Environmental Science & Policy 66 (2016) 73–81

Contents lists available at ScienceDirect

Environmental Science & Policy

journal homepage: www.elsevier.com/locate/envsci

A continuum of governance regimes: A new perspective on co-management in irrigation systems

Ulrich J. Frey[b,*], Sergio Villamayor-Tomas[c], Insa Theesfeld[a]

[a] Martin-Luther-University Halle-Wittenberg, Von-Seckendorff-Platz 4, 06099 Halle (Saale), Germany
[b] Ernst-Barlach-Weg 25, 70569 Stuttgart, Germany
[c] Thaer Institute and IRI-THESys, Humboldt University, Germany

ARTICLE INFO

Article history:
Received 4 May 2016
Accepted 18 August 2016
Available online xxx

1. Introduction

Over the past, natural resources have been managed to a large part by the state. However, local communities increasingly account for a substantial share of management as well. Approximately 76% of the world's irrigated area (277 million hectares, 40% of the world's food production), is managed by local Water User Associations (Garces-Restrepo et al., 2007).

Since state-governance did not always met expectations in the 1960 and 1970s (Acheson, 2006), many countries increased the involvement of local resource users in the management process (see Garces-Restrepo et al., 2007 for irrigation). This development led to a variety of different forms of collaboration between governments and communities. Indeed, despite the conceptual distinction, in practice there is considerable overlap between state and community-based governance and a wide diversity of experiences (Meinzen-Dick, 2014). Different ideas have been used to coin these experiences, including joint management, *community-based management* (Gruber, 2008), (*adaptive*) *collaborative management,* and, most prominently *co-management* (Armitage et al., 2009).

Despite some indications that co-managed regimes lead to positive ecological and social outcomes (Gutiérrez et al., 2011; Meinzen-Dick, 2014), there is still little more than rudimentary knowledge about the conditions under which the sharing of power between central government authorities and local communities is more efficient than either state governance or community governance systems on their own. However, some system attributes have been pointed out to affect performance, among them size, monitoring and trust (Frey and Rusch, 2013). Other studies have pointed out that larger and more complex systems may be better served by government regimes (Schlager, 2007; Ross and Martinez-Santos, 2010). The general argument is that the greater the scale, the more coordination and expert knowledge is needed. For this purpose, state-governance may be suited better. Which institution is most appropriate often depends also on the particular local conditions in place (Meinzen-Dick, 2014).

Assessing co-management regimes faces a specification problem. There is a variety of definitions of co-management depending on how scholars understand the division of labor between states and communities (Berkes, 1994; Carlsson and Berkes, 2005; Plummer and Fitzgibbon, 2004; Yandle, 2003; Singleton, 1998). Relevant processes are, for example, institution building, power sharing, building social capital and trust (Berkes, 2009). In particular, emphasis is put on the dynamic nature of interactions between state and communities (Olsson et al., 2004; Plummer and Armitage, 2007; Berkes, 2009). Moreover, co-management is rather a continuum of governance regimes than a particular form. Comparing different types of co-managed regimes may thus require looking at the particular aspects that define those regimes.

This paper aims to move towards a diagnostic approach to co-management research by analyzing specific processes and aspects upon which state and communities divide labor and coordinate. The paper is thus concerned with the relevance of different specifications of co-management rather than testing whether "co-management" works at large. For this purpose, we explore performance implications of using different classifications of governance systems along the state-only to the community-only continuum. We define these classifications based on sets of variables that inform about how labor is divided between the state and a particular community. We are aware that there are other

* Corresponding author: Ernst-Barlach-Weg 25, 70569 Stuttgart, Germany.
E-mail addresses: ulifrey@yahoo.com (U.J. Frey), sergio.villamayor@wsl.ch (S. Villamayor-Tomas), insa.theesfeld@landw.uni-halle.de (I. Theesfeld).

http://dx.doi.org/10.1016/j.envsci.2016.08.008
1462-9011/© 2016 Elsevier Ltd. All rights reserved.

dimensions of structuring governance, e.g. state-markets-community or collaboration and coordination as well as top-down and bottom-up.

In theory, states and communities divide labor with regard to a large number of processes and aspects. In practice, however, we expect that there is a limited diversity in the way of dividing labor which makes a difference in performance. In addition, we expect that fine-grained classifications (i.e., classifications based on the observance of a large number of variables) contain fewer cases in the state-only and community-only classes and more cases in-between. Finally, we expect classifications to capture performance differently—always depending on evaluation criteria.

We focus on irrigation systems, since they are a paradigmatic example of the evolution of management paradigms in common pool natural resource management—starting with technology-centered state-governed approaches until the 1970s. In the 1980s and 90s, the focus shifted towards local management regimes, including co-management and complete devolution to community based resource management (CBRM) (Plusquellec, 2002).

The article is structured as follows. In the next section we review a selection of co-management definitions and the different aspects at which they look. We then provide a short overview on the state of the art concerning performance of natural resource management regimes across different sectors. This is followed by details on the background of this study. The methods section describes how both co-management and performance is operationalized in this study. In the results, we present a comparison of classifications and performance. These results are analysed in the discussion, followed by a conclusion.

1.1. Classification of co-management as a continuum

Co-management is contrasted to state-governance by a sharing of power and partnership for complex governance issues instead of a top-down approach by the state alone (Berkes, 2009). The latter has clear limits (Armitage et al., 2009). In co-management, multiple interests and agencies are usually involved. It has also been contrasted to community-based management by emphasizing the positive role of the state, e.g. subsidies or large-scale technical and administrative help (Ostrom, 1992; Anthony and Campbell, 2011). Ideally, co-management may combine the strengths and mitigate the weaknesses of each partner (Singleton, 1998).

