APPENDIX 1 – CODING PROTOCOL

1. The analysis' aim

Using the SE-AS framework to describe the emergent phenomenon of our two case studies, i.e. lake ecological integrity, we aim to illustrate:

- Social-ecological dynamics, whether they are induced by human actions or ecological elements in the lakes catchment areas;
- Social dynamics that can affect ecological elements, and inversely, ecological dynamics that can affect social actors;
- Repercussions of those dynamics on ecosystems and their services, as well as on social actors and on the whole social-ecological system.

2. Definition of key terms (from Schlüter et al., 2019)

a. Action Situation (AS)

i. "(…) we expanded on Ostrom's concept of an action situation (AS). In particular, we extended the action situation beyond a purely social interaction context (social action situation, S-AS), to two other types of contexts: one that captures interactions between humans and nonhumans entities such as fish in a lake, a field, or a particular landscape, which we call a social-ecological action situation (SE-AS); and one that captures relations or interactions between ecological or biophysical elements such as predation of one species on another or the impact of a crop on soil quality, which we call an ecological action situation (E-AS)." (Schlüter et al. 2019)

ii. "(…) an action situation refers to the social space where participants with diverse preferences interact, exchange goods and services, solve problems, dominate one another, or fight (among the many things that individuals do in action arenas)." (Ostrom 2005: 14)

b. Outcomes (from Schlüter et al. 2019)

i. "(…) can be material or nonmaterial, such as a fish catch or a harvest, a perception, new knowledge, or meaning created through sense of place."

ii. "(…) are the result of actions and interactions that are enabled and constrained by rules and diverse agency, interests and goals of participating actors"

iii. "Human actors may adjust their behavior based on those outcomes (...) while ecological entities may disappear or change their functioning."

c. Phenomenon (from Schlüter et al. 2019)

"We use the term social-ecological phenomenon to refer to an empirical observation one wants to understand and explain, such as the collapse of the Baltic cod stock or a poverty trap."

3. The analytical steps

a. Lake Dümmer case

Text analysis software: MaxQDA

Number of coders: 3

i. Coding the interactions of actors, of ecological elements and of social and ecological elements the stakeholders mentioned in the interviews:
   - Individual coding: each coder codes six interviews;
   - Regular discussions on the action situations identified, their outcomes and their links; if reasonable, merging of action situation categories (codes); discussing whether some coded text is merely an assessment and no interaction;
   - Inter-coder reliability: cross-coding of the interviews among the three and checking whether coding is coherent.

ii. Assessing the action situations:
   - What do the action situations and their linkages – the configuration of action situations – tell us? Do they inform reduction of ecosystem services? Do they inform about change in dynamics in the ecosystem? Do we see an overarching phenomenon?
   - Reducing the action situations to a core set of relevant action situations that reflect the emergent phenomenon.

iii. Linking the action situations to each other; identifying the outcomes.

iv. As a final step, we go through the coded text passages, code by code and AS group by AS group (Social-Ecological, Ecological, and Social) to see if any new relevant AS emerges that we do not yet have considered; and to see which of the AS already identified might be confirmed by further identification in other interviews.

b. Lake St. Charles case

CLD analysis software: Vensim

Number of coders: 1

i. Identify the merged CLD variables as either social, ecological or social-ecological.

ii. Regroup single variables or group of variables that together illustrate the emergent phenomenon, action situations or outcomes by:
   - Selecting relevant CLD variables based on those most frequently mentioned during the interviews, as well as those with the greatest number of causal links;
   - Considering variables as part of an AS if actors or ecosystem elements can be identified within, and as outcomes if the variables were an expression of an ongoing process;
   - Color-coding the variables or groups of variables based on whether they represent social AS, ecological AS, social-ecological AS, the emergent phenomenon, external AS, or emergent outcomes.

iii. Identifying links, hence outcomes, between AS, through CLD variables causal links by:

- Considering only the strongest causal links between variables;
- When two AS were linked without any identified emergent outcomes in between, consider causal links as additional outcomes and describe them accordingly.

iv. Redrawing the AS configuration as an SES representation based on the SE-AS framework.

