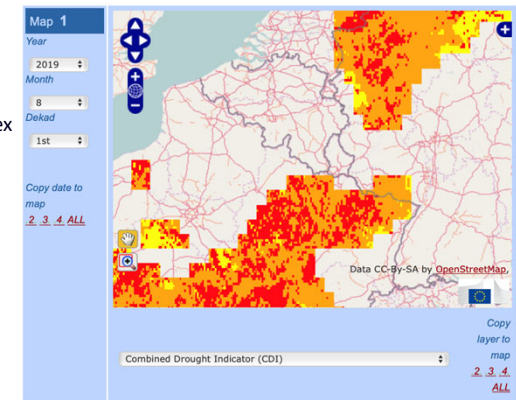
Hier steht Thema/Title der Präsentation

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Remote Sensing: merits and limitations

European Drought Observatory:

- Daily rainfall, soil moisture estimates, vegetation cover index



Hier steht Thema/Title der Präsentation

Governance as social learning – Framework for analysis: Different purposes for co-creating data for the evidence base

- **Compliance with EU and national regulations**
- **Opening new windows of accountability** concerning environmental degradation such as pollution
- **Beyond public communication - Participatory sensing and distributed learning about** the state of the environment to a wide range of stakeholders and in and the general public for awareness raising
- **Public engagement in local action fields** for environmental protection and regenerative activities
- **Participatory evaluation, reframing and improvement of existing policies and implementation measures and personal action**

1. Compliance with EU and national regulations on water quality

- 2001 Water Framework Directive specifies biological, physiochemical and hydromorphological parameters to monitor.
- Nutrient levels (nitrates and phosphates) are important indicators on ecosystem health and aquatic biodiversity.
- Challenges to data collection are associated with wide ranges of natural variability, further exacerbated by anthropogenic influences.
- Parameters in relation to water quality depend on the time of the day, the weather, season and geo-spatial considerations.

Indicator	Very Good	Good	Moderate	Unsatisfactory	Bad
Nitrate-nitrogen (NO ₃ ⁻ -N) [mg/l]	≤2.3	≤5.7	≤11.3	≤22.6	>22.6
Phosphate-phosphorus (PO ₄ ³⁻ -P) [mg/l]	≤0.033	≤0.163	≤0.326	≤0.653	>0.653

2. Accountability regarding pollution

Data sets for a full understanding of pollution emissions, including in important sites of aquatic biodiversity, the sampling density across space and time would need to be increased.

Whilst the WFD mandates sampling of larger water bodies, ecosystems with particularly high biodiversity are also often found in smaller streams and ponds.

Simple observations that may be documented with photographs may give important clues and warnings on possible sources of pollution in surface waters, such as pipes, old or leaky containers for chemicals.



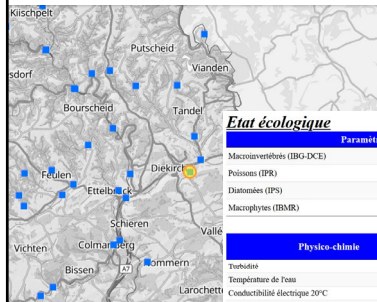
3. Public communication

Public access to environmental information has been granted in EU law building on the terms of the 1999 Aarhus Convention.

In Luxembourg results of evaluations of water quality are available online, with a map of the rivers that are subject to monitoring.

Officials were often worried about misinterpretation of such coarse representations of complex data.

3. Public communication: Geoportail



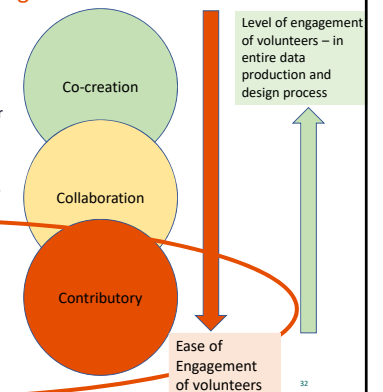
Eau écologique

Paramètres biologiques		Resultat	Etat	Valeurs seuils	Info
Microinvertébrés (IBG-DCE)	17		Info bon	16	
Poissons (IPS)					
Diatomées (IPS)	15.1		bon	13.27 - 16.81	
Macrophytes (IBMR)	8		très bon	6.23 - 9.35	

