

Identifying governance strategies that effectively support ecosystem services, resource sustainability, and biodiversity

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Edited by Elinor Ostrom, Indiana University, Bloomington, IN, and approved February 2, 2011 (received for review June 10, 2010)

Conservation scientists, national governments, and international conservation groups seek to devise, and implement, governance strategies that mitigate human impact on the environment. However, few studies to date have systematically investigated the performance of different systems of governance in achieving successful conservation outcomes. Here, we use a newly-developed analytic framework to conduct analyses of a suite of case studies, linking different governance strategies to standardized scores for delivering ecosystem services, achieving sustainable use of natural resources, and conserving biodiversity, at both local and international levels. Our results: (i) confirm the benefits of adaptive management; and (ii) reveal strong associations for the role of leadership. Our work provides a critical step toward implementing empirically justified governance strategies that are capable of improving the management of human-altered environments, with benefits for both biodiversity and people.

adaptive governance | Convention on Biological Diversity | knowledge leadership | Millennium Ecosystem Assessment | policy making

As ecosystems degrade and loss of biological diversity accelerates, it is becoming increasingly urgent to identify governance strategies that successfully mitigate human impact (1). Although many different approaches have been proposed, their effectiveness has rarely been compared systematically for different conservation outcomes, and samples of case studies are often small. Before 2004, only 35% of studies of natural resource management had five or more cases (2). Almost all studies with larger samples were multisite comparisons for a single theme at subnational level, with very few attempts at analyses at an international scale (3–5). This lack of basic empirical evidence on the performance of different governance strategies has led to polarized debates among conservationists (6), wastage of scarce financial resources, and a risk of poorly designed and ineffective conservation programs. In this study, we analyze a suite of 34 local and international case studies to identify governance strategies that may benefit three conservation outcomes, namely: (i) enhancing delivery of ecosystem services; (ii) ensuring sustainable use of natural resources; and (iii) maintaining biodiversity.

An early contention that common-pool resources are inevitably overexploited, in a “tragedy of the commons,” has been replaced by understanding that common property institutions under strong communal management can provide effective stewardship for the conservation of biodiversity (7, 8), especially

when central or local protective regulation is effectively enforced (4, 9). Governance strategies adopted for conservation therefore vary widely, embracing community management as well as centrally controlled, state-run protected areas and private property regimes. The Convention on Biological Diversity (CBD) encourages devolution of management responsibilities and has drawn attention to the importance of adaptive management (i.e., regular monitoring to enable “learning through doing”) (10) to complement protected-area governance (11, 12). Moreover, growing recognition of the often hidden values of ecosystem services (13, 14) now supports CBD’s recommendation to use economic or social instruments to promote effective conservation (6). Examples include waste-trading schemes, eco-labeling, creation of knowledge networks and, especially, public payment for maintenance of certain ecosystem services, for example through Reduced Emission from Deforestation and environmental Degradation (REDD) (15). However, discussion continues on the relative merits of protective regulation or positive social and economic incentives for conserving biodiversity within and beyond protected areas (16–18). To address socio-environmental objectives, it is therefore important to consider a range of processes and socio-economic tools within an envelope of institutional capacities, including a potential role for leadership (typically, in the form of providing knowledge on complex issues) that has recently come to the fore (19).

Critically, many regulatory tools (such as restrictions on access or use) and social or economic tools (such as moratoria, taxes, and subsidies) are applied as political expedients without instituting appropriate studies to assess their effectiveness. These tools have costs that affect their social sustainability. The performance of conservation schemes needs to be assessed, and it seems essential for such evaluations to move beyond single-

Author contributions: S.A. and R.E.K. conceived the study; T.H. and A.T. developed the analytic framework; B.D.M. and J.P. coordinated data collection; R.S., J.A., O.B., M.D., K.E., F.F., Z.K., M.L., D.M., I.N., O.P., J.P., A.V.R., R.J.A.S., T.S., Å.S., and L.V. collated data; R.E.K. prepared the final database for analysis; M.J.W. and C.R. conducted statistical analyses; C.R. coordinated manuscript preparation, and prepared a first draft; and C.R., R.E.K., N.L.-W., N.J.A., and M.J.W. co-wrote and edited the manuscript.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1007933108/-DCSupplemental.