4. Coding rules

i. We code both explicit and implicit action situations observed in stakeholders' discourse.
ii. We identify actors within the interactions while coding.
iii. If we find a direct effect from one action situation to another, we note the outcome while coding.
iv. We can put several codes on one interaction and later discuss which code best represents the interaction.
v. We weigh the action situations (regarding their importance – times mentioned, for instance) to understand which ones are the most critical according to stakeholders.
vi. Some categories build upon each other, meaning that they may occupy the same space in an action situation configuration. We must keep this in mind when coding and when analyzing the interactions.
vii. We must remain aware of the levels encountered when coding, as described in the SE-AS framework:
    - micro-level – the actors and the ecological elements;
    - meso-level – the action situations and their configurations;
    - macro-level – system level, emergent phenomenon.
viii. We also include AS describing hypothetical, future measures, adding either a "POT" (referring to "potential") or a different color with the code.

5. List of action situations used as codes

Categories of Actions Situations are either theory-driven, based on Schlüter et al. (2019) (†) and Pahl-Wostl et al. (2020) (‡), or data-driven (§), hence newly created ones for the purpose of this study. General examples are given for each category, plus examples from the Lake Dümmer case when the category was observed there, and the included CLD variables from the Lake St. Charles case when applicable.

Name	Description	Example	Example at Lake Dümmer	Included CLD variables from Lake St. Charles case
Social-Ecological Action Situations				
Converting †	Changing sea or landscapes through technology (e.g. building a dam) or by restoring or converting use to protect ecosystems (e.g. protected areas/reserves)	Changing the lake level through dam construction, changing the littoral zone (landing stages), construction on the shoreline (building/real estate), hydrological manipulation	• Dyke built in 1953: hinders the transportation of dead biomass out of the lake; changed water level; • Converting a creek in 2009 to reduce phosphorus load of lake	• Revegetalization of lake shores • Acquisition of natural areas for conservation purposes • Protection of natural areas and of the lake • High-impact development • Road networks
Cultivating / Harvesting †	Cultivating crops, harvesting natural resources such as fish, timber, grass, and livestock	Fishing, drinking water extraction		• Amount of water available - at water intake - per capita • Quality of water at water intake • Quality of water in wells • Need to find other source of water
Cultural activities †	Performing cultural or spiritual activities in nature	School excursions, wedding celebration, work retreats, identify with the lake		
Ecological disservice §	Disservice brought by natural systems to human populations	Floods, pests, natural disasters		• Floods • Flooding
Ecological manipulation §	Changing the food-web by regular interference, maybe also Changing natural dynamics, e.g. by inhibiting pest species or supporting desired ones	Biomanipulation (planting of macrophytes, trawling whitefish)	• Desludging the lake; • Restoring to nature of Hunte River; • water level regulation; • mowing macrophytes;	

Name	Description	Example	Example at Lake Dümmer	Included CLD variables from Lake St. Charles case
			• adding oxygen to lake water; • barriers against algae	
Ecological monitoring †	Observing or measuring ecological conditions	Studies, regular reporting, iconic species observation, measurement		
Polluting †	Introducing substances into ecosystems	Nutrients, plastics, inorganic compounds from agricultural, industrial, or water sewage treatment activities (private septic tanks, communal)	Farmers apply nutrients (phosphorus) on fields	• Overflow of wasterwater from treatment plants • Aging septic tanks • Overflow of wastewater from aging sepctic tanks • Erosion; road salt; contaminated runoff • Presence of contaminated sites
Recreating †	Spending time in nature, enjoying (physically, psychologically)	Swimming, boating, hiking, bird watching	• Water sports like sailing • Biking • Bathing • Fishing	• Recreational activities • Accessibility to the lake and natural ecosystems • Contaminated boats and material • Uncontrolled access
Sparing §	A specific social action (e.g. a measure) that wilfully cares for or ameliorates an ecological component's state	The application of less or ecological friendly fertilizer on soil in order to reduce the entry of nutrients into soil and water cycle		• Management of contamination risks • Optimal management of road network • White (salt less) roads • Sustainable management of rain water • Sediment retention infrastructure
Social Action Situations				
Application of measures ‡	Application of specific measures or programs. Outputs are not plans but more tangible products	Payment schemes, reduced pesticide application rates, a new filter technique, or a new governmental authority.	Advising farmers to implement voluntary measures to reduce fertilizer usage.	• Installation of boat wash stations • Structuring of recreational activities

