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Mapping Ostrom's common-pool resource systems coding handbook to the coupled infrastructure systems framework to enable comparative research

Michael J. Bernstein
Arizona State University, USA
mjbernst@asu.edu

Maria del Mar Mancha-Cisneros
Duke University, USA

Madeline Tyson
Arizona State University, USA

Ute Brady
Arizona State University, USA

Cathy Alida Rubiños
Universidad Del Pacífico, Peru

Hoon Cheol Shin
Arizona State University, USA

Sechindra Vallury
Arizona State University, USA

Skaidra Smith-Heisters
Arizona State University, USA

Elicia Ratajczyk
Arizona State University, USA

Abstract: In the study of common-pool resource (CPR) governance, frameworks provide a metatheoretical language to describe system states, dynamics, elements, and relationships. The coding manuals which accompany CPR frameworks–in addition to providing guidelines for connecting empirical case work to conceptual variables–define a vocabulary of coding questions. For empirical work, connecting variables and coding questions with framework elements contributes to conceptual advance. In the process of analysis and publication, it is tempting to offer a novel framework without also developing, applying, or modifying the foundational questions and variables of coding manuals buttressing said frameworks. However, if the scholarly community is to generate robust knowledge for the study of CPR dilemmas, we must provide the underlying work of comparing across frameworks. In this paper, we report on one way the community might conduct such comparisons. We present results and challenges of using a group consensus process to link the more than 450 coding questions derived from the original Institutional Analysis and Development Framework (IADF) to the recently proposed Coupled Infrastructure Systems Framework (CISF). Despite overlap, discrepancies in the conceptual positions of the IADF and CISF suggest a need to modify or create new coding variables related to concepts of system boundaries, externalities, cross-scale interactions, multi-functionality, and technological change. We suggest that such work needs provisioning if commons scholars are to navigate the continued challenges of tailoring frameworks and coding manuals to evolving CPR governance dilemmas.

Keywords: Common-pool resources, CPR frameworks, CPR governance, infrastructure, institutional analysis and development framework, qualitative coding methods, research design

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1. Introduction

The study of common-pool resource (CPR) governance–attending to complex social acts of providing for or taking possession of ecological and man-made systems–is necessarily interdisciplinary. Differing terminologies and diverse research frames among disciplines present communication, knowledge development, and theory building challenges to CPR scholars. In response to these challenges, scholars have developed a range of metatheoretical CPR frameworks. These frameworks, constituted by specific worldviews, help interdisciplinary

scholars build common vocabularies and shared understandings and thus work together toward CPR goverance theory building and model development (Binder et al. 2013; McGinnis and Ostrom 2014; Pulver et al. 2018).

Over time, numerous frameworks have been developed specifically to guide shared understanding of decision-making, collective action, and related interactions and outcomes associated with CPR governance. The Institutional Analysis and Development Framework (IADF) (Kiser and Ostrom 1982) was conceived to explain collective action in complex public economies of U.S. metropolitan areas. Since its initial application, scholars have enrolled the IADF in the systematic study of a diverse range of social dilemmas within a wide variety of CPR contexts (Ostrom 2005; Poteete et al. 2010). The IADF provides a language for comparative analysis through a vocabulary of coding questions associated with specific framework elements. This vocabulary was developed by Elinor Ostrom and colleagues through the Common-Pool Resource Research Project, a comprehensive effort to identify and evaluate coding questions of interest from more than one thousand unpublished case studies (Poteete et al. 2010) before being set down in the *Common-Pool Resource (CPR) Coding Manual* (Ostrom et al. 1989) (referred to below as "the manual[1]"). From the large number of cases that went into the creation of the manual, Ostrom and colleagues selected a smaller number for detailed analyses that would ultimately form the body of *Governing the Commons* (Ostrom 1990), earning Elinor Ostrom the Nobel Prize in Economics in 2009.

Over time, scholarship building on the IADF has generated understandings not only of social dilemmas related to human use of biophysical resources, but also of successful[2] CPR governance systems (Ostrom 2009a). These deeper understandings have, in turn, fueled the creation of additional frameworks with which to study CPRs. The Social-Ecological Systems Framework (SESF) for example, arose as an effort to improve on the IADF by giving more equal attention to biophysical and ecological dimensions of systems and facilitate interdisciplinary research in this vein (Ostrom 2007, 2009b). However, as we discuss in more detail below, while the SESF accounts for an array of social and ecological variables likely to influence collective action processes, it provides limited guidance on how to understand broader social-ecological system dynamics, interactions, or robustness beyond how variables may theoretically interact within action situations (Anderies et al. 2016, 2018). Binder et al. (2013) compared 10 frameworks[3]

[1] The coding manual includes a set of forms, instructions and coding questions.

[2] Ostrom defines successful case studies as those governed by institutions (i.e., rules, norms, and shared strategies) "...that enable individuals to achieve productive outcomes in situations where temptations to free-ride and shirk are ever present" (1990, 15). In her analysis, she uses the notion of "long-enduring systems" as well, meaning "resource systems, as well as the institutions, [that] have survived for long periods of time" (1999, 58).

[3] Driver, pressure, state, impact, response; earth systems analysis; ecosystem services; human environment systems; material and energy flow analysis; management and transition framework; socio-ecological systems framework; sustainable livelihood approach; the natural step; vulnerability framework.

widely used among CPR scholars and found no single framework sufficient to address all CPR-related research questions. Pulver et al. (2018) in a follow up study of 6 other frameworks[4] confirmed this result and highlighted a trade-off between generality in theory and context specificity in application. Existing frameworks in the study of CPR governance differ in their conceptualization, goal and applicability, and temporal, social, and spatial scale addressed (Binder et al. 2013; Pulver et al. 2018). Such differences may result, as McGinnis and Ostrom (2014) noted, from "investment in updating and improving" a framework. In addition to gradual differentiation, new frameworks also develop as scholars place different emphases on conceptual elements, states, relationships, or dynamics associated with CPR systems.

While an asset on one-hand, a rich diversity of analytical perspectives presents a challenge when comparing data across frameworks to develop knowledge and build theory (Poteete and Ostrom 2004; Binder et al. 2013; Partelow and Winkler 2016). Studies applying the same framework may differ in conceptual position. Thiel et al. (2015), for example, studied 20 publications using the SESF and found a low consistency of use and category measurement. Further, this proliferation confuses efforts to understand the relative importance of certain framework elements over others, as well as the identification of causal mechanisms related to theory building (Agrawal 2002). To address this challenge, Agrawal suggested a) greater attention be paid to comparative analyses using the same methods and b) a core set of variables be gleaned from the literature.