factor analyses. We developed an analytic framework to assess the relative importance of a suite of governance strategies for effective biodiversity conservation (20), based on measuring indicator variables in four main categories (Fig. 1A): (i) initial capacity; (ii) management priorities; (iii) main processes and tools aimed at those priorities; and (iv) environmental response variables that potentially depend on (i)–(iii). Using standardized questionnaires and expert judgment (*Materials and Methods*), we collected continuous and categorical data for 34 case studies across two levels of scale (Table S1). A total of 26 cases examined the management of study areas at local to subnational scale: 15 of these studies came from eight European countries, two from the United States, and nine from different developing countries. Eight additional cases involved the use of specific ecosystem services at an international scale, including organic agriculture around the Baltic Sea, North Sea fisheries, and a 27-country European Union-wide survey of six recreational activities dependent on wild resources.

For our sample of local case studies, we used information-theoretic (IT) modeling techniques to examine which factors, whether singly or in combination, best predicted variation in three environmental response variables (Fig. 1B): (i) provision of ecosystem services; (ii) sustainability of resource use; and (iii) conservation of biodiversity. As predictor variables, we identified—from an initial set of 22 putative variables—5 indicators of governance strategies that had been measured or assessed objectively, and which were of strong a priori interest based on major debates in conservation science (Fig. 1B, Table S2, and Table S3). By ensuring that each logical stage of our analytic framework was represented in the models (Fig. 1A and B), we were able to assess the relative importance of these different stages in achieving successful conservation outcomes. We omitted from our IT models all variables for the setting of management priorities: This approach both minimized the number of predictor variables (reducing the risk of spurious relationships) and ensured that key analyses were strictly based on objectively measured predictors (*Materials and Methods*, Fig. 1B, and Table S2). An alternative analytical technique, Ragin's Qualitative Comparative Analysis (21), could only be implemented with a restricted dataset (*Materials and Methods*), but its results corroborated those from the IT models, and are therefore not reported in detail. Although similarly comprehensive analyses were not possible with our more limited sample of eight international case studies, we used key results from our local-site IT analyses as candidate hypotheses for examining selected univariate relationships.

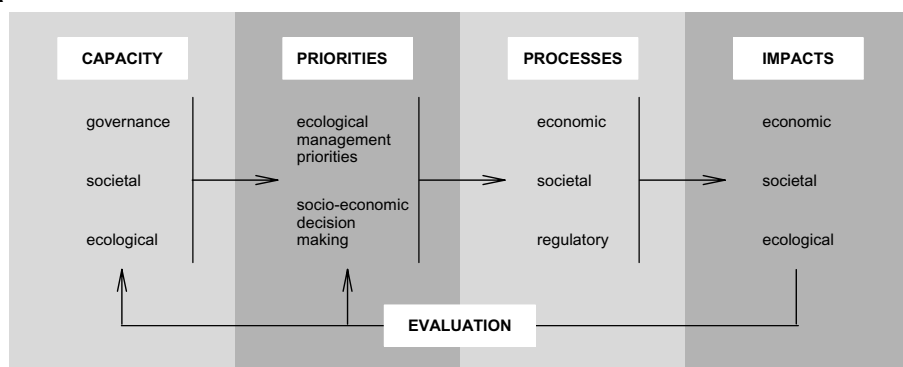
Materials and Methods), but its results corroborated those from the IT models, and are therefore not reported in detail. Although similarly comprehensive analyses were not possible with our more limited sample of eight international case studies, we used key results from our local-site IT analyses as candidate hypotheses for examining selected univariate relationships.

Results

Provision of ecosystem services was associated with both adaptive management (Fig. 2A) and knowledge leadership—a measure of the frequency with which a higher authority was consulted. Both predictors approached significance when they were included in the same model (Table S4A), despite being highly intercorrelated ($r_{26} = 0.701, P < 0.0001$). Dropping one of the two variables from the full model resulted in a strong positive relationship (at $P < 0.01$) for the variable remaining in the model. There was also a negative effect of regulatory tools when adaptive management was excluded (Fig. 2A and Table S4A). Considering the sustainability of resource use, the relationship with knowledge leadership was significantly positive when using five predictors, and that with adaptive management became strongly positive when knowledge leadership was removed (Fig. 2B and Table S4B). However, the model-averaged parameter estimate was higher for knowledge leadership ($\beta = 0.76$) than for adaptive management ($\beta = 0.52$) when the alternative variable was dropped. Finally, for conservation of biodiversity, both knowledge leadership and regulatory tools independently showed strong positive relationships in the full five-predictor model (Fig. 2C and Table S4C), whereas adaptive management had a significant effect when knowledge leadership was dropped.