Physico-chimie		Mesures	Valeurs seuils bio-frais	Mesures mesurées	Valeurs seuils concentration maximum admissible	Etat	Nombre d'analyses
Turbidité	16.7		16	15.4	/	SDM	4
Température de l'eau	9.7	20				°C	4
Conductivité électrique 20°C	592	/	646			µS/cm	4
Oxygène dissous	11	>7	12.7			mg/l	4
Saturation en oxygène	99	/	106			%	4
Demande biochim. en oxy. (DBO-5)	1.2	3	1.7			mg/l	4
pH	8.4	7 - 8.5	8.5			-	4
Phosphore-carbo-P	0.18	0.07	0.29			mg/l	4
Phosphore total-P	0.21	0.1	0.31			mg/l	4
Ammonium-NH4	0.06	0.13	0.09			mg/l	4
Nitrites-NO2	0.05	0.16	0.07			mg/l	4
Nitrates-NO3	20.8	25	22			mg/l	4

Citizen Science on water quality WATGOV Project at the University Luxembourg

- **Co-creation:** Co-design with different stakeholders yielded overlapping indicator sets of interest to local communities (12 Interviews, meetings with the project reference group, , 3 Co-design Workshops - GEO Parc Müllerthal, Municipality of Niederanven, Natur & Ëmwelt)
- **Co-production** collaborative with DEXIA Bil – corporate partners: self-organised data sets with trained volunteers employees
- **Contributory citizen science:** Water Blitz collaboration with Fresh Water Watch- Surprising results – ...



Hier steht Thema/Titel der Präsentation

Starting tool set – not to reinvent the wheel: Earthwatch – Freshwater Watch Tool

A tested tool to collect data on water quality with citizen volunteers (kit and software)

Basic kit:

- Nitrate and phosphate level assessment by colorimetric assay
- Secchi tubes to assess turbidity with SOPs
- Over 60 optional Indikators (Handouts)

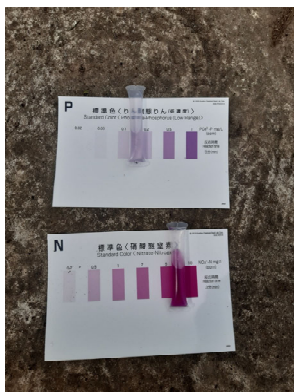


Citizen Science project: WaterBlitz

- Coordinated by FreshWater Watch in and beyond Europe.
- Anyone interested in the event could register to receive a free water testing kit.
- Data uploaded online, analysed by Uni Luxembourg (Karl Pickar, PhD).

Parameter	Description
Date	When data sample was taken
Location	Coordinates and/or detailed site description
Nitrate concentration	Match sample to one of 7 colorimetric ranges
Phosphate concentration	Match sample to one of 7 colorimetric ranges
Water Body Type	Choose from: stream, river, pond, lake, wetland, source
Land Use	Choose from: agriculture, forest, grassland/shrub, urban residential, urban park, industrial, other (specify)
Vegetation	Choose from (more than one possible): trees/shrubs, grass, other (specify)
Pollution	4 binary answers for the presence of the following: foam, litter, algae, oily sheen
Colour	Choose from: colourless, yellow, green, brown, other (specify)

Citizen Science project: WaterBlitz



Citizen Science project: WaterBlitz

The nutrient concentration data, collected in the intervals, need to be understood as ordinal data. Categories can be ordered, but not compared.

Using the guidelines for nitrate concentration to be below 5.7 mg/l for the water body to be classified as “good”, the highest two nitrate concentration intervals could thus be classified as high concentration intervals.

Citizen Science datasets are characterised by specific uncertainties.

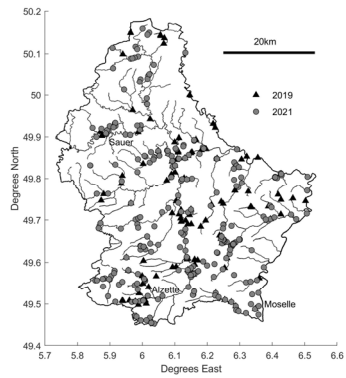
- Quality control / expert review
- Instrumental issues – sufficiently accurate equipment not always available
- Is the process followed? Should volunteer training be offered, or even obligatory?