Research on application of frameworks to the study of CPR governance suggests a need for mechanisms–such as guidelines for operationalizing research–to improve communication and comparability across CPR frameworks (Poteete and Ostrom 2004; Thiel et al. 2015; Partelow and Winkler 2016). Binder et al. (2013) elaborated that the generality of the SESF means data collected "within its structure" could in theory be used by other CPR frameworks. For our purposes, such theoretical applicability became an empirical question. In a nod to the need to overcome this challenge, Binder et al. (2013) suggested a database for common coding questions (to help collect and share data) be developed for use across multiple frameworks. Three such data collection instruments (e.g. coding manuals), attempt to do this and are, in fact, derived from the original CPR Coding Manual: the International Forestry Resources and Institutions (IFRI) database (Poteete and Ostrom 2004), the Nepal Irrigation Institutions Systems (NIIS) database (Benjamin et al. 1994), and the Social-Ecological Systems Meta-Analysis Database (SESMAD) project (Cox 2014). Despite the connection of coding questions in IFRI and NIIS to the IADF, and of SESMAD to the SESF, only the original manual's coding questions are designed to be applied to studies across topics. The pace of development of new research frameworks thus outstrips attempts at rigorous linking of frameworks to data collection instruments or coding manuals.

[4] Human ecosystem framework; resilience; integrated assessment of ecosystem services; vulnerability framework; coupled human-natural systems; and social-ecological systems framework.

Coding manuals, or "codebooks," represent collections of questions that query for conditions important to a particular research context. When used deductively, coding questions in a codebook probe for core themes relevant to analysis of CPR governance systems. Such analyses may then be used in comparison across sectors (e.g. fisheries, forestry, etc.) and scales (e.g. local, regional, etc.) of governance within or across frameworks. One original intent of the CPR Coding Manual was to aid CPR scholars in identifying core concepts and measures when applying the IADF for multiple sectors. This original purpose makes it an ideal data collection instrument to employ for the task of comparison–subsequently –across frameworks (as urged by Binder et al. 2013). Using an established coding manual in this way–working to identify alignments and lacunae in coverage when coding variables are mapped to frameworks derivative from the IADF–can better support comparison of results from empirical research of CPR governance. This act of mapping can also enhance identification of questions common to and left unanswered by frameworks, potentially making identification of core aspects of complex issues more efficient.

Greater integration of empirical data should allow for more extensive analysis and hypothesis testing for theory development and so inform CPR governance. Doing the work of making such connections can, as McGinnis and Ostrom (2014) noted, enhance frameworks and coding manuals to "provide an essential scientific dictionary for core concepts and their subconcepts so that multidisciplinary teams of researchers can work together more effectively" (30). We have attempted a means of demonstrating the benefits possible from using a core set of variables in this manner by mapping the original CPR manual to the CISF.

In the remainder of this paper, we present a means of provisioning comparison across data collection instruments of CPR frameworks. We share results of a "mapping"[5] of the original CPR Coding Manual questions (Ostrom et al. 1989) (associated with the IADF) to a pared-down version of the Coupled Infrastructure Systems Framework (CISF)[6] (proposed by Anderies et al. (2016)). By linking coding questions in the CPR Coding Manual to the CISF, we aspired to enhance the accessibility of each of these assets to other CPR scholars. In addition, we aspired to spark a larger conversation about how we, as a community of CPR scholars, can update existing and foster development of common languages to compare CPR governance systems. The process of mapping the 455 coding questions of the manual to the ten links and four nodes of the CISF helped identify areas for further research and conceptual renewal in the field. We discuss ambiguities we encountered in the mapping process, as well as implications for provisioning future work to map across other CPR frameworks, such as the SESF.

[5] We refer to this effort as the "mapping project" or "group mapping project" throughout this manuscript.

[6] To facilitate testing of this novel approach to mapping, we omitted fine-grained distinction between private and social infrastructures also possible with the CISF.

2. Methods

We selected the CISF (see Figure 1) for substantive and pragmatic reasons. The CISF was first conceptualized as the Robustness Framework in 2004 as a way to examine interactions among four core components of CPR systems: the resource, resource users, public infrastructure providers, and public infrastructure; as well as the impact of exogenous drivers/shocks on those elements (Anderies et al. 2004). Other diagnostic frameworks (c.f., Ostrom 2007, 2009b; Binder et al. 2013; Thiel et al. 2015) also have these emphases, however, we selected the CISF in part for how it makes explicit differences of hard, social, and human infrastructures as they pertain to complex resource systems (Anderies 2015) associated with sustainability challenges (Kates et al. 2001; Matson 2009). Attention to resource systems in this general way allowed our group, with a shared interest in research on governance of complex and novel CPR systems, to also accommodate our distributed foci across traditional and social-ecological *and* non-traditional social-technical systems (see section, *Sorting Process*).