Taken together, knowledge leadership had a strong positive effect on all three environmental response variables, whereas adaptive management was independently associated with the provision of ecosystem services but was otherwise interchangeable with knowledge leadership. Meanwhile, regulatory tools showed strong relationships with two response variables—negative for the provision of ecosystem services and positive for the conservation of biodiversity. Private ownership of land and state responsibility for land management, two of the three variables

A ANALYTIC FRAMEWORK



B REPRESENTATION IN MODELS

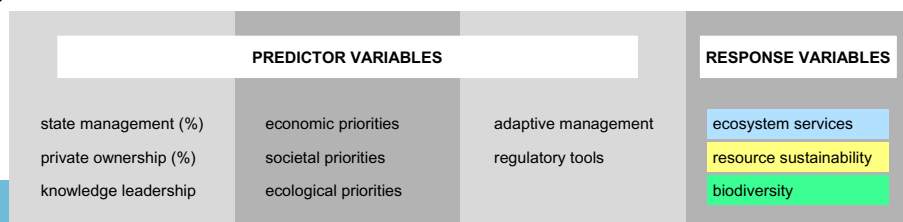


Fig. 1. Conceptual framework for analyzing the performance of different governance strategies. (A) The framework grouped variables into four main categories: (i) initial capacity; (ii) management priorities; (iii) main processes and tools aimed at those priorities; and (iv) the economic, societal, and ecological impacts of these governance strategies. Impacts were subsequently assessed and procedures were evaluated (no variables were included for this category). (B) For statistical analyses, variables were chosen that represented the logical structure of the framework. IT models were then used to examine which (combination of) variables from categories (i)–(iii) best explained variation in three environmental response variables of category (iv): provision of ecosystem services; sustainability of resource use; and conservation of biodiversity. Potential associations with the three priority-setting variables were analyzed separately, for reasons explained in *Materials and Methods*. For details on variable selection, see *Materials and Methods*, Table S2, and Table S3, and for results, see main text, Fig. 2, and Table S4.