Competing †	Aiming to do better than other actors, may involve interfering with their activities to reduce their performance; active demand by two or more actors or groups of actors for some environmental resource/s (Merriam Webster Dictionnary)	Advertisement for lake tourism, campaigning for own action/achievements like reducing pesticide use or restoring shores		
Conflicts †	Engaging in actions that aim to harm other actors; emotional disputes between actors; mental struggles resulting from incompatible or opposing needs, drives, wishes or external or internal demands (Merriam Webster Dicitionnary)	One sector coming up with a project/plan that disturbs the actions of another sector (e.g. construction of a dam that inhibits fishing/swimming/sailing)		• Tense political climate • Trust between stakeholders • Disputes/conflicts
Conflict resolution ‡	Social interactions specifically designed to resolve conflicts.	Legal procedures (law case), round tables (regular seminars), mediation between conflicting parties by an independent third actor		• Tense political climate • Trust between stakeholders • Disputes/conflicts
Coordination ‡	Social interactions specifically designed to support the coordinated development of strategies, plans, activities, instruments, monitoring processes, taking of measurement, etc.	Facilitation of meetings and communication channels by state offices or associations that accompany the specific task	Municipalities coordinate the implementation of immediate measures together with the state office for water management, coastal protection and nature conservation	Mobilization, sensitization and accountability of citizens and professionals towards the environment and the impact they exert upon it
Deliberating †	Communicating, exchanging observations and views, reflections, assessing outcomes, persuading each other	Water associations informing their members, chambers of agriculture informing their members, deliberation within forums (see above)	Dümmer council oversees, reports on and advises the implementation of the lake's rehabilitation concept	
Enforcement of rules ‡	Monitoring the achievement of certain pre-defined goals, environmental targets etc. and procedures that assess the compli-	State offices for the environment taking regular measurement of water quality, environmental NGOs counting species and re-		Imposed regulation

	ance with rules and their enforcement, and informal observation of others behaviour which might exert social pressure	porting the numbers, state offices checking on technical standards (e.g. of sewage treatment plants) or controlling the sale of pesticides to agricultural actors, etc. Sanctions in case of non-compliance, reporting on compliance, self-reporting		
Evaluating †	Evaluating outcomes of action situations	Reports of projects and council/association meetings, independent evaluation of the implementation of measures/policy instruments by a consultancy		
Information sharing †	Sharing information or knowledge between actors	Water council meetings, encounters of actors in so-called forums (i. e. working groups, regular meetings of different sectors, conferences, etc.)	Distributing information about the lake's state to the public through a public forum twice a year	• Education of citizens, professionals and politicalactors • Information/knowledge transfer
Investing †	Allocating financial resources to restore, conserve, or convert sea or landscapes	EU-financed projects to delineate reserves, national plans for renaturalisation of rivers and lakes		Budget available for conservation actions
Knowledge generation (and its distribution among actors) ‡	Produce knowledge regarding ecosystem dynamics and relevant to other governance functions and possibly also to operational activities	Information about ecosystem dynamics (e.g. pH-value, concentration of substances, residence time of water, etc.) to inform about lake's status and the potential measures to be taken to improve its status; about new techniques that clean a lake's waters.		
Lobbying †	Influencing political actors to follow one's own interests	Information campaigning (e.g. by Greenpeace, etc.), petitions, direct lobbying of interest groups at decision-making meetings (e.g. parliamentary sessions)		Citizen pressure in defense of individual rights