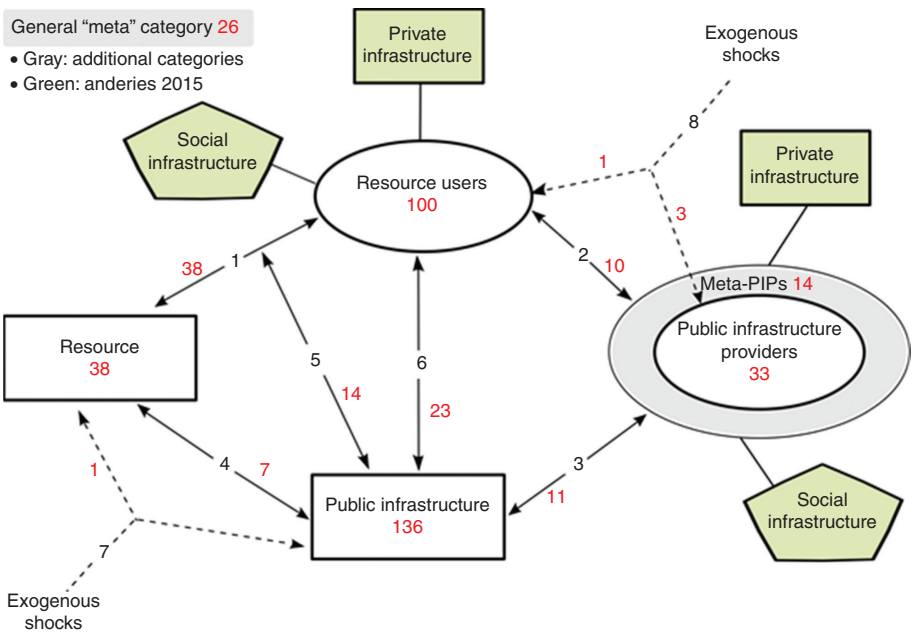

Figure 1: The Coupled Infrastructure Systems Framework, including distribution of CPR manual coding questions to CISF themes (adapted with permission from Anderies 2015). Black numbers 1–8 are original to the CISF. Red numbers reflect the number of CPR manual coding questions distributed to CISF component. Green sections indicate nuances of infrastructure types that we omitted in our analysis. The gray box and circle reflect amendments we proposed as a result of our mapping effort.

In addition, we selected the CISF for its usefulness when studying the interactions of multiple action situations within a complex CPR system in an integrated way. The CISF incorporates the exogenous elements of the IADF (biophysical context, rules, and attributes of the community of users and public infrastructure providers), allowing for integrated analysis of interactions and processes among those elements–as well as exogenous drivers and shocks to the system (Anderies et al. 2016, 2018). Thus, the CISF builds on the foundation of the IADF (and SESF), which support the analysis of decision-making, outcomes and feedbacks of a CPR system (Kiser and Ostrom 1982; Ostrom 2005; Cox et al. 2010), to further support analysis of emergent properties and co-evolution of interdependent infrastructures across multiple action situations. Where other diagnostic frameworks emphasize categories useful for framing empirical research questions, the CISF emphasizes the dynamics, resilience, and robustness of CPR governance.

In contrast to the IADF and the SESF, the CISF re-conceptualizes governance of resource–resource user interactions as an emergent feature of a system (Anderies 2015). However, as Anderies continues:

> The notion that "governance" is not something we do but, rather, something that emerges as a system feature may seem strange at first glance. Upon closer inspection, however, it becomes evident that most outputs of human activities are "emergent" in the sense that they involve inputs that are taken for granted, not a design consideration, or may even be unrecognized in the production process *(270).*

This is particularly important given the complex and often unpredictable nature of contemporary coupled infrastructure systems CIS being studied.

Finally, pragmatically, until now the CISF has lacked a specific, structured set of coding questions. Working to map IADF-sourced CPR Coding Manual questions to the CISF presented an opportunity to develop such a coding manual. Doing so in this way further enabled one of our core aspirations to explore a means of identifying alignments and lacunae in complementary frameworks used in the study of CPR governance.

2.1. Data source: original CPR coding manual

Ostrom et al. developed the original *Common-Pool Resource Systems Coding Handbook Based on the IAD Framework of Elinor Ostrom and the original CPR Project* to clarify terms used in the study of collective action dilemmas (1989).[7] The 358-page manual contains a standardized list with definitions of coding questions associated with the IADF. The manual contains an introduction to the CPR project and the IADF, as well as 11 specific coding forms (listed in Table S1

[7] References to the historical development of the coding manual are drawn from preface and introductory material in the coding manual itself. This document is available at: https://seslibrary.asu.edu/resources.

of supplementary material). These 11 coding forms contain descriptions of the overarching themes of a section; instructions for use; general notes relevant to questions within the form; a list of coding questions; and sets of response options for the analyst.

The forms of the original manual contain 455 coding questions. These questions constituted the source material for our mapping project. We counted individual coding questions as single units of observation, noting the coding form from which they were drawn. We then sorted each individual coding question into the various components of the CISF. Figure 1 offers a representation of the CISF, with elements expanding on the 2004 Robustness framework covered in grey.[8] Detailed descriptions of CISF components may be found in Table S2 of the supplementary material, as well as in Anderies et al. 2004 and Anderies 2015.

2.2. Sorting process

The mapping process was conducted by the authors (see Table S3 in supplementary material for a presentation of the departments and fields of study of coding group members). Group membership did not change during the process. The group was formed as an extension of a large-N coding project that re-examined 69 small-scale CPR case studies to determine the link between design principle co-occurrence and social/ecological success of the CPR governance system (Baggio et al. 2016; Barnett et al. 2016; Ratajczyk et al. 2016). The authors, from five different countries and three different doctoral programs, held varied academic backgrounds and research foci but all utilized a variant of CPR methods and theories to inform their research and examine complex and novel CPR systems (Table S3). Since all members of the group knew each other, had mentors in common, and pursued research questions through a CPR lens, the potential for bias cannot be ruled out. However, we worked to minimize this potential for bias through the diversity of our backgrounds and research perspectives. That the placement of many coding questions resulted in spirited discussions and required consultation with the creators of the CISF offered some indication that bias from group composition was contained.

Our group met to conduct mapping exercises in monthly 4-hour working sessions over the course of three university semesters, beginning in Fall 2015. We employed a consensus method to sort coding questions among CISF themes. Each group member led at least one sorting session for a single coding form; no group member led for more than two coding forms so as to further minimize the potential bias from any one individual in a sorting conversation. We printed the manual on paper and cut it into strips with a single coding question on each strip (marking the back of the paper with source location for tracking) to facilitate physical pile sorts.

[8] As noted in the introduction for the purposes of this initial mapping effort, we opted to maintain a coarser-grained perspective. As a result, we did not distinguish between private and social infrastructure.

At a sorting, the rotating lead group member would facilitate discussion of coding questions in their respective coding form until all questions had been discussed. When we could reach consensus on mapping a coding question to a CISF component, we taped the coding question to a large whiteboard drawing of the CISF. At any given time, two group members took digital notes: one recorded mapping relative to the CISF in a spreadsheet and into a newly created Wiki-site for further development in service of dissemination and research; the other recorded conversations surrounding placement in the mapping. Entering data into the spreadsheet enabled rapid quantitative analyses of coding question distribution among CISF components.