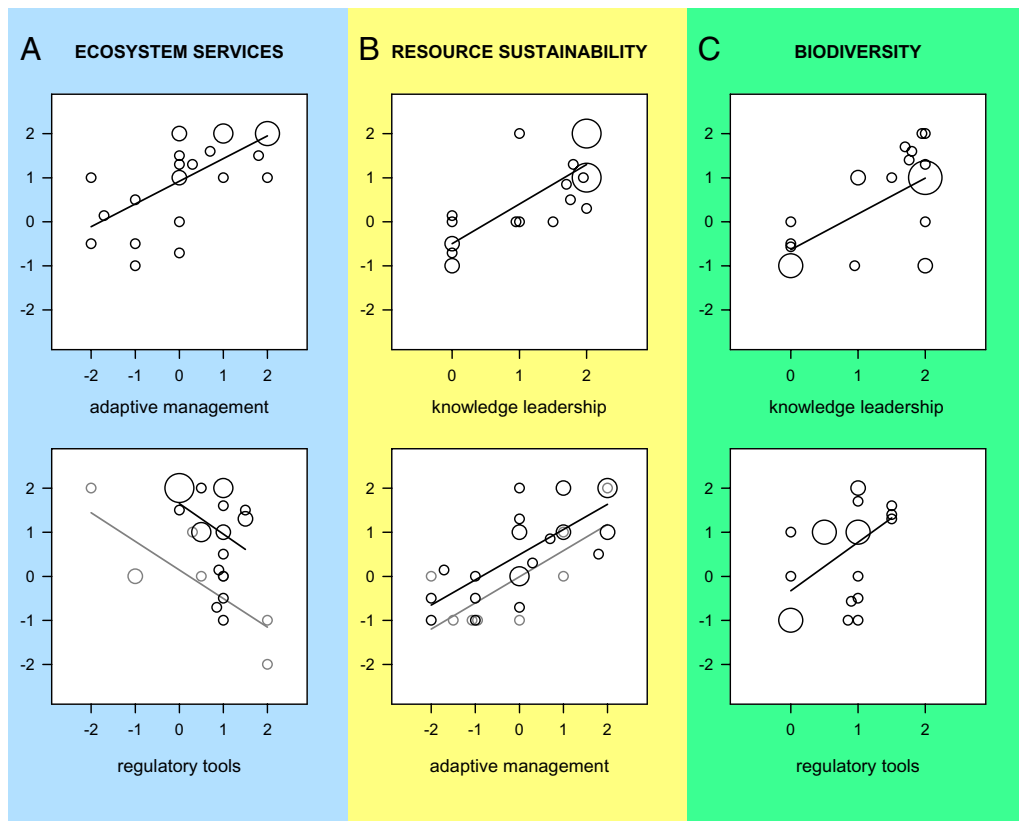


Fig. 2. Key associations between governance strategies and three environmental response variables. (A) Provision of ecosystem services. (B) Sustainability of resource use. (C) Conservation of biodiversity. Based on the independent assessment of case studies (*Materials and Methods*), variables were assigned along a three- or five-point scale, with all three environmental response variables ranging from -2 for “very low” status or “ $>10\%$ decrease in 10 years” as a trend, to $+2$ for “very high” status or “ $>10\%$ increase in 10 years” as a trend. Although statistical analyses were conducted separately for local (black open symbols and black lines) and international (gray open symbols and gray lines) case studies (see main text and *Materials and Methods*), some panels show data for both levels of scale to illustrate consistency of patterns. Putative relationships at the local scale were examined in IT models using multiple predictor variables, and results served as candidate hypotheses for targeted testing of associations at international level (for results, see main text). Symbol size is proportional to the number of overlapping data points (i.e., case studies), some adjacent data points are jittered slightly for clarity, and lines are best fits from univariate linear regressions. Two local case studies, which had been omitted from IT models because of missing data, are included in plots for completeness, where appropriate. For a schematic illustration of the underlying analytic framework, see Fig. 1.

characterizing initial capacity (Fig. 1, A and B), showed no significant associations in any of the models.

The setting of management priorities also appeared to have strong effects on our three environmental response variables. An emphasis on ecological priorities was positively associated with the conservation of biodiversity ($r_{26} = 0.717, P < 0.0001$), whereas setting of economic and social priorities was associated with the provision of ecosystem services ($r_{26} = 0.645, P < 0.0001$, and $r_{26} = 0.667, P < 0.0001$, respectively) and the sustainability of resource use ($r_{26} = 0.626, P = 0.001$, and $r_{26} = 0.502, P = 0.009$, respectively).

At an international scale, the provision of ecosystem services decreased with the relative importance of regulatory tools (Fig. 2A; $r_8 = -0.794, P < 0.019$), whereas sustainability of resource use increased with the degree of adaptive management (Fig. 2B; $r_8 = 0.747, P < 0.033$). Both results confirm patterns observed for the local case studies (Fig. 2A and B and Table S4, A and B). Likewise, as in our local-scale IT analyses, knowledge leadership was positively associated with both the sustainability of resource use ($r_8 = 0.363, P < 0.377$) and the conservation of biodiversity ($r_8 = 0.620, P < 0.101$) (compare Fig. 2B and C). However, these relationships failed to reach significance with our limited sample size of only eight international case studies (relationships were highly significant for all three environmental response variables when pooling local and international data; $r_{34} > 0.55, P < 0.001$).

Discussion

Strong benefits of community tenure or management would have resulted in negative relationships between other tenure or management regimes and ecosystem service status or sustainability. In view of the strong and consistent positive relationships with adaptive management and knowledge leadership, there was a striking lack of association with private land ownership or state management responsibility. In part, this lack of effects may reflect having to choose these particular variables purely on statistical grounds (Table S2), thereby ignoring weak positive relationships of resource-use sustainability with community management in preliminary regression-based analyses (20). However, effects of ownership and management also tend to depend on the social institutional setting (8), so their detection might have required interaction terms with variables not considered in our models. A candidate variable would be the duration of conservation management, because almost all our studies were in Europe, North America, or special conservation areas (Table S1), where balances of state, private, and community tenure and management institutions were perhaps already relatively favorable, so that the greatest remaining variation was in short-term tools and processes such as regulations, leadership, and adaptive management.