It is a very common, yet very damaging illusion, that high uncertainty in science entails low quality.

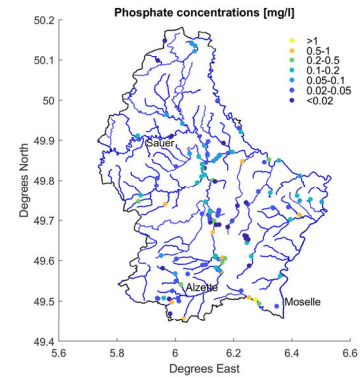
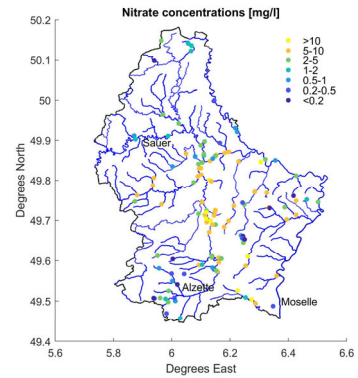
The key to quality being skilled management, not elimination, of uncertainty.

Citizen Science project: WaterBlitz

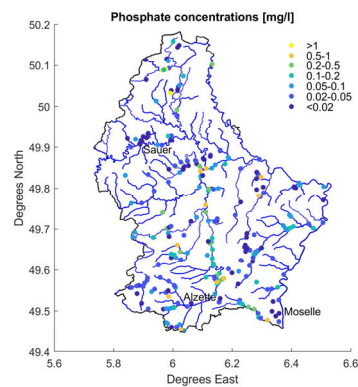
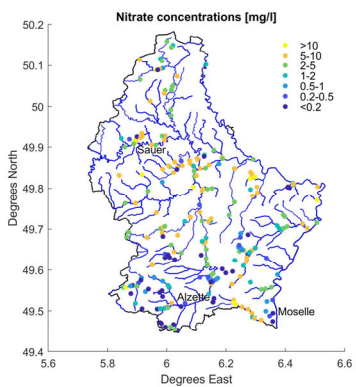
September 2019: 132 points
 May 2021: 296 points



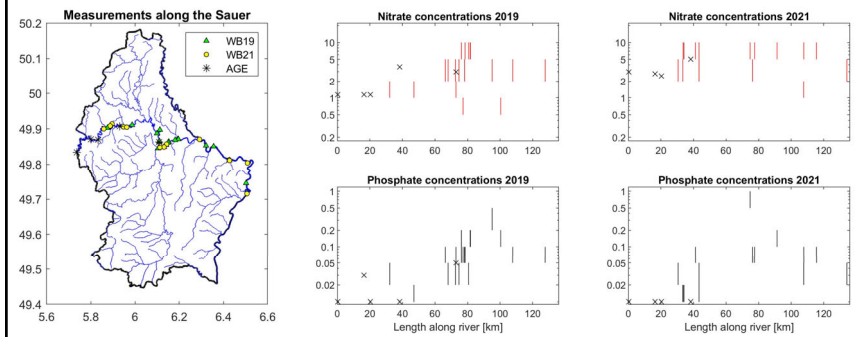
Citizen Science project: 2019 WaterBlitz



Citizen Science project: 2021 WaterBlitz



Citizen Science project: WaterBlitz – interpretations of ordinal data and uncertainties



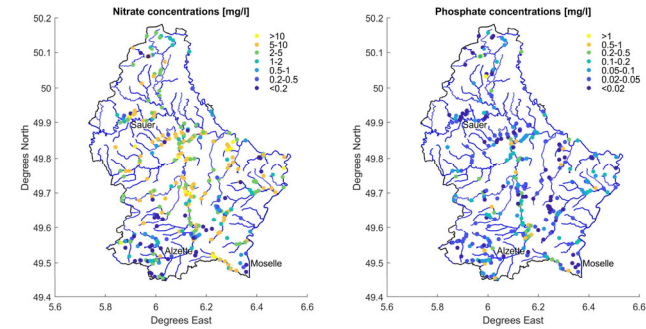
Citizen Science project: WaterBlitz

The data collected during the Water Blitz events also provides insight into smaller water bodies, which often are not sampled for official statistics.