During the sorting process, if even one person within our group withheld consent, the code was set aside as "unresolved." We subsequently brought "unresolved" coding questions to further discussion in a second round of sorting with additional input from John M. Anderies and Marco A. Janssen, co-developers of the CISF. We complemented our notes from these sessions with recordings of our meetings with Anderies and Janssen. As we resolved each remaining issue, we summarized the rationale for each decision and recorded mapping placement in our spreadsheet and the Wiki-site. Because the process of sorting stretched over two years, these detailed meeting records served a vital function as our group's collective memory.

3. Results

Upon completing the mapping process, a majority of coding questions could be closely aligned to core sections of the CISF without extensive deliberation. In a separate methodological discussion (below), we cover those questions that required extensive deliberation. Table 1 presents an overview of the final results of our mapping effort from the 11 sections of the coding manual to the 12 components of the CISF (see Table S4 in supplementary material for the specific location of each coding question in the CISF).

The large number of coding questions mapped from the *Operational Level* and the *Subgroup* coding forms to the CISF Resource Users section makes sense, given the original coding forms related to "attributes of community" and "action situations." We found it sensible to see coding questions from "operational rules," "operational level," and "subgroup" forms distributed largely to various Links (particularly 1 and 6), Resource Users, and Public Infrastructure components of the CISF. We also found unsurprising the seamless sorting of "collective and constitutional-choice levels of analysis" information to CISF components Public Infrastructure Providers and surrounding Links (i.e. based on Public Infrastructure Providers generally assuming or being delegated authority to alter or create constitutional and collective choice rules).

The placement of a large number of coding questions related to the physical and material conditions of a CPR to the Resource component of the CISF reflects the focus in the original coding forms on physical and material conditions of a

Table 1: Distribution of coding questions among the CISF components and the coding forms of the CPR Manual.

		CISF Component														
Type of Information	CPR Coding Form	Resource	Resource Users	PI	PIPs	Meta-PIPs	Link 1	Link 2	Link 3	Link 4	Link 5	Link 6	Link 7	Link 8	Meta	Total
	1.Screener	1	1													2
Physical and material conditions of CPRs	2.Location	16	5	3	1			1			1	2			4	33
	3.Appropriation resource	19		1	7		5			4	1				2	39
Attributes of the community Action situations Patterns of interactions Outcomes	4.Operational level	1	41	21	4		24		3		5	13	1	1	13	127
	5.Subgroup	1	49	1			9	4	5		6	5			1	81
Operational rules-in-use	6.Operational rules			101								2			6	109
Collective and constitutional-choice levels of analysis	7.Country/Region/Time			4	4				1			1		2		12
	8.Collective choice		4		4											8
	9.Organizational structure			5	8	14		3	2	1				1		34
	10.Interorganizational level				5			2			1					8
	11.Nepal irrigation									2						2
	Total	38	100	136	33	14	38	10	11	7	14	23	1	4	26	455

The colors represent the ranges of the number of coding questions within each mapping category. Light blue=1–3; Medium blue=4–6; Dark blue=7–12; Light purple=13–20; Dark purple=21–50; Red=over 51 coding questions.

resource. Distributions to Link 1 and Resource Users suggests the *Location* and *Appropriation Resource* coding forms describe not only the state of a resource, but also the interactions between the Resource Users and a Resource. An example coding question from this *Appropriation* form, WATERORI, asks: "What are the main sources of water used for irrigation?", which refers to a characteristic of the Resource component within the CISF (i.e. water). As an additional example, the coding question, MAINTRES, asks "Are there specialized staff or workers to undertake maintenance?", which refers to a Public Infrastructure Provider (i.e. in charge of provisioning of maintenance infrastructure). As reflected in the absence of codes distributed to Link 2 – little attention was paid to interactions between Resource Users and Public Infrastructure Providers in the original manual.

4. Discussion

Through mapping the coding vocabulary of the IADF to the language of the CISF, we found that the majority of original CPR coding questions translated seamlessly. In the process, we identified aspects of CISF components for which no CPR coding vocabulary existed, specifically related to exogenous shocks (Links 7 and 8). We also identified aspects of CISF components for which coding vocabulary was significantly diminished, as in the case of interactions between Resource Users and Public Infrastructure Providers, Public Infrastructure Providers and Public Infrastructure, and Public Infrastructure and Resource. These gaps may be

traceable to the explicit attention of the CISF to dynamics and feedbacks among heterogenous sets of infrastructure–a feature missing from the more static focus of the IADF (Anderies et al. 2016, 2018).

A final type of finding consisted of coding questions about which we were unable to reach initial consensus when mapping. These related to four primary topics: 1) Demarcations between physical (natural) and institutional (human-made) boundaries; 2) Externalities resulting from interactions among interconnected resource systems; 3) Ambiguities among organizational actors and institutions across levels; and 4) Complications arising from conceptualizations of technology in the CISF. We found these discrepancies to be a direct reflection of the challenge of applying a CPR governance perspective to coupled infrastructure systems. Further discussion and analysis of these discrepancies–recounted below–enabled us to identify conceptual and methodological gaps in the CPR coding question vocabulary as it relates to CPR governance systems.

4.1. Methodological discussion: deliberations

4.1.1. Natural and human-made boundaries

The *Location* and *Appropriation Resource* coding forms in the original coding manual addressed issues related to physical and institutional characteristics of a resource system, including location, boundaries, and biophysical conditions. The first issue we encountered here related to a difficulty separating "natural" boundaries from "institutional" (human-made) boundaries using only the original CPR manual coding question "vocabulary." The CISF offers clear distinctions between *Natural Infrastructure* (i.e. a particular resource such as a forest or fishery) and *Public Infrastructure* (hard and soft human-made infrastructure such as a public road and a fishing regulation) (Anderies 2015; Anderies et al. 2016). Such demarcation allows for a clearer distinction between boundary creation and manipulation within the study system. In the manual, however, such distinctions are not as easily made. For example, the coding question RAINDIST asks, "What is the distribution of rainfall in this location?" Potential answers in the manual refer to rainfall spreading evenly throughout the year or being concentrated over rainy seasons. Other coding questions cover a range of "location dependent" biophysical components (e.g. temperature, dominant soil type, rainfall distribution, elevation, and size) (see supplementary Table S5). Yet use of the word "location" in these questions does not differentiate between natural or human-made locations, making the mapping from coding manual to CISF problematic.