Different definitions reflect different understandings about why co-management may be more suitable than community-only or state-only management. Some definitions highlight that the state and communities share responsibility and power over the management of the resource (Berkes, 2009; Berkes, 1994; Pomeroy and Berkes, 1997). As put by the World Bank, co-management is about

> "[. . .] the sharing of responsibilities, rights and duties between the primary stakeholders, in particular, local communities and the nation state; [it is] a decentralized approach to decision making that involves the local users in the decision making process as equals with the nation-state" (World Bank, 1999).

Other, more specific, definitions focus on the possibility to create synergies in the division of labor between state and communities. Koontz (2004) and Anthony and Campbell (2011), for example, highlight different ways states can complement community-based management regimes, from providing financial resources and incentives to using coercion and organizing spaces for information sharing among communities.

In recent years, studies focusing on the adaptive capacity of co-management regimes (Costanza, 1998; Berkes et al., 2003) have partly merged with co-management-approaches (Plummer and Armitage, 2007; Folke et al., 2002).

Regardless of definition, most authors emphasize the existence of a *continuum* of governance regimes in which management responsibilities are shared, i.e. allocated, to communities and/or state. In the majority of cases, however, this is neither spelled out in detail nor operationalized in any way. We return to this in the Methods section.

1.2. Co-management regimes and performance

Despite much recent research and some indications that co-managed regimes lead to positive ecological and social outcomes (Gutiérrez et al., 2011), it is still unclear whether this is a robust result. This might be related to the classification problem of co-management itself, mentioned above. Different understandings and operationalizations of co-management may result in different findings about performance.

Numerous advantages have been associated with co-management as compared to state-management: First, *a greater sensitivity to local conditions*, resulting in more sustainable harvesting, *improved compliance* through better monitoring, peer pressure and making use of local knowledge (Gutiérrez et al., 2011). Second, a *higher legitimacy*, creating incentives to comply with rules without external sanctioning (Cinner et al., 2012). Third, *equity and efficiency* of decisions is enhanced. Fourth, local capacity building helps efforts to be more *long-term* (Plummer and Armitage, 2007). Fifth, clear ownership and property rights encourage *participation* and productive involvement in decision-making (Gutiérrez et al., 2011). It is another question whether these advantages can be transferred into practice.

In forestry, numerous studies have demonstrated that certain factors, e.g. monitoring are important for successful management without explicitly addressing differences in regimes (e.g. Pagdee et al., 2006; Coleman and Steed, 2009; Gibson et al., 2005; van Laerhoven, 2010).

In fisheries, some studies have shown that co-managed regimes are associated with more positive outcomes than state regimes. For example, one study reports more beneficial outcomes in co-managed regimes for livelihoods, fish biomass and compliance with rules (Cinner et al., 2012). While not concerned with a direct comparison, another study finds robust relationships between co-management attributes and success measures like social welfare, sustainable catches and community empowerment (Gutiérrez et al., 2011).

In *irrigation* contexts, the benefits of community-based management and co-management over state-only governed systems are well understood by both scholars and practitioners (Garces-Restrepo et al., 2007). A well-known case of successful community-based management is that of Nepalese irrigation systems, where farmer-managed systems outperform agency-based systems in terms of productivity, water delivery and condition of system infrastructure (Lam, 1998 Tang, 1992). State interventions had only positive short term effects (Joshi, 2000; Lam and Ostrom, 2010).

In sum, three conclusions should be noted. First, evidence regarding the effectiveness of co-management and interventions is not conclusive, although in general co-management practices are rated as more positive than negative. Second, different operationalizations of what constitutes co-management or community-based management may be part of this inconclusive evidence. Third, there are very few studies comparing state-governed, co-managed and community-managed systems

Table 1
NIIS variables informing about division of labor between state and communities (Note: recoded values in last column are recoded again, with GOV = 1, COM = 2 and CBS = 3; see also text below).

Variable	Description/question	Values	Recoded values
WHO-BUILT	Who constructed (or initiated and directed) the system?	Farmers themselves or farmers hiring workers to construct the system (1) Government agency or official (2) Non-govermental agencies: (3)	1 = CBS 2 = GOV 3 = –
EXTREP	Does/do the leader(s), chief executive(s) or administrator(s) report to any external or higher level authority? Does the executive or administrator files reports to any external or higher level authority regularly as part of his or her usual responsibility?	Yes (1) No (2)	1 = COM 2 = CBS
EXE-CAPPR	Is/are the leader(s), chief executive(s) or administrator(s) position(s) filled by appropriators?	No (1) Yes, through elections (2) Yes, externally appointed with advice by appropriators (3) Yes, externally appointed without advice by appropriators (4) Yes, through inheritance (5)	1 = GOV 2 = CBS 3 = COM 4 = GOV 5 = CBS
ENFRULE	The enforcement of the rules of this organization (or group) is primarily undertaken by	Members of the organization (or group) itself (1) Members and external officials (2) External officials only (3)	1 = CBS 2 = COM 3 = GOV
HEAD-SAME	Are the headworks operated by the same agency(s) (or the same group(s) of people) as the appropriation resource?	Solely by the agency (1) Jointly by the agency with others (2) Solely by appropriators (3)	1 = GOV 2 = COM 3 = CBS
DIST-SAME	Is the distribution system operated by the same agency(s) (or the same group(s) of people) as the appropriation resource?	Solely by the agency (1) Jointly by the agency with others (2) Solely by appropriators (3)	1 = GOV 2 = COM 3 = CBS
INTER-VEN	Information indicating that some government or private agency has attempted to provide assistance to the system through grants, loans, technical assistance or other major forms of intervention?	No (1) Yes, Either DIHM or DOI has rebuilt the system or otherwise made major investments (2) Yes, FIWUD has undertaken major investments (3) Yes, MPLD has undertaken major investments (4) Yes, CARE/NEPAL ADB/Nepal has funded major investments (5) Yes, some other agency has undertaken major investments: (6) Yes, an Irrigation Line of Credit Program: (7)	1 = – 2– 7 = COM

directly, which is a particular problem for performance comparisons.

