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Meta-analysis reveals that fisheries co-management alters socio-economic outcomes and resource well-being.

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Abstract

Over half a century of governing efforts have failed to prevent the depletion of fish stocks around the globe. Ineffective management of over-exploited resources has resulted in a lack of willingness to comply with regulatory systems, magnifying problems at a time when many of the world's fisheries face increasing pressure or crisis. Co-management, the sharing of management responsibilities between government, fishermen's organisations and other stakeholders, has been advocated as the solution to engaging stakeholders. However, an evidence base is required to assess whether co-management improves the sustainability of fisheries. Here, we used qualitative and, for the first time, quantitative meta-analyses to assess the outcomes of local fisheries co-management schemes around the globe, by asking: (1) does co-management improve the socio-economic and biological factors underpinning fisheries? (2) how do the characteristics of the most successful co-management structures compare to less successful structures? Data from multiple studies was extracted and measured against performance criteria through meta-analysis, assessing process (compliance, control, conflict, influence and participation) and outcome indicators (household income, access to resource, fish yield and resource well-being). Co-management has an overall positive influence on all but one of the process indicators (conflict; no significant effect), but a negative influence on access to resource and resource well-being. Case studies that reported positive outcomes possessed attributes such as government support, funding and dedicated project staff, indicating certain prerequisites are required to establish a successful co-management scheme, though data limitations restrict our ability to draw more general conclusions.

Keywords: Co-management, commercial fishing, fisheries management, meta-analysis, participatory fisheries management

1. Introduction

Over-exploitation of resources coupled with ineffective management has led to distrust within the fishing industry (Kaplan and McCay, 2004), with constant debate over the effectiveness of management regimes in maintaining or achieving sustainable resource utilisation (Sen and Nielson, 1996). Ineffective management has resulted in a severe lack of willingness to comply with regulatory systems (Thomas et al., 2015), further increasing problems at a time when many of the world's fisheries are under increasing pressure or face crisis, resulting in distrust between the industry, fishing communities, and governing bodies (Phillipson, 2002).

Co-management, also termed participatory fisheries management, has been advocated as a solution to engaging stakeholders in problems faced by fisheries (Pomeroy and Berkes, 1997; Njaya, 2007) and involves the sharing of management responsibilities. This may involve multiple institutional linkages among user groups or communities including fishermen's organisations, research institutions and civil society (Evans et al, 2011), as well as government agencies and non-governmental organisations (Olsson et al., 2004). Co-management results in spatially-explicit analysis and management that is responsive to spatial and temporal variability in target species' characteristics, habitat qualities, socio-political factors and user-group cultures (Zanetell and Knuth, 2004). Resource management decisions can then be made in conjunction with resource exploiters and other interested parties, such as scientists, to promote sustainability in the fishery through responsible participation. This approach aims to ensure resource sustainability, as well as providing protection to the local environment and addressing the needs of other stakeholders (Phillipson, 2002). Further, the self-organising process of co-management has the potential to make the social-ecological systems more robust to change (Olsson et al., 2004).

Co-management has instrumental values that other fisheries management initiatives lack: (1) an enhanced sense of ownership from key stakeholders encourages responsible fishing, (2) a greater sensitivity to local socio-economic and environmental constraints, (3) improved management through the use of local knowledge, (4) collective ownership by user groups in decision making, (5) increased compliance with regulations through peer pressure and (6) improved monitoring, control and surveillance by fishers (Gutiérrez et al, 2011, Bown et al, 2013). Taken together, co-management has the potential to increase both community and ecosystem resilience through the sharing of knowledge and creation of management plans tailored to specific places and situations (Olsson et al., 2004).

Co-management is a process that takes place along a continuum, covering a range of management models that diverge from the centralised fisheries management system, with variable participation by different groups as co-managers (Carlsson and Berkes, 2005). This participation can range from consultative to informative, depending upon the level of government involvement. In some cases, stakeholders are consulted on management issues, but decisions are ultimately made at the government level (Pomeroy and Pido, 1995). In contrast, an informative co-management arrangement allows stakeholders to form associations and seek only legal backing from the government (Kristiansen et al., 1995). It is therefore essential to understand if a relationship exists between the level of decentralisation and the success of the fishery.