Gander River: From the 10 readings sampling it, 3 recorded nitrate concentration in the highest available interval, >10 mg/l, and 5 further ones in the 5-10 mg/l interval. Also some of the highest phosphate concentrations.

Mullerthal Region: In an area about 10km across, 4 readings of nitrate above 10 mg/l and 8 between 5-10 mg/l were observed, with just 3 readings in other intervals.

Citizen Science project: WaterBlitz



Co-creative process with stakeholders: APP structure and indicators based

Type of water body

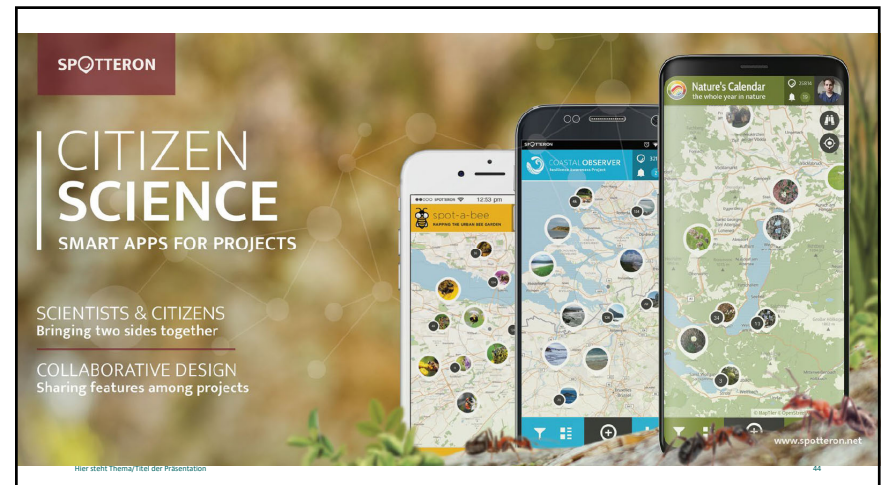
Stilles Gewässer (See oder Teich)	Fliessgewässer (Fluss oder Bach)	Quelle	Brunnen
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State of the environment

Physische Eigenschaften: <ul style="list-style-type: none"> Farbe und Oberfläche Wasserstand Fließgeschwindigkeit Sedimentgehalt Flussbett begradigt? Temperatur 	Chemischer Zustand: <ul style="list-style-type: none"> Nitrat und Phosphatgehalt pH Härtegrad Sauerstoffgehalt Schaum? 	Biologischer Zustand: <ul style="list-style-type: none"> 15-20 Zeigerarten Im Wasser Am Ufer In der Luft
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Influence of humans and technology

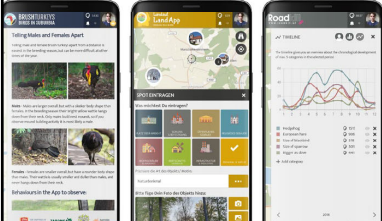

Verschmutzung/Abfall: <ul style="list-style-type: none"> Abflussrohre Plastik Klopapier Andere Auffälligkeiten 	Landnutzung : <ul style="list-style-type: none"> Siedlung Industriegebiet Landwirtschaftliche Fläche Wald Wiese 	Wie empfinde ich diesen Ort: <ul style="list-style-type: none"> Was fällt mir auf? Naturnähe Was sind meine Sinneseindrücke (sehen, hören, riechen, fühlen)? Wie fühle ich mich? Warum?
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APP CUSTOMIZATION MODULAR & FLEXIBLE TOOLS

Every Citizen Science project is individual, so we have built SPOTTERON with modularity and flexibility in mind.

The data structure, content areas, questionnaire, look & feel and project branding can all be adjusted and new custom functionalities can be developed for your project's needs.

Hier steht Thema/Titel der Präsentation 45

Comparative analysis: official data and citizen science

Purpose	Official data	Citizen science	Investments required to harness the potential of citizen science for water governance
Compliance	+	--	Development of quality criteria and quality control processes for greater acceptance of citizen science.
Accountability	+	++	Coordinated co-design of citizen science approaches and capacity building in official national and EU statistical systems for engaging in quality control.
Public Awareness	+	+++	Targeted policies and implementation to embed citizen science for water monitoring in regular practice, for example in the school curriculum.
Public Engagement in action/Empowerment	-	++	Establishment of web-platforms and social processes possibly institutionalised as interconnected living labs and citizen observatories that link local data co-creation to local action and monitoring of effects.
Reframing and improvement of policies, measures and production of the evidence base	--	+	Investment in connected social processes across the EU, such as regular workshops linking meaning-making of data co-creation and diverse view on what 'progress means' that connect across governance levels and localities.