1.3. Background

This study builds on a pioneering study by Wai Fung Lam (Lam, 1998). This study was one of the first comparing the performance of a large number of community-based irrigation systems from an institutional analysis perspective. Lam (1998) compared the performance of farmer-managed (FMIS), agency-managed (AMIS) and jointly-managed (JMIS) systems and found that AMIS, the flagship of governmental reforms, did perform worse than older JMIS or FMIS (Lam, 1998 Tang, 1992). This study, however, left open the question of whether AMIS underperformed for reasons other than type of management. It is an open question whether the AMIS were already underperforming even before the government takeover, and whether that aspect was precisely what motivated government investments and interference. This underlines the importance of investigating further in detail differences between governance regimes, for example the question whether larger and more complex systems require state involvement in order to provide sustainable governance regimes (Ross and Martinez-Santos, 2010).

2. Methods

2.1. Operationalization of co-management and performance

Lam's (1998) definition of agency-managed (AMIS), jointly-managed (JMIS) and farmer-managed (FMIS) systems was based on one variable ("type of irrigation system"), which again was based on the formal assignment of cases to either of the mentioned three types of irrigation property regimes. In line with our research question we first suggest a more precise classification. One important variable not included in Lam's (1998) classification is that of "intervention". This binary variable captures whether the government or a non-governmental organization has provided economic, technical or any other major assistance to a system (see Table 1). Thus, in our first step of re-classification, we add that particular variable to the variable originally used by Lam to re-classify the systems into AMIS, FMIS and JMIS. This means dividing up the FMIS group into those that have been intervened (INTV) and those that have not been (FMIS). Then, we replicate Lam's performance assessment.

The data set contains a number of other governance variables. Although these variables are not as directly related to the irrigation reform in Nepal as the intervention variable, many of them inform about the division of labor between state and communities (see Table 1). We use them in our second re-classification to explore more diverse configurations of co-management. We use the following abbreviations: GOV = state-governed, COM = co-management, CBS = community-based systems. These are not to be understood as closed categories, but to describe and to operationalize a continuum of property regimes.

We organize these seven variables informing our more nuanced classification according to one central aspect of co-management—the level of participation and involvement in decision-making of local actors. Participation levels have been described as an ascending ladder ranging from a mere exchange of information to equal partnership between state and local users (see Appendix,

Table 5; Arnstein, 1969; Berkes, 1994). This ascending ladder is useful as a guide to select for participation levels in co-management (see Appendix, Table 5).

In order to operationalize the idea of a governance regimes continuum that expresses degrees of participation we use the seven variables in Table 1 to develop an index rating each answer option. We indicate state-governance with 1, co-management with 2 and community-based management with 3. No variable has been weighted. To deal with the few missing values (88% of cases had complete or almost complete information, only 4% of the cases had four or less out of seven data points that make up the index for each case), we divided the sum by the number of values. The index has a mean of 6.4 indicating the dominance of community-based systems in this sample. While we can demonstrate that this index supports the conceptualisation of management regimes as a *continuum* (see Results), we nevertheless divide this continuum into three groups (GOV, COM, CBS) in order to be able to compare performance with the traditional classifications. Furthermore, we are able to measure the shift that occurs through applying this new classification.

Performance in Lam's work was assessed by three dimensions: the physical condition of the infrastructure, a series of water delivery quality indicators, and a set of agricultural productivity indicators (see Table 2; for a full description of all variables that make up the dimensions, see Table 2 in the Appendix, variables 2–16).

It has been convincingly shown that a unidimensional model of performance does not perform too well in comparison to a model which keeps the three dimensions apart. They seem to capture different aspects of performance that should not be conflated (Lam, 1998). For this reason, we keep these dimensions separate in our analysis. The following paragraph describes the variables underlying these dimensions:

(a) *The condition of the system* is measured by estimating the overall *physical condition* of the system and the overall short-run *economic technical efficiency* of maintenance in terms of cost-benefits.
(b) *Water deliverance performance* is measured via three dimensions, namely adequacy, equity and reliability. First, adequacy is operationalized by "[. . .] a Guttman scale created by combining the six variables in the initial NIIS database that measure the availability of irrigation water at different parts of an irrigation system in different seasons." (Lam, 1998). Thus, there is data on the head and tail end respectively, for each season, monsoon, spring and winter. Second, equity of water deliverance is considered, which is a combination of three variables (see Appendix: variables 10, 11, 12). The variables quantify whether appropriators have been disadvantaged (variable 10), whether the worst off have been deprived of their benefits (variable 11) and whether the distance between least and most advantaged individuals has increased or decreased (variable 12). Equity ranges from 0 (scoring 0 in all three variables) to 4 (scoring 1 in all variables).

Third, reliability of water supply is operationalized by checking whether farmers at the tail end receive a predictable and reliable supply of water.