Related, the original coding questions vocabulary is limited when trying to analyze more complex resources systems where, for example, "locations" and "boundaries" cross spatial scales. For example, the coding question "BOUNDAR2" asks the analyst to identify whether the boundary of a resource is a result of natural/constructed and/or institutional arrangements; the coding question "LOCBOUND" asks for description of how the boundaries of the location were determined (see Table S6 in supplementary material for the full details of each abbreviated coding

question related to this set of our deliberations). Neither offers a way to address potential location/boundary overlap or cross-scale interaction.

4.1.2. Complex resource externalities

Although the study of externalities is the subject of entire journals and professions, we found the subject of externalities captured only by a single question, RESCONF, in the original coding manual. This question, originally in the *Location* coding form, asks the analyst to characterize the majority of the effects between the appropriation of multiple resources as adverse, conflicting, complementary, or nested. That only a single coding question covers what today is an entire field of analysis represents a logical extension of the type of cases for which Ostrom et al. (1989) selected to further study: small-scale systems largely focused on a single primary resource, thereby inviting minimal complicating impact on other resources.

For study of more complex coupled-infrastructure systems, the question arose of how to better address externalities when mapping from coding manual to framework. Entertaining externalities in the context of the CISF gave rise to several immediate issues: 1) How to bound the analysis of a system vs its externalities; 2) How to take into account a multitude of potential inter-resource effects; and 3) How to resolve issues of scale that result from having a diversity of nested, interacting infrastructures included.

4.1.3. Ambiguities with organizations and institutions

We identified ambiguities with classifying organizations and institutions when we attempted to sort coding questions about organizations–or individuals within an organization–serving as Public Infrastructure or Public Infrastructure Providers in different circumstances. We observed three general types of ambiguities. The first related to specifying Public Infrastructure or Public Infrastructure Provider organizations in analysis (i). A second related to distinguishing between interacting operational- and collective-choice level infrastructures (ii). The third ambiguity pertained to bounding and specifying sets of infrastructures implicated by appropriation and/or provisioning (iii). Ultimately, each challenge relates to a core observation: infrastructures entail legacies of operational and collective-choice decisions.

4.1.3.1. Specifying organizations

We traced issues with specifying organizations in analysis to the *Organizational Structure and Process Form* in the manual[9] (a complete list of coding questions for which this issue arose can be found in supplementary Table S8). The coding question MEMBAPPR exemplifies this type of ambiguity. MEMBAPPR asks, "What is the relationship of the size of this organization (or group) to the number of appropriators" (Ostrom et al. 1989, 133). In the context of the CISF

[9] One coding question also came from the *Location* form.

the question may seem to be about the description of an organization, which, by nature is underlain by social infrastructure and potentially classifiable as a Public Infrastructure Provider; yet, the question also asks for description of the Resource User community. Further, the word "relationship" seems to imply the involvement of a Link, but then the request for information about number of appropriators seems generally about an organization.

4.1.3.2. Operational- and collective-choice level ambiguities

The issue of operational- and collective-choice levels of ambiguities arose in cases where a coding question plausibly referenced the execution of a rule by an individual (or organization) or inquired after the individual (or organization) charged with said execution. For example, consider the case of a water appropriator who is a member of a water appropriation association and serves formally as a water monitor. If a coding question asks for the association charged with provisioning monitoring rules, then said organization is serving to set operational level rules and operates at the collective choice level as a Public Infrastructure Provider. In this example, however, any given individual member of the association serving as a monitor might also be said to carry out enforcement at the operational level, and thus be considered Public Infrastructure.

4.1.3.3. Bounding and specifying appropriation and provisioning infrastructures

We also observed a difficulty sorting four coding questions that referenced appropriation, production, and provisioning resources. In the original manual's glossary, Ostrom et al. (1989) defined these actions as follows:

- "Appropriation Resource: One of four stages of the delivery of a resource: production, distribution, appropriation, and use" (354).
- "Production Resource: The production of water for irrigation involves making water available at locations and times when it does not naturally occur in the form of precipitation and immediate runoff" (357).
- "Provision: Provision has a distinct and separate meaning from production. The following quotation provides a definition for provision: The organization of provision relates primarily to consuming, financing, arranging for production, and monitoring the production of a set of goods and services" (357).

We found that any of the coding questions related to appropriation, production, or provisioning by design entailed a diverse array of infrastructures, thus complicating our mapping to the CISF. This observation aligns with the underlying rationale for the development of the CISF: social infrastructures are necessarily leveraged with natural infrastructures across CPR governance arrangements.

4.1.4. Complications from technology

A final general class of issue we encountered emerged as difficulties related to analyzing technology and technology systems. By and large, reference to technology in the coding manual pertains to whether "technology or technologies employed were the same throughout the period" of inquiry (Ostrom et al. 1989, 143) (see supplementary Table S9). In the original coding manual, specific questions related to rules governing the use of technology (USETECH, RULTECHC, BEGTECHX, ENDTECHX) while limited in number, were unambiguous when mapping to the CISF. Coding questions TECHEXTR, BEGNTFER, and ENDNTFER referenced the overall CPR case of interest to the analyst and were thus placed in our proposed "META" category.

Given contemporary reliance on technologies in resource governance, we noted an overall lack of attention to technology in the coding manual. For example, in the case of NEWTECH, we found the phrasing, "Is there new technology introduced?" (Ostrom et al. 1989, 167) largely underspecified key details needed for rigorous analysis with the CISF (i.e. vital analytical distinctions would result from whether and how a new technology were public or private in use or provisioning). Second, and related, we noted a difficulty in even attributing public-ness or private-ness to technologies when thinking about them as interconnected infrastructures (as the CISF encourages). Public technologies may be captured for private use and benefit. Similarly, private technologies may impinge on or be used for public benefit. Consider, for example, an unsecured home Wi-Fi-network (owner's private infrastructure, available for external public use). As a counter example, consider public road infrastructure: if a private company builds a remote facility, then public infrastructure must be built to the facility, despite *de facto* use of the "public road" for private purpose (similar for cases of water infrastructure). This complexity with demarcating technology-related externalities alerted us to the need for expanding some of the vocabulary of the CPR manual to more complex CISF case language.