Adaptive management, incorporating monitoring and feedback, has long been proposed as a powerful tool to ensure successful conservation outcomes (10, 22). Indeed, we found that adaptive

management had strong, positive associations with all three environmental response variables, providing empirical support for the recommendation of recent international agreements that implementing adaptive management, and concomitant devolution of governance, are needed to ensure the sustainable use of biodiversity (12, 23). Future studies should investigate whether, at least under certain circumstances, benefits of adaptive management and knowledge leadership are an alternative to effective tenure or management institutions, and what additional advantages they can provide when both approaches are combined.

Although biodiversity conservation seemed to benefit from setting of ecological priorities and was associated positively with regulations, the provision of ecosystem services was correlated strongly and positively with economic priorities, and was at the same time negatively associated with regulations, at both local and international scales. These results confirm the importance of different regulatory emphases, in a dual approach to conservation that incorporates both protection and use (6, 24). Sometimes this duality may best be achieved by the spatial separation of areas for protection or use of resources (25). In areas where conservation is to be promoted through use of ecosystem services, our analyses indicate a need for cautious use of regulations. More generally, our finding that the three investigated conservation outcomes were associated with different sets of governance strategies carries the important implication that, if all three outcomes are desired simultaneously, a joint (or compromise) set of strategies has to be implemented; governance strategies that benefit one outcome may not necessarily support the other two.

Using a newly-developed analytic framework and extensive survey data, our study succeeded in identifying governance strategies that best explain, across two levels of scale, the provision of ecosystem services, sustainability of resource use, and conservation of biodiversity. We suggest that future work should focus on two main goals. First, further studies are required that replicate and refine our analyses by using more accurate measurements of socio-economic factors and environmental variables (26). Second, and perhaps more importantly, our study sets the scene for investigating causality through planned experiments. We envisage coordinated, large-scale trials of different approaches across administrative areas within countries—as a socio-economic equivalent to landscape-scale experiments in ecology—that test key predictions derived from correlational analyses, such as those presented here. Taken together, such work will help establish empirically justified governance strategies that can help improve the management of human-altered environments, with benefits for both biodiversity and people (27).

Materials and Methods

Data Collection. Twenty-two teams collected data for the Governance and Ecosystem Management for the Conservation of Biodiversity project (20) from 34 case study sites (Table S1). Teams were selected for their ability to identify a wide range of terrestrial and aquatic ecosystems within different jurisdictions in countries at various stages of development. Nineteen teams were tasked with assessing/quantifying one to three local to subnational case studies that already existed in 19 countries, yielding 26 cases for analysis, termed “local cases.” Meanwhile, three teams were tasked with assessing/quantifying eight case studies across multiple countries, termed “international cases.” Standard questionnaires were used at each site to collect a range of 80–85 ecological, economic, and social datapoints, from which 22 variables (Table S2) were later derived, using a priori processing rules (Table S3 and ref. 20).

Of the 22 putative predictor variables, 14 for “initial capacity” were based (Table S2) on: (a) measuring or estimating proportions of state, private, or community management (variables 1–3 in Table S2) or ownership (variables 5–8) across the study site; (b) whether 1, 2, or 3 of these types of management (variable 4) or ownership (variable 9) were present; (c) scores from “best professional judgment” of whether vertical integration (variable 10), horizontal social integration (variable 11), local community participation (variable 12), and multilevel governance (variable 13) was considered high (+2), good (+1), basic (0), scarce (–1), or very low (–2); and (d) whether major

external sources of advice were consulted, and if so, whether more than once annually (giving scores of 0, 1, and 2 for knowledge leadership; variable 14). For “management priorities,” ecological (variable 15), economic (variable 16), and social (variable 17) priorities were assessed (e) as not appropriate (–1), at minimal levels (0), or appropriate levels (+1). For “processes and tools,” knowledge generation (variable 18) was scored like variables 10–13, whereas adaptive management (variable 19) was constructed (f), according to whether monitoring and management were absent (–2), management of species (–1) or ecosystems (0) was present without monitoring, or species (+1) or ecosystems (+2) were managed with monitoring; finally (g), there was a five-point scale from high (+2) to absent (–2) constructed from answers to 3–5 questions about listed abundance, implementation, awareness and acceptance of market, regulatory and social tools (variables 20–22).