(c) The third dimension of success, *productivity*, is measured via three additional variables. The number of tons per hectare (variable 14) measures the yield, i.e. the output in absolute terms, whereas the head and tail intensity (variables 15 and 16) measure the cropping intensity at the head and tail end, respectively. Maximum intensities reach 300%, which means three harvests per year.

2.2. Data

Data on all the above and other independent variables below are obtained from the Nepal Irrigation Institutions and Systems (NIIS) dataset, hosted at the Ostrom Workshop in Political Theory and Policy Analysis in Bloomington. The dataset contains information about the governance of 244 local irrigation systems in Nepal. For each case there is information on 566 variables, ranging from geographic information (e.g. Terai or non-Terai), technical specifications (e.g. existence of headworks), physical attributes (e.g. size of the system), social attributes (e.g. ethnic diversity) and governance features (e.g. water allocation rules, monitoring, collective choice).

The quality of the data is very high, since each case has been checked by several coders and missing data has been complemented by revisits to Nepal. Therefore, it was not necessary to exclude cases. In general, incomplete data is not a problem with only about 5% of all 9516 (244 cases $\times$ 39 variables) data points missing. Finally, it is important to note that the data has not been collected as a random sample.

Next, we test whether different specifications of co-management affect the assessment of performance. For this purpose we explore performance differences between groups of property regimes in different classifications (Lam's classification, Lam's plus the intervention variable classification, and the 7-variable index-based classification which depicts a continuum of governance regimes). We used independent two-sided *T*-tests and Mann-Whitney-*U* tests where there was no homogeneity of variances (applies only to dimension 2: equity). All tests were calculated with the R-package stats, (www.r-project.org) with Bonferroni correction.

3. Results

3.1. Comparison of classifications

As indicated in the methods section, in our first re-classification, we added cases of intervention (INTV) to the original

Table 2
Three performance dimensions for irrigation systems (Lam, 1998).

Dimension and variable of performance	Description
Physical Condition: Condition	Physical condition of the system
Physical Condition: Economical Efficiency	Efficiency of costs and benefits of running the system
Water deliverance: Adequacy	Amount of water supply at the head/tail end during winter/monsoon/spring season
Water deliverance: Equity	Existence of inequalities or disadvantaged groups in terms of water delivery
Water deliverance: Reliability	Predictability and adequacy of water supply for tailenders
Productivity: Metricton	Agricultural production per hectare per year
Productivity: Head intensity	Number of harvests per year at the head end
Productivity: Tail intensity	Number of harvests per year at the tail end

classification by Lam. By distinguishing between farmer-managed, jointly-managed, agency-managed systems and farmer-managed systems with government intervention (INTV) a new split up is the consequence.

As can be seen in Table 3, adding intervention as a classification criterion results in a rather large shift of the majority of the 199 originally farmer-managed systems (136 or 68% of 199) into this category (INTV) while only 63 cases (32%) remain in the original category (FMIS).

In our second re-classification, we work with the seven-variable index. With this index we aim to express a continuum of governance regimes. Yet, for reasons of comparison we still split the sample up into three classes. To be able to compare classifications, we use three cut-offs. The cut-off values are based on the recoding options presented in Table 1, i.e. systems with a majority of values indicating state-governance are put in category GOV. We account for the sample being skewed towards community-managed systems by classifying regimes below 1.75 as having a prevalence for state-governance (GOV). Values between 1.75 and 2.5 point towards regimes that show a mixture of decision-making by both state and community (COM) and values above 2.5 indicate regimes that are dominated by community characteristics (CBS).

If both the broad classification by Lam (1998) and this contextual classification are compared, an overall shift of 12% of cases in other categories can be observed.

The following figure shows the distribution of systems according to the index-based classification:

Most notable, the share of 7% state-governed regimes in Lam's classification drops to only 2% in the 7-variable classification (see Table 3). Co-managed regimes increase from an 11% share to 17%, while the number of community-based regimes stays practically the same (82% vs. 81% share).

In order to characterize the classified regimes, we performed tests on the independent variables as well. For example, rule following improves from GOV to COM and is still better in CBS (KW-test, $n = 244$, $p < 0.01$), but is insignificant for JMIS and FMIS comparisons.

3.2. Comparison of performance

We begin this section with the means of each performance variable according to governance regime—both for the traditional