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ANSWER TO THE THREE QUESTIONS....

- Can volunteers be engaged to get any data at all?
Yes: Water Blitz, corporate programmes show very promising results
- What are issues with data quality?
Quality control required by professional scientists
Large amount data required as they are ordinal
- Who can and will use this data – for what purpose?
Complement official data when sampling rates are low
Flag potential pollution hotspots

<https://sustainabilityscience.uni.lu/nexus-futures/citizen-science/>

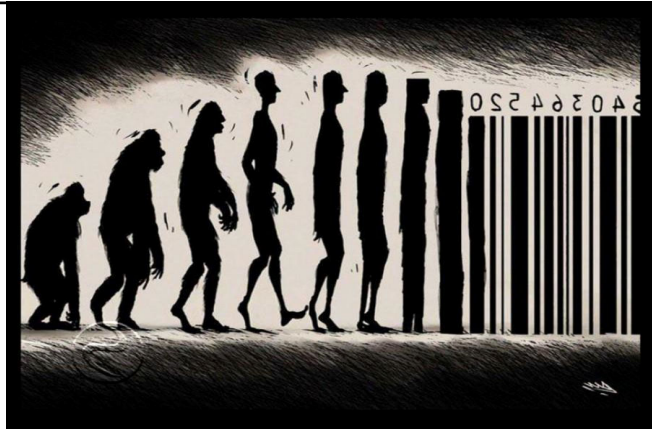
Hier steht Thema/Titel der Präsentation 47

Designing monitoring regimes

- Technologies of representation and documentation shape awareness of stocks and flows of scarce global commons and interdependence of our actions.
- They create new forms of accountability and documentation for learning.
- We constitute our identities and development trajectories from measurement regimes.
- Ethics of monitoring are complex: care of COERCIVE approaches and infringement on human rights and privacy.
- Monitoring must be embedded in reflexive social learning processes




www.geekpress.fr



In sum --- Why Citizen Science?

1. **Sense making about the environment:** Civilians can become more meaningfully engaged when they are empowered and equipped to monitor data about their own environment
2. **Gain own experience:** Civilians come to understand the nature of scientific knowledge, the meaning of data (validity & reliability) better when actively engaged in scientific inquiry.
3. **Build own local capacities and expertise:** Civilians discover how easy and quickly one can become an expert in a specific issue in their own local environment.
4. **Access without great costs:** Access to cheap ICT with enormous monitoring and storing capacity makes 'doing science' easier and more affordable.
5. **Learn to assess and evaluate dynamic complexity of environmental processes:** Monitoring social, technological and environmental change in parallel for reflection about complex systems and how to better act upon them is in reach now.
6. **Gain awareness of consequences of own actions (household contributions)...**By self-monitoring the impact of one's own actions, one can become more reflexive and effective in bringing about change.

Conclusions

- Innovation and design for the 'Great Transformation' to attain the UN SDGs will not only concern new technologies and infrastructures
- New approaches to governance in complex dynamic human environment systems require new approaches to place based knowledge co-creation processes involving social as well as technological innovation.
- Participation and evaluative data co-creation and interpretation processes are required. More meaningful approaches to aggregation and disaggregated ways to present data across scales of governance in multi level governance systems are helpful.
- Transformative science focuses on these and other questions with a view to contribute to producing knowledge for action in practice.

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Can citizen science complement official data sources that serve as evidence-base for policies and practice to improve water quality?

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Dr Ariane König, Senior researcher, Institute of Education and Society, University of Luxembourg



Dr Kristina Hondrila, Research associate, Institute of Education and Society "Development of an analytical framework for actionable knowledge for the evaluation of transformative sustainability science."



Karl Arthur Pickar, Ph.D. Candidate, Institute of Education and Society, University of Luxembourg. "Sustainable water governance from transformative learning: Exploring the potential of citizen science."