In addition to the 22 variables mentioned above, three environmental response variables (provision of ecosystem services; sustainability of resource use; conservation of biodiversity) were scored through best professional judgment, using a five-point scale ranging from –2 (very low or >10% decrease in 10 y) to +2 (very high or >10% increase in 10 y). Several questions in our standard questionnaire prompted observer teams to identify appropriate topics for assessment in their allocated case studies. Anticipating a large range of potential topics across a diverse set of case studies, we considered it important for this part of the survey to provide teams with a certain amount of freedom in data collection (see below). For example, observers were allowed to examine any number of topics for a given response variable (Table S1), and it was left to their expertise and personal judgment to synthesize diverse data for inclusion in their final report (for each case study, scores were entered in an “executive summary table,” which was submitted to the project organizers; ref. 28). Although scoring of the three response variables was inevitably less standardized than for other variables used in our analyses, we considered this approach essential for effectively capturing the status and trends of very different ecosystems and for assessing case studies of varying data availability and quality. Importantly, from an analytical point of view, our approach will only have added noise to our dataset, thereby making detection of effects less likely. If there was systematic under- or overestimation of success by teams across the environmental response variables, this bias could have increased similarity of effects detected for the different response variables, but would generate neither the observed relationships with predictor variables nor the differences in results between response variables.

With our study approach and project resources, it was not feasible to assess “biodiversity” with quantitative diversity measures or proxy indicators (26); rather, where appropriate (Table S1), observers examined the status and trends of selected, relevant species. This approach enabled us to identify important relationships with our suite of (governance) predictor variables (see below), setting the scene for more elaborate future analyses (see main text).

Variable Selection. For the IT analyses (see below), we identified a reduced set of predictor variables from the 22 listed in Table S2 (which were also intended for a suite of other analyses; ref. 28). With a sample of 26 local case studies, we expected to have sufficient replication for fitting a maximum of five predictor variables, because “the residual mean square will tend to stabilize and approach the true value of σ^2 as the number of variables increases, provided that all important variables have been included, and the number of observations greatly exceeds the number of variables in the fitted equation—five to ten times as many” (29). We selected variables that were objective, of intrinsic scientific interest (for a priori reasons), and which covered the first four stages of our analytic framework (Fig. 1, A and B). Thus, our full IT models included as predictors: (i) percentage of state-managed land; (ii) percentage of land owned privately; (iii) knowledge leadership; (iv) adaptive management; and (v) regulatory tools. These variables correspond, respectively, to categories (a), (a), (d), (f), and (g) described above. By using only a small subset of the predictor variables available, we also addressed conclusions of an earlier project report, which cautioned not to “overfit” statistical models (28).

Although our three environmental response variables (provision of ecosystem services, sustainability of resource use, conservation of biodiversity) were scored, and not measured, this approach is unlikely to have created spurious relationships with the five chosen predictor variables (or vice versa). Two important aspects of our experimental design sought to reduce scope for systematic bias. First, all five predictor variables (Table S2) were either assessed directly (land ownership and management) or constructed from multiple data points after the survey, using a priori defined rules (Table S2 and Table S3). For example, knowledge leadership and adaptive management were each constructed from the answers given to two basic survey questions. This way, observers could not know, at the time of conducting

their evaluation, how their answers would later combine to produce data for particular variables. Second, our 26 local studies in 19 countries were assessed by 19 different observer teams, with participants who had not managed the projects they scored, minimizing scope for systematic bias. Furthermore, the measures and scores for activities in six of the eight cases at the international level were averages of data provided by single observers in each of 5–25 countries.