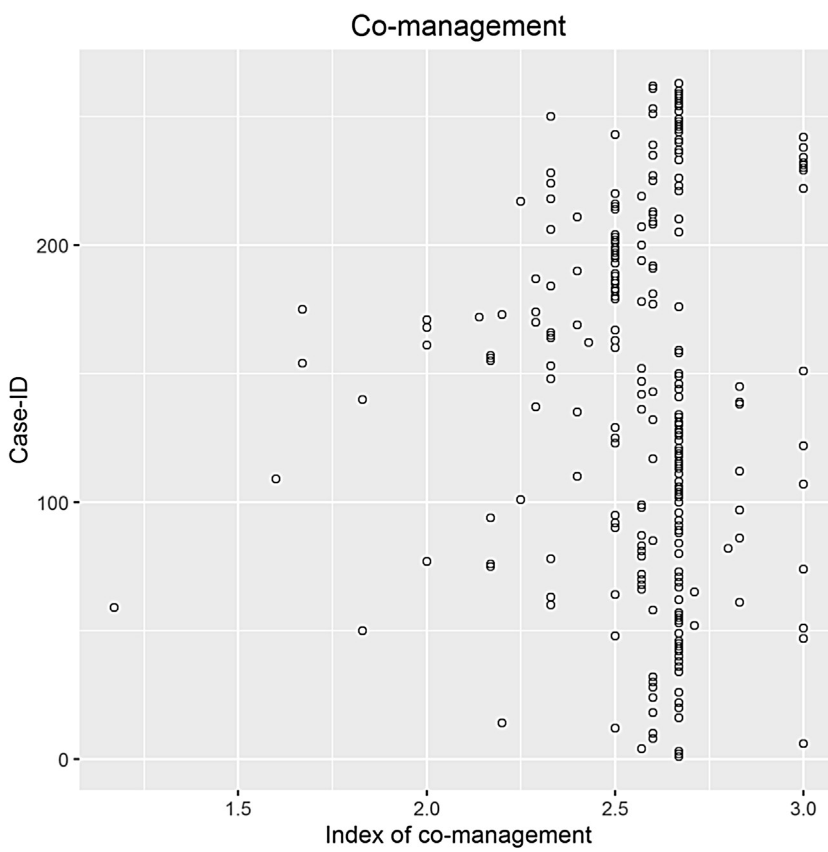

Fig. 1. Index-based continuum of co-management.

Table 3
Comparison of classifications.

Type of system	Lam (1998)	Intervention classification	7-variable index-based classification
Agency-managed irrigation systems (AMIS)	17 (7%)		4 (2%)
Joint management irrigation systems (JMIS)	28 (11%)		41 (17%)
Farmer-managed irrigation systems (FMIS)	199 (82%)	63 (26%)	199 (81%)
Government-intervened systems (INTV)		136 (56%)	

Lam's classification (AMIS, JMIS, FMIS and the added INTV) in columns two to five, while the results for the seven variables index-based classification are in columns five to seven. The first column shows the dimension for performance with the range of possible values in parenthesis. The recoding scheme can be found in the Appendix, Table 3, as well as further descriptive statistics for all variables in the Appendix, Table 1. For all performance variables, a higher value means better performance, except for condition and economical efficiency.

To assess performance, we test group differences according to Lam's classification and the seven variables index-based classification presented above. All eight performance variables are not normally distributed (Shapiro-Wilk-Test, $p < 0.01$). The three metric productivity variables are equal in variances (Levené Test for Equality of Variances n.s.), thus we conduct one-way ANOVAs with post-hoc Scheffé comparisons. Since all other performance variables are ordinal indices, Kruskal-Wallis-tests are performed with Bonferroni-correction.

Beginning with the *traditional classification*, our results align with those of Lam (1998). Community-based regimes (FMIS) perform significantly better than all other systems in adequacy of water supply (Kruskal-Wallis-test, df = 2, n = 204, $p < 0.01$) and reliability (KW-test, df = 2, n = 236, $p < 0.001$). The same is true for productivity, where more metric tons (Anova, df = 2, $p < 0.05$), and a higher head and tail intensity are produced by FMIS than by AMIS or JMIS (Anova, df = 2, $p < 0.001$). Post-hoc Scheffé tests show that differences occur between FMIS and both AMIS and JMIS respectively. In contrast, agency-based regimes (AMIS) are significantly better in condition and economical efficiency of the system (KW-test, df = 2, n = 242, $p < 0.001$).

Conforming with theory, FMIS and CBS show a statistically higher rule compliance than all other forms of management, show a higher level of local activity and have a better working system of monitoring and sanctioning (MW-test, n = 242, $p < 0.05$). In addition, FMIS exhibit more trust (MW-test, n = 242, $p < 0.01$). This is not true for CBS comparisons.

Farmer-managed systems with government intervention (INTV) perform better in water adequacy than all other systems combined as one group (t-test, n = 242, $p < 0.01$ with Bonferroni correction). No significant differences can be found for water reliability and productivity. Regarding condition and economical efficiency, systems with intervention perform worse (Mann-Whitney-*U* test, n = 242, p = 0.029).

Moving on to the *seven variables index-based classification*, we see that a more nuanced approach limits significant differences between groups (GOV, COM, CBS) to physical condition, economical efficiency and head intensity with community-based systems performing worst in physical condition (KW-test, n = 242, $p < 0.05$) and economical efficiency (KW-test, n = 242, $p < 0.01$), but best in head intensity (KW-test, n = 242, $p < 0.05$). Post-hoc tests reveal that differences occur between all groups. There is no significant difference in equity. For productivity, the only post-hoc Scheffé-test that shows significant differences is between GOV and CBS for head intensity (Anova, df = 2, $p < 0.05$). In addition, we find significant positive correlations between the index and physical condition (Spearman's rho = 0.15, $p < 0.01$; lower values indicating better performance), between index and tail intensity (Spearman's rho = 0.18, $p < 0.01$) and water adequacy (Spearman's rho = 0.22, $p < 0.01$).

Due to infrastructure provision problems, larger and more complex systems often have to rely on state-engagement. Therefore another question comes up: Are larger systems in our sample rather managed by the state than by communities? Within this sample, we can reject this hypothesis, since we find the same number of community-based systems (45) in the small and the large system subsample (index-based). The number of co-managed systems is almost equal as well (76 in the small vs. 72 in the large sample), as are state-managed systems, 1 vs. 5. These differences are not significant (Chi-Square-Test, p = 0.82).

4. Discussion

4.1. Classification

We have shown that the number of cases in each category changes depending on classification, even when only one variable is added to Lam's classification. This clearly shows the empirical volatility of co-management as a concept and the need to be very explicit about how this concept is operationalized, i.e. which specific variables are referred to as determinants. Still, we find some congruence across classifications which shows that there is indeed a limited diversity of patterns.