4.2. Methodological discussion: proposed modifications

Our experience and results demonstrate the value of revisiting foundational methodological work to better understand various aspects of CPR governance frameworks. Doing so has helped us better understand where the field has been and–by placing the CPR Coding Manual in conversation with the contemporary CISF–identify strengths, limitations, and opportunities with original (IADF) and derivative (CISF) approaches to studying CPR governance. Below, we offer a series of recommendations for modifying existing or adding new coding questions to the CPR manual to cover areas of particular interest to the CISF (and, concurrently, of hitherto less prominence in the IADF).

4.2.1. Demarcating natural and human-made boundaries

As our collective understanding of infrastructure expands with the CISF's conceptual perspective, the IADF metatheoretical distinction of "location" from

"boundary" becomes more difficult. Consider for example the case of researchers and practitioners working on marine conservation of bluefin tuna, a species migrating thousands of miles every year. Such migration makes the idea of identifying a single study location highly problematic. This, in turn, complicates the identification of salient user groups and communities to analyze. Further, not only do different user groups need to be identified, but the multitude of different potentially relevant rules, strategies, and norms also increase in complexity with scale.

Accordingly, when mapping coding questions to the CISF, we found a need to specify certain coding questions in the CPR Coding Manual to reflect a coupled infrastructure perspective on boundaries in more complex and interconnected systems; a perspective that enables a differentiation among human mediated (e.g. demarcation of nation states), and natural (e.g. the presence of the ocean) separations. We did so by adding wording to distinguish whether a coding question refers to "natural infrastructure" (e.g. replacing "location" with "natural infrastructure" in variables COUNTRY and SOILTYPE), or "institutional infrastructure" (e.g. replacing "boundary" with "institutional infrastructure" in variables BOUNDAR3 and DISTAPPR). Table 2 outlines several examples that exemplify this rewording process. Further examples of variables that are expanded to better illustrate the distinction between location/natural infrastructure and boundary/institutional infrastructure are listed in Supplementary Table S5.

Sometimes it was necessary to lump or split coding questions in order to capture the variety of elements and interactions they represented in a more com-

Table 2: Exemplary coding questions that required expansion in order to better reflect a complex CIS perspective by distinguishing between human-defined boundaries (i.e. institutional infrastructure) and location (i.e. natural boundaries).

Original variable	Variable description	Modified variable	Modified description
COUNTRY	What is the name used TODAY for the country in which the *location* is situated?	2_RAINDIST	What is the name used TODAY for the country in which the *natural infrastructure* is situated?
SOILTYPE	What is/are the dominant soiltype(s) of the *location*?	2_SOILTYPE	What is/are the dominant soiltype(s) of the *natural infrastructure*?
BOUNDAR3	Is the *boundary* the same or smaller than the *location*?	2_BOUNDAR3	Is the *institutional infrastructure* the same or smaller than the *natural infrastructure*?
DISTAPPR	Is the *boundary* of the distribution resource roughly equivalent to the *boundary* of the appropriation resource?	2_DISTAPPR	Is the *institutional infrastructure* of the distribution resource roughly equivalent to the *institutional infrastructure* of the appropriation resource?

plex CIS. For instance, the original description of variables LOCBOUND and BOUNDAR2 failed to address issues of scale mismatch and overlap, which made it difficult to map them to the CISF. However, by lumping the content of the two coding questions and then splitting this consolidated content into three alternative coding variables (see Table 3), we were better able to connect to the appropriate CSIF components. We suggest this proposed revision will help researchers better parse their research question and identify details about a research location and system boundaries.

4.2.2. Resolving complex resource externality issues

In mapping to the CISF, we found a need for additional coding questions reflecting how "externalities" are internalized in coupled infrastructure systems. The ability to detect, manage, and engage with externalities changes depending on the scale of observation and relevance of boundaries to what is considered a relevant location. With the case of fisheries, a common example of this is pollution in or damming of waterways traversed for spawning, as happened in the case of the Kali Gandaki "A" Hydroelectric Dam (Nepal) (Larinier 2001). Fishermen who face overfishing dilemmas often have no knowledge about or leverage over "upstream" decision points. This may greatly affect their ability to predict future conditions or engage in successful collective action.

Table 3: Lumping and splitting process of variables BOUNDAR2 and LOCBOUND to better categorize the various aspects within the CISF these variables test for. Doing so facilitates analysis of interactions and key elements in the CISF, including identification of natural and/or institutional infrastructure, how institutional infrastructure is created (e.g. majority voting rules; Link 3 interaction), and how institutional infrastructure may regulate or otherwise mediate appropriation and distribution of resources in Link 1 (Link 5 interaction).

Original variable	Variable description	Revised split of coding questions
BOUNDAR2	Is the boundary the result of natural/ constructed attributes and/or institutional arrangements?	*2_BOUNDNIB:* *Are the boundaries natural, hard human-made, or institutional (i.e. soft human-made)?* *Assigned to Public Infrastructure element in the CISF*
LOCBOUND	How have the boundaries of this location been determined? (e.g. is this primarily a natural or constructed "ecosystem" boundary such as a harbor, or is the location defined institutionally as when a village is the location?)	*2_BOUNDDET:* *By what process have the institutional boundaries been determined?* *Link 3 interaction (between public infrastructure provider and public infrastructure) in the CISF* *2_BOUNDAFA:* *How do boundaries affect access?* *Link 5 interaction in the CISF (how does the public infrastructure mediate the link 1 interaction between resource users and the resource?)*

Several original coding questions (NUMBERES, GRESNAME) allow the analyst to clarify which resources will be included in the system of study. To pay greater attention to externalities, we suggest creating a new coding question, 2_RESNAMES, and reformulating several follow-up coding questions (RESNAME1, RESNAME2, RESNAME3, RESNAME4), to more specifically delineate resources being considered part of a coupled infrastructure system. Then, for any of the resources in the system that generate negative externalities or spillovers, we recommend moving the original coding question RESCONF to a "Meta Category" section of the coding manual and creating a disambiguating coding question, "2_RESCONF_M" (Table 4).

Nationalization and privatization have been seen as principal means for solving problems of externalities in CPRs from the top-down, but within successful CPRs, bottom-up solutions can include quality standards, technological prescriptions, location/temporal constraints, or any other number of rules (Arrow 2000). To help determine what human-made infrastructures (soft or hard) are created to mitigate, manage, or promote externalities, and how these infrastructures alter the dynamics of resource appropriation/production, we proposed two additional coding questions: 2_RESCONF_PI and 2_RESCONF_L5 (Table 4). 2_RESCONF_PI addresses whether public infrastructure is created to address an externality. 2_RESCONF_L5 would, in turn, capture the dynamics by which such Public Infrastructure may impact Resource use by Resource Users.