Previous assessments relevant to fisheries co-management reviewed the impact of implementing co-management schemes or focused on the conditions required for successful implementation (Napier et al., 2005; Gelcich et al., 2006; Chuenpagdee and Jentoft, 2007). Training and empowerment appear to be key features, with implementation requiring facilitators who can work with the stakeholders to explain what co-management entails and what they can realistically expect (Napier et al., 2005; Chuenpagdee and Jentoft, 2007). Only three previous studies have analysed the outcome of fisheries co-management arrangements. Maliao et al (2009) and Evans et al (2011) examined the outcome of fisheries co-management schemes in the Philippines and across the developing world, respectively. Both reported that co-management had improved inclusion of stakeholders in governance but the impact on ecological outcomes varied. Further, Allison and Badjeck (2004) reviewed fisheries co-management experiences in tropical inland fisheries, primarily focusing on conceptual and analytical aspects of co-management. For the successful design and implementation of co-management programmes that were well supported, they found that it was essential for those involved to have a comprehensive understanding of four inter-related topics: property rights, power relations, structure of communities and issues surrounding trust between stakeholders. They also identified that support from the government was critical.

Here, we assess the outcomes of fishery co-management schemes around the globe through meta-analysis. This work builds upon work carried out by Evans et al (2011) which examined the impact of co-management schemes from developing countries. Our study extends this review, incorporating more recently published data and a new quantitative analysis, to include co-management schemes in the developed world, to assess and understand what attributes are associated with more successful strategies. We further build upon previous work by collecting information on the funding and funding bodies, dedicated project staff and the co-ordinating body responsible for implementing the co-management schemes to understand whether certain attributes associated with co-management implementation influenced the schemes success. This meta-analysis, therefore, both provides information on the overall success of co-management strategies and aims to tease apart the more successful schemes from others and understand the differences between them to provide insight into what attributes contribute to the success of co-management arrangements.

We hypothesised that 1. Co-management, as a whole, would improve a range of socio-economic factors associated with fisheries, 2. Improvement in the biological health of the fishery would be dependent on the amount of time that a co-management scheme had been in place and 3. The presence of specific prerequisites would influence the success of co-management schemes. Co-management is shown to be a valuable tool in fisheries management if certain attributes are incorporated. While we expect co-management to have positive effects overall, there are several factors that can contribute to its success, including time since implementation, especially if introduced as a last resort, which could confound the outcomes. This research synthesises and builds upon previous results, providing the first fully quantitative analysis of fisheries co-management, and contributes to the field at a time when fisheries management is under review.

2. Methods

2.1 Meta-analysis

The indicators used in this meta-analysis are the most common indicators assessed in the available literature, representing the attributes that are considered most influential to the success of co-management schemes (Evans et al, 2011), categorised as Process and Outcome indicators. Process indicators reflect processes that are considered crucial to the success of a co-management arrangement and must be put in place from the start of the co-management process. Outcome indicators reflect the overall objective of co-management and are the goals that the fisheries aim to achieve (Maliao et al, 2009).

We included results from published and unpublished data sets in our initial literature search, recording measurements taken for both process and outcome indicators, which were categorised into three groups; (1) Natural Systems: observing ecological factors, (2) People and livelihoods: addressing social factors and (3) Institutions and governance: reflecting the governance process, the policies and the institutions involved in the co-management arrangements (see Table 1 for full definitions). The process indicators were: participation, influence, control, conflict and compliance; and the outcome indicators were: fish yield, resource well-being, household income, and access to resource. The indicators chosen are named to correspond to the terminology used in the studies they have been extracted from, to maintain consistency. For example, resource well-being refers to the fisheries resource health or status, rather than the well-being of human stakeholders involved in the schemes. Data collected was generated through stakeholder perception analyses, typically based on interviews with fishermen, which resulted in time-series or treatment-control comparison data. Quantitative data reported was related to biodiversity, household income and fish catch and this was reported in a time-series format.