Results do not diverge too sharply between indices. This makes us confident that the variables used do indeed capture key aspects of collaboration and thus align with previous efforts. However, some differences emerge (see Appendix, Table 1): trust and participation levels that have traditionally as well as in Lam's classification been seen as important distinctive features between regimes become insignificant in our direct comparison.

The conceptualization of co-management as a continuum of governance-related variables is not only possible but also makes sense. Our results illustrate how, as we increase the number of variables that make up the classification, the number of state-only regimes decreases. In fact, the distinction of state-only vs. community-only management regimes is rather artificial as there is always some level of interaction between states and communities.

One main argument of this paper is that the distinction between state, co-management and community-based regimes can be understood along a continuum of governance variables. However, here, the continuum is again subdivided into three groups. The first reason for re-introducing three groups is a pragmatic one—i.e. to be able to compare new and old classification in respect to performance but also to other independent variables. In addition, the former, supposedly clear-cut groups have been replaced with fuzzy *clusters* of systems, which is more plausible from a practioner's point of view. More importantly, "purely" state-governed systems based on Lam's classification have been revealed to be practically non-existent. Moreover, systems that show co-managed characteristics become more common (an increase from 11% share to 17%).

Our analysis of the characteristics of systems based on our seven variables (Table 1) compared to Lam's assignment of categories shows that those 63 systems that are classified as "all farmer-managed" are attribute-wise in fact community-based (CBS). Co-managed systems show – as expected – a mixture of all systems characteristics. Furthermore, distinguishing systems with intervention from other systems makes sense attribute-wise, since these systems are distinguishable from GOV, as they are very homogeneous in terms of variables. The great majority of 133 systems show only characteristics of CBS and thus demonstrate the non-disruptive nature of interventions by the state. However, our characterisation of systems diverges from the broad classification concerning state-governed systems, since almost no system exhibits GOV-attributes as indicated in Table 1.

To sum up the points made: First, co-management patterns can be expressed – with the exception of GOV – by attributes expressing collaboration and communication. They indeed form ascending degrees of actors and institutions working together. Second, co-management can rightly be put in the middle of the continuum, since these systems show both characteristics of community-based management and state-governance as we would expect. Third, interventions by the state in this sample tend to be non-disruptive of local structures since these systems continue to show characteristics of community-based management with just some rare GOV attributes in a few cases. Fourth, the broad classification of community-based management is, by and large, borne out by using a classification scheme based on more variables, since all former FMIS cases only show community-based attributes (CBS).

4.2. Performance

Several discussion topics emerge from the analysis of results. First, it has to be noted that results shift with a more nuanced classification from the clear-cut results of Lam's traditional classifications to more mixed results in general. Given that irrigation systems with a higher level of community involvement in Nepal seem to perform better in water deliverance and productivity, while those with lower levels seem to have a better physical condition, the most important question remains why this might be the case. It may be, because state-governed systems tend to be more focused on infrastructure development and may enlist more technical expertise from engineers.

Different regression models for each performance indicator emphasize the relevance of the following key variables for performance: *monitoring and sanctioning, the level of local activities and trust as well as communication hindrances*. These findings conform very well with general social-ecological systems theory: Numerous studies find that monitoring and sanctioning play a pivotal role in natural resource management (van Laerhoven, 2010; Chhatre and Agrawal, 2008). Conditions that facilitate local level activities have been connected to the existence of arenas and the possibilities to meet for local users, in turn promoting participation in decision-making (Ostrom, 1990; Pomeroy et al., 1998; Cinner et al., 2012). Communication between users and other stakeholders is no less relevant, since both the understanding of the resource system and practices that improve sustainable management may profit from it (Olsson et al., 2004). This is true as well for overcoming obstacles like a high heterogeneity. Finally, trust has been characterised to be essential for group cohesion, rule following and the curbing of free riding behaviour (Gutiérrez et al., 2011).

Scholarly debate suggest that successful community-based management may be confined to smaller systems, whereas the state tends to be needed in larger systems to handle the complexities of large-scale management (Meinzen-Dick, 2014; Schlager, 2007; Ross and Martinez-Santos, 2010; Baland and Platteau, 1996). In contrast, we find that even if the sample is restricted to larger systems ($n = 122$; system area > 80 ha), there are clear performance advantages for more community-based systems within our co-management index for water deliverance and productivity, but not for the physical condition (two-sided *t*-tests with Bonferroni correction, $p < 0.001$; Mann-Whitney-test for equity, $p < 0.001$). This holds true for Lam's classification as well. If instead of the median of system area (80 ha), the median of the number of users (125) is used, these results hold as well (two-sided *t*-tests with Bonferroni correction, $p < 0.001$; Mann-Whitney-test for equity, $p < 0.001$). Although these effects are within sub-samples, we checked for size effects on performance for the whole data set. In general, smaller systems perform better than larger systems in productivity and water reliability, whereas larger systems performed significantly better in physical condition, equity and adequacy (two-sided *t*-tests with Bonferroni correction, $p < 0.001$; Mann-Whitney-test for equity, $p < 0.001$).

While this article has focused on states and communities, coordination functions can also be fulfilled by private property regimes. It is an open question whether market mechanisms provide effective coordination among smallholders. However, such mechanisms are particularly effective for coordination if they are relatively easy to measure (e.g. water deliveries) and exclude those users who do not pay. In addition, if users have alternatives, competitive sources make them independent of one provider, if there is only one (Meinzen-Dick, 2014).