Networking †	Creating and maintaining social ties	Stakeholders meet in forums (annual meetings of associations, workshops, councils) and keep contact outside the forum, stakeholders meet due to a common project (e.g. the installation of a polder, see Dümmer case)		• Consultation and harmonization within a same municipality • Consultation and cooperation between different municipalities and citizens • Consultation between decision makers, municipalities and stakeholders
Planning ‡	Produce some kind of plans regarding the use of the resource	strategic plans, operational water management plans, etc.	The water management plan for the Hunte River (as part of the remediation plan)	Interpretation of gray zones within regulation
Rule making †	Developing an operational rule, e.g. the level at which individuals can harvest a common pool resource; developing collective choice rules that determine who is involved in decision making	Supra-national directives (e.g. WFD), national and regional water law, sewage treatment regulation, policies	Remediation plan for the lake	• Standardized framing/horizontal regulation • Strict regulation/urbanistic constraints • Top-down approach from MCQ
Social monitoring †	Monitoring compliance of others	Compliance of different stakeholders with regulations or norms		
Trading †	Exchanging goods or services between two or more actors, selling products at markets	Fish selling (private business, cooperatives, patron-client), fishing licences, concessions to water extraction, boat-renting		
Ecological Action Situations				
Competition †	Individuals of the same or different species compete for a limited food resource or space	Algae-Macrophytes light and nutrient competition	• Algae and macrophytes compete for nutrients and habitat • Fish species fight for habitat and food and for oxygen	• Invasive species • Biodiversity
Facilitation †	Individuals of one species facilitate growth or reproduction of another species	Macrophytes facilitate pike reproduction		

Infection †	One organism infects another organism with a disease			
Predation †	Individuals of one species prey on another	Zooplankton on phytoplankton, bream on zooplankton, pike on bream		
Reduction §	The presence of one ecological component (in a specific state, e.g. hotter, more abundant, …) reduces the capacities of another ecological component	A high amount of macrophytes in a lake ecosystem reduces the light climate within the lake		• Cyanobacteria • Biodiversity
Species-habitat interaction †	Generation of offspring, facilitated by suitable ecological environment	Bream disturbs macrophytes and the sediment		
(Non-) Transporting §	A substance/particle in one ecological element is transported to another ecological element, e.g. via water flow, wind…; A natural flow between two ecological elements is inhibited, therefore there is a "non-transportation" between them	Phosphor in and on soil is washed off by rain and into streams and lakes. A dyke inhibits the natural flow of water in and out of a lake. The water does not transport biomass out of the lake any longer.	• Phosphorus that has been washed off the fields and into stream water is transported into lake water • Biomass cannot be washed out of the lake	• Impervious surfaces • Rainwater runoff
Vegetation - soil interaction †	Vegetation growth stabilizes soil; soil quality affects vegetation growth and vice versa	Macrophytes stabilize soil		

6. References

Ostrom, Elinor. 2005. *Understanding Institutional Diversity.* Princenton, NJ: Princeton University Press.

Pahl-Wostl, Claudia, Christian Knieper, Evelyn Lukat, Franziska Meergans, Mirja Schoderer, Nora Schütze, Daniel Schweigatz, Ines Dombrowsky, Andrea Lenschow, Ulf Stein, Andreas Thiel, Jenny Tröltzsch, and Rorigo Vidaurre. 2020 "Enhancing the capacity of water governance to deal with complex management challenges: A framework of analysis." *Environmental Science and Policy* 107: 23-35.

Schlüter, Maja, L. J. Haider, Steven J. Lade, Emilie Lindkvist, Romina Martin, Kirill Orach, Nanda Wijermans, and Carl Folke. 2019. "Capturing Emergent Phenomena in Social-Ecological Systems: An Analytical Framework." *Ecology and Society* 24 (3).