We fully recognize that additional coding questions may be needed to capture a range of other aspects of public infrastructure such as: Do Resource Users have a seat at the table in designing 2_RESCONF_PI (constitutional/collective choice levels institutions)? In what form? For what scales are 2_RESCONF_PI institutions created? How is 2_RESCONF_PI enforced? How does the physical scope of Resource 1 relate to Resource 2? What conflict resolution mechanisms are available to mitigate resource conflicts? Creation of more nuanced cross-scale coding questions would benefit from a comprehensive literature review, in-depth case study analysis, and provisioning by the community of commons scholars to further update the coding manual.

Table 4: Proposed coding questions on the topic of resource externalities and spillovers to allow for characterization of infrastructure when using the CPR manual for CISF analyses.

Proposed coding questions	Description
2_RESNAMES	Delineation of all resources to be considered in the analysis
2_RESCONF_M	Characterization of all between resource interactions (spillovers and externalities) to be considered in the analysis
2_RESCONF_PI	Is there public infrastructure created specifically to mitigate/promote externalities/spillovers?
2_RESCONF_L5	How does 2_RESCONF_PI alter resource?

4.2.3. Clarifying ambiguities with organizations and institutions

The third area we found warranting attention was how, in larger-scale, interconnected, dynamic CPR governance arrangements, communities and organizations may have multiple functions, making them difficult to disentangle as Resource Users or Public Infrastructure Providers.

4.2.3.1. Related to complexity in specifying organizations

To resolve the issue of complexity in specifying organizations, we recommend creating a "meta Public Infrastructure Provider" theme within the CISF. This "meta-PIPs" then is inspired by the "attributes of community" element of the IADF. This "meta" portion of the IADF creates a space for analysts investigating CISs to qualitatively describe Public Infrastructure Providers involved in an overarching manner. To answer the question, "What type of organization ought to be described?", we turned to the CPR coding manual itself. In the *Organizational Structure and Process Coding Form*, Ostrom et al. (1989) specify focusing on "organizations that are related to the appropriation process of the resource" (128). We recommend that organizations of focus be specified based on the nature of the social dilemma being investigated. As such, we suggest creating a coding question 2_SOCDIL to ask about the nature of the social dilemma. Our consensus was that an analyst ought to tailor his or her study to the organizations implicated by or involved in managing said social dilemma.

In amending the CISF to include a "meta-PIPs" theme, we found it useful to relocate several coding questions to this group. ORGPARAG, which requests a thick, qualitative summary description in the original question, was thus placed in meta-PIPs. For MEMBSUB, the challenge was less about describing the organization than about describing Resource Users and subgroups. Therefore, one possibility we have also considered is the addition of a meta-RU section related to resource user subgroup characterization. Establishing a meta-RU could make more straightforward the description of membership of an organization relative to subgroups where Public Infrastructure Providers are concerned.

4.2.3.2. Related to operational- and collective-choice level ambiguities

We identified a need to capture the effects created when rule development at a collective choice level may be far removed from operational level action, a phenomenon of increasing concern as the more immediate connections between governance action and resource users of original IADF cases become the exception, rather than the rule.

The need to delineate between when an agent is acting at either an operational or collective choice level capacity is prominent in situations in which the agents who are charged with implementing the rules of an organization are also engaged in collective choice decision making about the rules they are charged with enforcing. This can lead to corruption, unsustainable decision making and regulatory capture, such as has happened in fisheries and civil forfeitures. Fishery licensors have the potential to gain benefits and large rents by preferring willingness to pay

over other attributes such as knowledge of the resource or responsible fishery practices (Hanich and Tsamenyi 2009). Civil forfeiture by police demonstrates a similar challenge in which police may have the opportunity to enrich their departments through actions at the operational level, i.e. seizure of individual items of worth from individuals who are arrested (Piety 1991) based on favorable procedures police themselves craft at the collective-choice level.

The case of original coding questions FUNDS and FISOURCE offers an illustration of the way we proposed to resolve the ambiguity of operational and collective choice levels in our analysis. Each of these coding questions refer to the sourcing of funds for an organization. FUNDS, as written in the coding manual, appears to be about an attribute of the general purpose local government, and thus Public Infrastructure Providers. However, the answer choices for FUNDS imply underlying rules about taxation (e.g. "More than 80% from local taxes and related sources" 68), and thus a relationship between Public Infrastructure Providers and Public Infrastructure (Link 3). FISOURCE appears to be an attribute of an appropriation management organization, and thus also related to Public Infrastructure Providers, however, answer choices in the manual imply underlying rules about the ways that funds are permitted to be sourced, thus implicating Public Infrastructure (e.g. "Membership fee", 140). To remain true to the original CPR manual, we determined FUNDS and FISOURCE each connect to Public Infrastructure Providers. Yet we agreed there was also good reason to have coding questions explicitly dig into rules regarding the source of funding/financing of general purpose local governments and appropriation management organizations. Therefore, we propose that in the future the community of scholars studying the commons create new coding questions related to rules governing organizational financial sources for general purpose local governments and appropriation management organizations (e.g. 2_ORGFISRULG (enumerating the actual rules that enable FUNDS); 2_ORGFISRULA (enumerating the actual rules that enable FISOURCE)).

4.2.3.3. Bounding and specifying appropriation and provisioning infrastructures

The challenge of managing coding question assignment in this case became how to word a sufficiently generalizable text with respect to changes in the state of shared infrastructures. Our determination was that an alternative wording of a single question, with references to a beginning and end state, be developed and placed in a meta category for public infrastructure (PI_META). Although we hope the community will come together to develop actual wording and response options at a later date, we offer a potential re-characterization of coding questions (2_SHRDINF; 2_BEGCONDI; 2 ENDCONDI) with the text, "What are the hard-physical structures maintained by the community that are used to access, withdraw, and distribute the resource." Such a question may sufficiently capture the diversity of shared infrastructures accounted for in the original manual.