Concerning performance, one important question is that of cause and effect. It may be that only community-managed systems that perform badly are taken over by the state or supported with interventions. The preceding paragraph has shown that such a supposed mechanism does not hold for size. It may, however, hold true for performance—a difficult management situation or bad performance in the past could lead to interventions by the state. If this were the case, the results on performance would be biased in favour of community-based systems (Table 4).

5. Conclusion

In line with Meinzen-Dick (2014), who also points out that appropriateness and performance of governance institutions depends on the particular local conditions, we were interested in testing whether appropriateness, represented by different specifications of co-management, affects performance. For this purpose, we explored performance differences between groups of governance regimes via three different classifications (Lam's classification, Lam's plus an intervention variable classification, and a 7-variable index-based classification).

We have shown in this paper that it can be valuable to provide a finely tuned classification of property regimes. They represent a continuum ranging from farmer-managed to state-managed

Table 4
Means of dependent variables according to classification (*, **, *** stand for p-values < 0.05, 0.01 and 0.001 respectively, used tests in the text, bolded values indicate best performance).

Dimension/Variable and possible range	AMIS	JMIS	FMIS	INTV	Index: GOV	Index: COM	Index: CBS
Physical Condition: Condition (1:4)	**2.35*** **	2.64	3.02	3.07	**2.5***	2.66	2.99
Physical Condition: Economical Efficiency (1:4)	**2.71*** **	2.57	3.27	3.34	**2.5** **	2.85	3.22
Water deliverance: Adequacy (0:6)	3.82	3.55	**4.44** **	4.86	2.67	3.75	**4.46**
Water deliverance: Equity (1:4)	2.53	2.57	**2.76**	2.84	2	2.59	**2.76**
Water deliverance: Reliability (1:3)	1.56	1.78	**2.34*** **	2.31	2.25	1.98	**2.28**
Productivity:Metricton (1:12)	4.84	4.7	**5.97** **	5.77	4.06	5.56	**5.67**
Productivity:Head intensity (100:400)	202.71	215.39	**244.89** **	240.25	168	217.64	**244.64***
Productivity:Tail intensity (50:400)	180.71	201.65	**236.19*** **	230.37	170.75	213.54	**233**

systems. Particularly hybrid cases – co-management regimes – show a large variety if their classification is based on a broader list of variables. In addition, by using a three-dimensional model of irrigation performance, we are able to statistically distinguish between different aspects. By using a broader basis, the index-based classification for co-management decisions, our analysis is able to demonstrate that a large number of individual irrigation systems moves away from the extremes in the continuum, namely state-only- and community-only-governance (see Fig. 1).

From a governance continuum perspective, it makes more sense for policy-makers to treat systems as state- or community-*dominated* instead of exclusively either of the two. A first step in this direction is the development of a classification of community involvement on seven variables. However, it seems necessary to increase our knowledge of key attributes for co-management in order to fill this concept with a precisely defined meaning. This would help increase performance diagnosis in the field.

In general, irrespective of size or number of users, systems with a higher involvement of local users perform better in water reliability and productivity. In contrast, systems that exhibit more state-governed characteristics, fare better in the physical condition of the irrigation system. Farmer-systems that have been intervened by the government (i.e. via infrastructure investments) improve only in water adequacy and equity of water distribution. All in all, systems did not show large differences in equity, which is otherwise often used as an argument in policy reforms pushing for more farmer engagement.

In contrast to some scholarly work (Ross and Martinez-Santos, 2010), two hypotheses could not be supported by our data set. First, that large-scale systems in general tend to be managed by the state. Second, that successful community-based management is confined to smaller systems. A further part of the puzzle is that cause and effect of governance and performance is often unclear because a given performance could lead to regime shifts (e.g. interventions by the state) or certain characteristics of governance could be responsible for the success and failure of a given system.

However, in line with the scholarly debate on collective action theory, we find a higher rule compliance, a higher level of local activity and a better working system of monitoring and sanctioning for systems with a higher involvement of local users. This shows that there should not be any blueprint solution as to when to call for state involvement in natural resource management. In contrast, the particular performance of any governance regime is context-specific. However, this study has shown that it is easy to jump to conclusions on state involvement if a stereotyped classification of governance regimes is followed.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors at the University of Halle-Wittenberg.

Acknowledgments

We thank Lin Ostrom and Julie England for their support.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2016.08.008.