2.2 Data Collection

Data was collected in a multi-step procedure to ensure that a global list of past and present fisheries co-management initiatives was compiled. A thorough literature search was initially conducted which included (a) an electronic search for published and grey literature and (b) contacting authors and mailing lists to identify other potential case studies and data that had not been published. The electronic databases searched were the World Fish Catalogue (http://www.worldfishcenter.org), ISI Web of Science (www.webofknowledge.com), and Google Scholar (www.google.com/scholar), using a combination of the following search terms; fish, fisheries, community, community-based management, co-management, participation, participatory management, collaborative, self-governance and eco-system based with dates searched from 1970 to 2015 inclusive. In cases where the search results produced very high numbers (>20,000 in some cases), the search was refined using the terms: impacts, outcomes and assessments. Grey literature was collected by conducting a search of the World Wide Web using the terms listed above. Researchers were contacted individually for any available data sets where the reported material was not descriptive enough to be used e.g., confidence intervals, standard deviations, and/or sample sizes were not included, and mailing lists (Ecolog: https://listserv.umd.edu/archives/ecolog-l.html; and Fishfolk: http://seagrant.mit.edu/cmss/fishfolkfaq.html) were contacted so that unpublished data could be included to minimise, e.g., publication bias. Conference papers, government reports and dissertations were also sourced by contacting government agencies where appropriate and searching library catalogues for dissertation titles before contacting the authors for relevant information.

Papers were rejected when they contained no quantitative or qualitative data, but instead described the co-management arrangement. These were typically social studies that described the implementation of co-management or assessed the roles of various organisations once co-management had been implemented. Attempts were made to contact authors to retrieve data that were used in these reports, but several responses indicated that these data were confidential.

Case-studies with available and appropriate data for analysis were then systematically selected. The abstract, methods and results of each paper were reviewed and excluded if: (1) only secondary results were reported (e.g., where previous results were reviewed or interpreted); (2) no reference was included describing the methodology or basis for the findings; and/or (3) if there were any indications of flaws in the methodology for the collection or the analysis of data. For example, one study reported a miscommunication between researchers and translators that could have resulted in a loss of information. Further, comparisons were difficult to make if there were no temporal or spatial controls and as such, even though indicators such as compliance were reported on, there was no ability to deduce if this compliance has increased or decreased since the co-management regime had been introduced. The minimum length of co-management implementation required for case-studies to be included was 1 year. Data collected could include studies that reported a difference over time at one site, where the pre-co-management arrangement was considered the control, as well as those that compared spatially distinct co-management sites with control sites where co-management was not implemented and the control site was managed by the same structure that the co-managed site had previously been. In these studies, the type of fishery compared was similar in both resource and fishing method. Both approaches were included to broaden the range of studies that could be used in this meta-analysis and to provide a full comparison when discussing study methodologies.

A total of 382 papers were retrieved through the initial literature search and a further nine were received by directly contacting researchers (see Supplementary Material C for a full list of references considered). 35 key informants were contacted including researchers and fisheries management experts. Responses were received from 37% of these informants, which provided raw data or clarification of results found in published papers or reports and enabled them to be incorporated into the meta-analysis. Of these papers, 91.3% were rejected due to lack of suitability for inclusion in meta-analysis (See Supplementary Material C). Papers were rejected as they contained no quantitative or qualitative data, but instead described the co-management arrangement. These were typically social studies that described the implementation of co-management or assessed the roles of various organisations once co-management had been implemented. Attempts were made to contact authors to retrieve data that were used in these reports, but several responses indicated that these data were confidential. Qualitative data was generated through stakeholder perception data collected from surveys, questionnaires and interviews that resulted in time-series and treatment-control comparison data. This was typically in the form of a scale of 1 to 10, where a score of 1 represented poor condition and 10 representing excellent condition. The quantitative analyses were based on time-series (or spatial comparison) data and reported in indicators such as fish yield and household income, which included quantitative data from landings and individuals' incomes.

Of the 36 papers remaining, 4 were rejected as the data they contained were not relevant to this study or did not provide a comparison either between sites or before/after co-management had been implemented. Of the 32 studies selected for analysis, eight included data from more than one site and in some cases from more than one country, taking the total number of sample studies included to 43.

The organisation and development of different co-management systems were seen as potential effect modifiers. For this reason, information was collected on the organisational structure of the co-management system in place with respect to: (1) who co-ordinated the co-management arrangement (NGO's, Government, Industry, Fishermen, Communities); (2) whether there was funding in place and who supplied it; (3) if there were project staff allocated solely to guide the implementation process and (4) the type of co-management arrangement and therefore the degree of decentralisation involved. Given the relative lack of consistency in data reported on these points, this information was not scored to be used in the meta-analysis but was used for preliminary investigation of whether the presence of certain attributes might be associated with the success of co-management initiatives. Notes were also taken if there were any other potential effect modifiers or effects that could bias the results.