4.2.4. Addressing complications from technology

Our study revealed the need to expand attention to issues of technology in CPR systems. As CPR research frameworks like the SESF and CISF attempt to grapple with what are increasingly recognized as complex interdependent social-technical-ecological systems (Miller et al. 2014), greater inclusion of advances in scholarship related to the ways in which values and cultures shape and are shaped by technology (c.f., Callon 1987; Law 1987; Pinch and Bijker 1987, etc.) may be of increasing importance to empirical and theoretical work on CPR governance. In the CISF, we find that it is the *de facto* public- or private-ness of a technology, rather than the *de jure* deploying owner of a technology, which is most important in the ontology of the CISF. As such, we recommend splitting the NEWTECH coding question into two separate, new questions – one each about public and private infrastructures, respectively, allowing for more straightforward linking of these new coding questions to the CISF.

Questions of *de jure* vs *de facto* use of technology bring to the fore a potential opportunity for future scholarship by the community of commons scholars. Knowledge of and rights to exclusive rents of technologies confer political power to organizations, enabling them to reshape collective choice arrangements to their advantage (c.f., Schelling 1978; Joskow and Rose 1989). Technologies privilege communities of certain abilities and disadvantage others (c.f., Noble 1978; Wajcman 1991). Social groups involved in technology development have specific attributes that re-inscribe themselves on physical artifacts, and thus impose additional norms to a new user community–especially if that community has been marginalized (intentionally or unintentionally) from a development process. And of course, excluded social groups find ways to "hack" technologies designed for one context to realize benefits in a completely different one; often resulting in unintended spillover effects on natural and social infrastructures (Ika 2012). Each of the above illustrations implicates resource use; rules on the rights of parties involved in technology development; cultures of business, research, policy, user, and public communities; and rules governing the use and flow of information about such technologies. Whereas the original coding manual was not developed with such questions in mind due to its focus on small-scale CPR systems, the CISF is well suited to investigate these questions, marking an opportunity to augment the set of coding questions used by commons researchers generally, and for a better understanding of shared infrastructure systems in contemporary, "advanced, technology-dependent societies," in particular.

5. Conclusion

> *"The words we use and the ideas with which we work are the most fundamental part of human reality." – V. Ostrom 1997*

Codebooks are collections of thematic codes querying conditions important to a particular research context. Codebooks require regular review and updating when

used over longer periods of time (Bernard et al. 2017). The codes within them represent building blocks of theory development (Guest and MacQueen 2008), while frameworks, like the CISF, represent means of organizing such diagnostic inquiry to support theory building and model development (Ostrom 2005; McGinnis and Ostrom 2014; Anderies 2015). CPR frameworks necessarily prioritize "what matters" or "what counts" when it comes to resource governance. Differences across frameworks, we have shown, make it vital to be clear about the "words we use and the ideas with which we work" (Ostrom 1997)–namely the coding questions we ask and the variables and relationships we study. Analysis is nothing if not purposeful selection and exclusion; it may also entail accidental omission. Comparing across frameworks offers analysts an important opportunity to reflect on how our acts of selection, exclusion, or omission color the lenses through which we study CPR governance systems.

Ostrom's CPR coding manual represents a selection of vetted thematic codes which identify key dimensions of contemporary coupled infrastructure systems and, we find, remains generally useful for analysis of CPR governance systems. Coming from a generation of commons scholars who did not originally work with the CPR Coding Manual, we found value in tracing the history of ideas set forth by this data collection instrument to better understand two CPR frameworks separated in time and by focus. Concomitant implications of globalization and interconnected sustainability challenges make review and reorganization of several CPR variables necessary to enhance coding manual utility and framework relevance. By mapping coding manual questions to the CISF, we not only provided a common data structure for the framework but also contributed to reviewing and updating the manual's organization and content–a process relevant immediately to the IADF and adaptable for use with complementary frameworks.

In completing this work, we have enhanced communication between early and contemporary scholarship on commons governance: an homage to Ostrom's original vision of employing a, "Consistent, nested set of concepts that can be used in our analysis, research, and policy advice in a cumulative manner" (2005). Our mapping an established vocabulary of the IADF to the CISF now affords the commons research community an additional data collection instrument with which to compare cases, identify open questions, and advance theoretical inquiry. Such inquiry can be enriched as additional CPR framework languages like the SESF are also connected to the vocabulary of the original CPR coding manual.

The practice of sustaining and expanding the coding manual positions it as something of a boundary object (Star 2010). Increasing scholarly exchange around and structuring information to advance alteration and addition of coding questions in this way could further enrich interdisciplinary research on complexities of CPR governance including, among other issues: multiple, nested physical scales; human organizational scales; issues of multifunctional entities; and externalities among and heterogeneity of resource systems. Capturing the results of such exchange to a database of codebook variables could enhance transferability and knowledge building across CPR frameworks.

CPR scholars will need additional infrastructures to manage the additional complexities of expanding or re-specifying complementary frameworks and underlying coding manuals as boundary objects. Such an infrastructure for community scholarship would need to catalogue new coding questions and new processes and to establish revisions to text and definitions in coding vocabularies of the CISF, SESF, and other frameworks. Most immediately, and particularly for the CISF, this boundary object could be useful for elaborating considerations of private, public, soft-human, human-made, and social infrastructures related to Resource Users and Public Infrastructure Providers components (greyed out areas of Figure 1). To this end, we have developed a wiki (https://ciscodebook.seslibrary.asu.edu/wiki/Coding_the_Commons_Wiki) in the process of our analysis to start provisioning this function. More generally, the community might benefit from a set of additional formal social infrastructures to update existing and develop new elements of the CPR coding manual (in addition to provisioning for linking to other frameworks).

Going back to Ostrom's *Common-Pool Resource Systems Coding Handbook* helped us better understand areas of overlap, divergence, and general gaps between the IAD and CIS CPR frameworks. Understanding such relationships among CPR frameworks can support more robust synthesis of empirical work and, in turn, drive theory-building on governance of open-access resource systems. Our effort, however, demonstrates that comparison of data collection coding manuals requires the investment of a range of resources (person hours, web infrastructures, print materials, meeting space, mentoring, etc.): it requires provisioning. We hope our case of mapping coding questions to the CISF will inspire future efforts to connect CPR frameworks, such as the SESF, and spark a larger conversation about how we, as a community of CPR scholars, can take action to ensure the vocabularies, languages, and lessons of commons governance research remain vibrant and relevant far into the future.

6. Supplementary files

Supplementary tables S1 through S9 may be found through the Open Science Foundation project entry at http://doi.org/10.18352/ijc.904.s1

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