References

Acheson, J.M., 2006. Institutional failure in resource management. Annu. Rev. Anthropol. 35 (1), 117–134.
Anthony, D.L., Campbell, J.L., 2011. States, social capital and cooperation: looking back on governing the commons. Int. J. Commons 5 (2), 284–302.
Armitage, D.R., Plummer, R., Berkes, F., Arthur, R.I., Charles, A.T., Davidson-Hunt, I.J., Diduck, A.P., Doubleday, N.C., Johnson, D.S., Marschke, M., McConney, P., Pinkerton, E.W., Wollenberg, E.K., 2009. Adaptive co-management for social-ecological complexity. Front. Ecol. Environ. 7 (2), 95–102.
Arnstein, S.R., 1969. A Ladder Of Citizen Participation. J. Am. Inst. Planners 35 (4), 216–224.
Baland, J.-M., Platteau, J.-P., 1996. Halting Degradation of Natural Resources: Is There a Role for Rural Communities? Clarendon Press, Oxford.
Berkes, F., Colding, J., Folke, C., 2003. Navigating Social-ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge, New York 1 online resource xxi, 393.
Berkes, F., 1994. Co-management: bridging the two solitudes. North. Perspect. 22 (2–3), 18–20.
Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manag. 90 (5), 1692–1702.
Carlsson, L., Berkes, F., 2005. Co-management: concepts and methodological implications. J. Environ. Manag. 75 (1), 65–76.
Chhatre, A., Agrawal, A., 2008. Forest commons and local enforcement. Proc. Natl. Acad. Sci. U. S. A. 105 (36), 13286–13291.
Cinner, J.E., McClanahan, T.R., MacNeil, M.A., Graham, N.A., Daw, T.M., Mukminin, A., Feary, D.A., Rabearisoa, A.L., Wamukota, A., Jiddawi, N., Campbell, S.J., Baird, A. H., Januchowski-Hartley, F.A., Hamed, S., Lahari, R., Morove, T., Kuange, J., 2012. Comanagement of coral reef social-ecological systems. Proc. Natl. Acad. Sci. U. S. A. 109 (14), 5219–5222.
Coleman, E.A., Steed, B.C., 2009. Monitoring and sanctioning in the commons: an application to forestry. Ecol. Econ. 68 (7), 2106–2113.
Costanza, R., 1998. Principles for sustainable governance of the oceans. Science 281 (5374), 198–199.
Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. AMBIO 31 (5), 437–440.
Frey, U.J., Rusch, H., 2013. Introducing artificial neural networks to the analysis of social-ecological systems. Ecol. Soc. 2, 40.
Garces-Restrepo, C., Vermillion, D., Munoz, G., 2007. Irrigation Management Transfer: Worldwide Efforts and Results. FAO. www.fao.org/3/a-a1520e.pdf.
Gibson, C.C., Williams, J.T., Ostrom, E., 2005. Local enforcement and better forests. World Dev. 33 (2), 273–284.
Gruber, E., 2008. Key principles of community-based natural resource management: a synthesis and interpretation of identified effective approaches for managing the commons. Environ. Manag. 45, 52–66.
Gutiérrez, N.L., Hilborn, R., Defeo, O., 2011. Leadership, social capital and incentives promote successful fisheries. Nature 470 (7334), 386–389.
Joshi, N.N., 2000. Institutional opportunities and constraints in the performance of farmer-managed irrigation systems in Nepal. Asia-Pac. J. Rural Dev. 10 (2), 67–92.
Koontz, T.M., 2004. Collaborative Environmental Management: What Roles for Government? Resources for the Future.
Lam, M.A., Ostrom, E., 2010. Analyzing the dynamic complexity of development interventions: lessons from an irrigation experiment in Nepal. Policy Sci. 43, 1–25.
Lam, W.F., 1998. Governing Irrigation Systems in Nepal: Institutions, Infrastructure, and Collective Action. Institute for Contemporary Studies, San Francisco.
Meinzen-Dick, R., 2014. Property rights and sustainable irrigation: a developing country perspective. Agric. Water Manag. 145, 23–31.
Olsson, P., Folke, C., Berkes, F., 2004. Adaptive comanagement for building resilience in social-ecological systems. Environ. Manag. 34 (1), 75–90.
Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge.
Ostrom, E., 1992. Crafting Institutions for Self-Governing Irrigation Systems. Institute for Contemporary Studies, San Francisco.
Pagdee, A., Kim, Y.-S., Daugherty, P.J., 2006. What makes community forest management successful: a meta-study from community forests throughout the world. Soc. Nat. Resour. 19, 33–52.
Plummer, R., Armitage, D., 2007. A resilience-based framework for evaluating adaptive co-management: linking ecology, economics and society in a complex world. Ecol. Econ. 61 (1), 62–74.
Plummer, R., Fitzgibbon, J., 2004. Co-management of natural resources: a proposed framework. Environ. Manag. 33 (6), 876–885.
Plusquellec, H.L., 2002. How design, management, and policy affect the performance of irrigation projects: emerging modernization procedures and design standards. RAP 2002/20. FAO, Bangkok, Thailand (ix, 155).
Pomeroy, R.S., Berkes, F., 1997. Two to tango: the role of government in fisheries co-management. Mar. Policy 21 (5), 465–480.
Pomeroy, R.S., Katon, B.M., Harkes, I., 1998. Fisheries co-management: key conditions and principles drawn from Asian experiences. Paper Presented at the 7th Annual Conference of the IASCP, 1–23.
Ross, A., Martinez-Santos, P., 2010. The challenge of groundwater governance: case studies from Spain and Australia. Reg. Environ. Change 10 (4), 299–310.

Schlager, E., 2007. Community management of groundwater. In: Giordano, M., Villholth, K.G. (Eds.), The Agricultural Groundwater Revolution: Opportunities And Threats to Development. CABI International, Wallingford, pp. 131–152.
Singleton, S., 1998. Constructing Cooperation: The Evolution of Institutions of Comanagement. University of Michigan Press, Ann Arbor.
Tang, S.Y., 1992. Institutions and Collective Actions: Self-Governance in Irrigation. Institute for Contemporary Studies, San Francisco.
World Bank, 1999. Report from the International Workshop on Community-Based Natural Resource Management. World Bank. http://www.worldbank.org/wbi/conatrem/.
Yandle, T., 2003. The challenge of building successful stakeholder organizations: New Zealand's experience in developing a fisheries co-management regime. Mar. Policy 27 (2), 179–192.
van Laerhoven, F., 2010. Governing community forests and the challenge of solving two-level collective action dilemmas—a large-N perspective. Glob. Environ. Change 20 (3), 539–546.

U. Frey is a free lance researcher.

S. Villamayor-Tomas is a senior researcher at the Department for Economics and Social Sciences at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL).

I. Theesfeld is professor at the Department of Agricultural, Environmental and Food Policy at the University of Halle-Wittenberg.