2.3: Coded Meta-analysis

Data which presented quantitative and/or qualitative results on the impact of co-management were collected mainly through surveys and interviews but were measured and presented in different forms that made a quantitative meta-analysis of co-management impact based on all data collected difficult. Therefore, we applied two meta-analytical approaches. First, we followed the approach developed by Evans et al (2011), who coded studies depending whether a *p*-value was reported for indicator responses. This method was applied to the 32 studies included here that contained adequate data (Table 2). An indicator with either a positive change over time, or a positive (spatial) outcome compared to the control site, was received a score of 1. Responses reported as significant at $p \leq 0.05$ received a score of 2. Reports of no change resulted in a score of 0. An indicator with a negative response received a score of -1, or -2 if significant at $p \leq 0.05$. This approach has some limitations as *p*-values were often not reported, therefore some studies could be incorrectly (conservatively) coded as non-significant under this method of reporting. 24 of the 44 studies included failed to report p-values, therefore the coded analysis was also followed by a second, fully quantitative method (see below).

We applied Spearman's rank correlation analyses to determine whether there was any relationship between the coded result for indicator variables and the length of time (years) that co-management had been in place.

2.4: Response Ratios: Quantitative Meta-analysis

Of the 32 articles highlighted for use in the meta-analysis, 12 presented data, incorporating 17 sample studies, that were appropriate for use in the quantitative meta-analysis. We used the Response Ratio (*RR*) as a standardised effect size for comparison across studies, as it quantifies a proportionate change in variables following an intervention and was considered the most appropriate effect size based on the way the selected studies had reported results. The natural logarithm of the response ratio was taken, to improve statistical properties (Koricheva and Gurevitch, 2013). Effect sizes were calculated as:

$$\ln(RR_i) = ln\left(\overline{X_i^e} \big/ \overline{X_i^c}\right), \qquad \text{(eqn. 1)}$$

where $\overline{X_i^e}$ is the mean score of the indicator post co-management (or in the managed site) and $\overline{X_i^c}$ is the mean of the indicator prior to co-management (or in the unmanaged 'control' site). Effect sizes were then weighted as the inverse of the reported variance ($w_i = v_i^{-1}$). When the variance was not reported and could not be directly derived, v_i was approximated based on the study sample sizes as (Maliao et al, 2009):

$$v_i = \left[\frac{N^A + N^B}{N^A N^B}\right] + \left[\frac{\ln(RR_i)^2}{2(N^A + N^B)}\right], \qquad \text{(eqn. 2)}$$

where N^A represents the post co-management study sample size and N^B represents the sample size of the indicator variable prior to co-management.

We accounted for heterogeneity among studies by comparing Cochrane's Q test and the I^2 value. Assessing heterogeneity is crucial to understand sources of variation both within a study and between multiple studies and to determine whether a fixed- or random effects modelling approach was more appropriate (Huedo-Medina et al., 2006, Maliao et al., 2009, Cooper, 2009). If heterogeneity among studies was detected, we used the weighted effect size (eqn. 3; see Supplementary Material B for details). The mean effect size could then be calculated as:

$$\overline{\overline{\ln(RR)}} = \frac{\sum_{i=1}^{n} w_i ln(RR_i)}{\sum_{i=1}^{n} w_i} \qquad \text{(eqn. 3)}$$

The confidence intervals of the individual study effect size could then be calculated as (Supp. Mat.):

$$\overline{\overline{\ln(RR)}} \pm z_{95\%} s.e. \qquad \text{(eqn. 4)}$$

This can also be used to find the upper and lower confidence interval for the mean weighted effect size $\overline{\overline{\ln(RR)}}$. The weighted effect size, the effect sizes of the individual studies and their confidence intervals were back-transformed to RR_i, to produce forest plots comparing effect sizes from individual studies to the overall effect size calculated for each indicator.