For two reasons, none of the variables for setting management priorities (Fig. 1B and Table S2) were included in our IT models. First, based on model-economy considerations, we could only accommodate five predictors with our given sample size. Second, the priority-setting variables were the only variables of interest that were represented as simple scores; the other five predictor variables, and all three environmental response variables, had been either measured directly, or constructed from quantitative variables (see above). Because the priority-setting variables may have been prone to some subjectivity (those observers who were strongly orientated toward a particular priority may have been also more likely to be positive about particular management outcomes), we examined them in separate, univariate tests and interpreted results cautiously.

Statistical Analyses. We chose an IT modeling approach to analyze our dataset of local case studies. IT analyses are similar to multiple regression analyses, but circumvent problems associated with conventional stepwise procedures that inflate Type-1 error rates (30). Our IT modeling followed standard methodology (refs. 31 and 32 and Table S4 legend), and used previously reported algorithms (32) run in “R” (33). We ran models with a normal error structure (based on linear least-squares regression) on the original scores, because Kolmogorov–Smirnov, Ryan–Joiner, and Anderson–Darling tests indicated normality of errors based on residuals of a full model with all five predictors fitted to each of the three response variables (all tests were $P > 0.10$; compare Table S4). We used the adjusted version of Akaike’s information criterion (AICc) to control for bias, as the ratio of the number of observations ($n = 24$) to the number of predictors ($n = 5$) was much less than 40 (31). Two case studies had to be excluded from analyses owing to missing values (but were included in plots in Fig. 2, where appropriate).

We calculated 95% “confidence sets” of models fitted to each dataset (32). A confidence set is the smallest subset of candidate models for which the Akaike weights sum to 0.95 (i.e., we had 95% confidence that this set contained the model best approximating the true model). For example, Table S4, A to C, show all model combinations within the 95% confidence set of models (31, 32), with the best-fitting at the top (e.g., the best-fitting model for ecosystem services, with $w_i = 0.124$, included knowledge leader-

ship and adaptive management alone; Table S4A). We assessed the importance of each individual predictor based on the summed Akaike weights (SAWs) across all models in the 95% confidence set containing that predictor. The statistical significance of each sum was determined relative to that of a randomly generated null predictor (with zero mean, SD of 0.5, and data between -2 and 2 , i.e., comparable with our real data) by using 100 randomization runs (Table S4). For all three environmental response variables, we ran models with all five predictors, as well as reduced models without knowledge leadership and without adaptive management, respectively, because they were highly intercorrelated (see main text).

We also explored analytical approaches that are routinely used in the social sciences, such as Qualitative Comparative Analysis (QCA) or fuzzy set QCA (fsQCA) (21). Although these are powerful, established techniques, their utility can be limited in certain scenarios, because: (i) meaningful variation in the dataset is lost, because variables must be condensed into binary form before analysis (i.e., to scores of 0 or 1) (e.g., in our case, the percentage of land ownership in our study sites cannot meaningfully be classified as 0 or 1); and (ii) missing values in the dataset greatly reduce effective sample size (rows with missing data are excluded from analyses). IT techniques do not suffer from these limitations, and were therefore our method of choice, but we decided to investigate informally whether QCA would produce similar results and corroborate our key findings. We first conducted a “crisp-set” analysis, which used the actual (untransformed) data, including only data where we had actual scores of 0 and 1 (i.e., even if a predictor scored 0.99, rather than a 1, it was excluded). In the next step, we used the most inclusive “fuzzy-set” rule, in which any predictor that scored ≥ 0.51 was given a 1 and any scoring ≤ 0.49 a 0. The results for the minimum-model output showed high consistency for both QCA and IT analyses.

Comprehensive IT analyses were not possible with our sample of eight international case studies. However, our key results from local case studies allowed the formulation of clear candidate hypotheses, which we could examine by conducting targeted, univariate Pearson’s correlations.

ACKNOWLEDGMENTS. We thank the many government departments, non-governmental organizations, and individuals who provided data and three referees for excellent comments that substantially improved the manuscript. This work was cofunded by the European Community’s Sixth Framework Programme Contract 028827, project Governance and Ecosystem Management for the Conservation of Biodiversity, and Seventh Framework Programme Contract 212304, project Transactional Environmental Support System. C.R. is a Biotechnology and Biological Sciences Research Council David Phillips Fellow, funded by Grant BB/G023913/1.

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