Dr Jacek Stankiewicz Post Doctoral Researcher, Earth System sciences, hydrological modelling

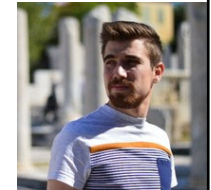

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Vielen Dank!

Transformation for resilience in complex social-ecological systems: Perspectives from ecology

Purpose:

- Built on the critique of World 3 that the model did not sufficiently account for foresight, intentionality, and the ability of people to learn.
- To identify critical features in a system that affect or trigger reorganization and transformation in response to crisis, and as such determine the resilience of a system.

Approach and assumptions/hypotheses:

- An alternative computer-based systems approach was developed to model of ecosystems under severe pressures such as boreal forests subjected to fire or insect infestations.
- The underlying assumption was that the complexity of living systems of nature and people emerges not from a random association of a large number of interacting factors, but from a smaller number of critical controlling processes that create and maintain this self-organization.
- Higher-level resilience then comes from feedback loops that can learn, create, design, and evolve ever more complex restorative structures.

Holling, 2001 ; Gunderson& Holling, 2002

Experience in self-organised systems

- The organized whole is an open system that maintains itself by exchanging with its environment:
 - matter
 - energy and
 - Information

At the level of organisms feedback mechanisms that allow to *transfer, test, and store experience* on how to adapt to changes in the environment, genetically. Also with 'epigenetics'. These evolutionary processes allow species to persist over time and help them to adapt to a changing environment.

At the level of ecosystems, experience can be transferred, tested, and stored by forming patterns of behaviours and interactions that are self-organized and can repeat themselves. (e.g. culture, social norms, practices and structures)

The adaptive cycle

Systems of nature and of humans are hierarchically organized.

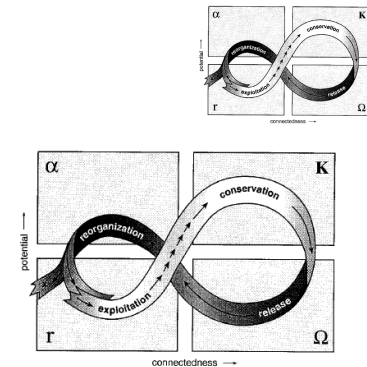
As they co-evolve, one systems constrains the other.

Systems can be seen as interlinked in nested sets interacting in never-ending transformative **adaptive cycles** of

- Growth
- Accumulation – transformation of resources (nutrient, biomass, coupling with resources and competition grows stronger)
- Restructuring – opportunities for innovation
- Renewal- novel recombinations, experiments...

The nature of the transformation is determined by the systems' characteristics relating to :

- **The inherent potential for change** (is related to 'wealth' of the range of future options possible)
- **Flexibility or rigidity is affected by the degree of connectedness of internal variables:** Internal controllability of control processes, is a measure that reflects the degree of **flexibility or rigidity** of such controls, such as their sensitivity or not to perturbation.
- **The adaptive capacity** (Or resilience) – vulnerability to unexpected shocks.



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Self-organisation, structural coupling with the environment, and resilience

- There is structural coupling between a system (e.g. building, district, a region) and its larger environment.
- The more complex the coupling (channels and dimensions across which there is material, energy and information flows), the more resilient the system can become in the face of rapid environmental change and the risk of collapse
- Systemic behaviour emerges from patterns of interactions between the constituents and the environment
- Which system has more feedback loops with its environment – a horse or a car?
- (Which one is man-made?)

Voluntary assignment: Considering feedback loops between the environment and the social spheres... write a quick paragraph with the following variables for each society....

- Frequency of Flooding
- Population on flood plain
- Memory of Flooding
- Mitigation with technology and large infrastructures
- Adaptive capacity in flood events

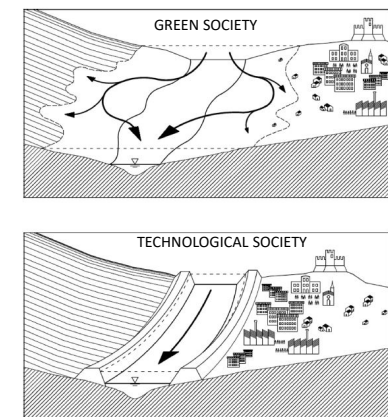


Figure 3. Schematic representation of (top) green and (bottom) technological societies.