2.5 Funnel Plots

Publication bias is a major problem in meta-analysis due to significant data being more likely to be published than non-significant data and the unpublished data is often difficult to access (Arnqvist and Wooster, 1995). Funnel plots present individual study effect sizes against the corresponding sample size, and asymmetry in the plot indicates publication bias as precision in estimating the overall effect size will increase as the sample size of the individual studies increases. If bias is present then the results from the small studies should scatter widely at the base of the graph, narrowing as the sample size increases. In the absence of bias the plot will resemble an inverted, symmetrical funnel (Egger et al., 1997). We used funnel plots to investigate the potential for bias to influence our interpretation of results (Supplementary

Material A, Figure A1), but note that caution should be applied when interpreting these plots (Lau et al., 2006).

3. Results

The majority of co-management case studies were carried out in Asia (72.7%), followed by the Americas (11.4%), Africa (9.1%), Europe (4.5%) and Australasia (2.3%; Table 2). Of the cases included from Asia, 44% were in Bangladesh and 34% were in the Philippines. The sites reported included marine and inland aquatic habitats ranging from coral reefs and mangrove forests to seasonal wetlands and lakes. The mean time that co-management has been in place was 7.05 years (standard deviation = 4.02). Most of these studies focused on other parties that would be directly impacted by changes in fishing practices, including fish processors and traders, as well as those who were managing the co-management process. The individual studies based on stake-holder perceptions reported their results as averages taken across the stake-holder groups included. Not all studies reported values for every outcome and process indicator and as such, sample size has been included (Figure 1, Figure 2).

3.1 Coded (Qualitative) Meta-analysis

The first method involved a coded meta-analysis of information from all 44 studies, for all 9 indicators. While all process indicators were heavily skewed towards positive results, with median response values ≥ 1, outcome indicators were more variable (Fig. 1). Spearman's correlation rank analyses determined whether there was any relationship between the coded result for each study's indicator variable and the length of time (years) that co-management had been in place. There was no significant correlation between study outcome and time for any of the indicators, so no further results are reported for this.

3.1.1 Institutions and Governance Indicators

The five institution and governance (process) indicators all displayed positive trends, with at least two-thirds of studies for each process indicator reporting positive results (Fig. 1). Participation showed an overall positive trend with 16 of the 20 cases indicating that an increase in user's participation in the fishery has occurred since the introduction of the co-management structure, 10 of which were reported as being statistically significant ($p \leq 0.05$). 12 of 18 cases reported an increase in conflict resolution, eight of which were significant. 13 of 18 cases reported a significant increase in compliance. The user's influence over co-management decisions showed an overall increase with the introduction of co-management; 14 of the 16 cases were positive, although only 4 of these were significant. 14 of the 15 cases reported an increase in the user's control when co-management was in place, 12 of which were significant.

3.1.2 People and Livelihoods

The people and livelihoods (outcome) indicators displayed variable results (Fig. 1). The studies included in the household income analysis were split evenly with 11 of the cases reporting a positive response (6 significant) and 11 reporting a negative change (5 significant). Of the 20 cases reporting on stake-holders' access to the resource, 11 showed a decrease in access rights (2 significant) following co-management, 9 reported positive responses (4 significant).

3.1.3 Natural Systems

The outcome indicators for natural systems also showed conflicting results. An overall increase in fish yields was found, however co-management also resulted in reports of an overall decrease of resource well-being. 12 of the 17 cases (2 significant) reported an increase in fish yield in co-managed fisheries. Of the 6 cases that reported a decrease in fish yield, one was reported as significant. On the other hand, resource well-being showed an overall decrease within co-managed fisheries with 11 of the 20 cases reporting a decrease in fish abundance within the fishery, 2 of which were reported as significant. An increase in the number of fish captured and condition of the resource was observed in 9 case studies and reported as significant in 4 cases.

3.2 Response Ratios: Quantitative Meta-analysis

The implementation of co-management in the fisheries studied has resulted in a statistically significant increase in four of the five process indicators and a significant decrease in one of the three outcome indicators (Fig. 2). Fish yields could not be included in this method due to the sample sizes not being reported.

The users' compliance with co-management agreements (RR = 1.43, 95% CI = 1.25 – 1.64), control over the resource (RR = 1.48, 95% CI = 1.25 – 1.76), influence in co-management decisions (*RR* = 1.37, 95% CI = 1.17 – 1.61) and participation in the co-management structure (RR = 1.35, 95% CI = 1.12 – 1.64) were all reported to increase significantly following implementation. Results for conflict between stakeholders and government were far more variable, with no significant change reported overall. Resource well-being showed a significant decline following co-management (*RR* = 0.79, 95% CI = 0.69 – 0.91), while there was no consistent evidence for change across studies for household income or access to the resource (Fig. 2).

3.3 Detecting publication bias

Funnel plots were used to detect bias in the studies included in the quantitative meta-analysis, plotting effect size against sample size for each study. Sample size indicated the number of participants that had taken part in interviews, surveys or focus groups. Bias was inferred if the funnel plot was asymmetrical. Figure 3 shows an example produced for users' participation in co-management arrangements. The funnel plot shows that publication bias can affect results, with larger studies, or those with a greater number of respondents, having a more pronounced effect on the overall effect size. The funnel plots for the other indicators measured exhibit the same general result (Supplementary Material A, Figure A1).

4. Discussion

4.1 Does co-management improve fisheries?

Our analyses have synthesised the available literature to show that fisheries community co-management schemes have shown positive impacts on social factors, reflected in all process indicators studied. Further, our results demonstrate that co-management can help not only in resolving conflict but also in increasing compliance with rules and regulations that the stakeholders themselves have participated in creating. Results from the biological and economic factors are less clear, which may suggest that these schemes require more time in place before benefits can be seen (the studies assessed here had been in place for a maximum of 10 years). These results are consistent across both qualitative (coded) and quantitative meta-analyses, although it is important to point out that the data available for inclusion in these meta-analyses remains limited in scope – both geographically and in terms of data quality (Table 2). The majority of studies included came from Bangladesh (14) or the Philippines (11), with relatively little quantitative information available on co-management schemes in other continents. When evaluating the outcomes of fisheries co-management programmes, it is preferable to compare standardised quantitative performance data, such as catch per unit effort, biodiversity assessments, income generated, species population characteristics and other community livelihood parameters. Unfortunately, many programmes lack the funds needed to collect even basic baseline data, especially those located in developing countries (Webb et al, 2004), as was the case for the majority of the studies assessed here. Accessible results from co-management studies outside of Asia are required, while all studies need to present the basic descriptive statistical information (effect sizes, sample size, variance estimates) to ensure that they can be meaningfully incorporated in future analyses and syntheses.

4.2 Relationships between Process and Outcome Indicators

Our study expands on information provided by previous analyses of fisheries co-management (Evans et al., 2011; Gutierez et al., 2011). Our first (qualitative) analysis followed the methods of Evans et al. (2011) and due to the nature of our study, there is some inevitable overlap in the co-management schemes examined (33% similarity). Our study indicates that co-management has a positive effect on all process indictors studied, a result which was consistent with Evans et al (2011); 41% of studies in Evans et al.'s (2011) qualitative meta-analysis came from the Philippines, which they thought highly influenced the results for the process indicators considered. Although our study included substantial information from the Philippines (25.6% of all studies analysed), we included more studies in our analysis (43 in total, Table 2), providing further general and robust quantitative support for the observation that co-management positively affects the process indicators studied.

For the outcome indicators, co-management had a positive effect on fisheries yield and a negative effect on access to resource, consistent with results from Evans et al (2011). However, Evans et al (2011) found that co-management also had a positive effect on household income and resource well-being which does not align with results from our study. The qualitative results for household income were evenly split, with 50% reporting positive outcomes after the implementation of co-management schemes and 50% reporting negative outcomes (Fig. 2). Resource well-being is overall shown to decrease with fisheries co-management (Fig. 2). Differences in results could be due to difference in sample size. Evans et al (2011) had a smaller sample size for studies included (29 *vs.* 43). Another reason could be that our study included data from schemes that have been set up more recently. The case-studies included in our analyses had a co-management arrangement in place for a minimum of 1 and a maximum of

10 years. This range may not have allowed adequate time for the resource to recover from previous fishing effort in all studies. Our results also build upon those of Evans et al. (2011), by incorporating quantitative effect sizes and explicitly considering the impact of publication bias on our findings. Both of these aspects add important detail and context to help us interpret results more robustly.

Participation is perceived to be a key co-management process; the development of participation between stakeholders, the governing body and, in some cases, scientists and environmental groups, is vital for the successful transition from top-down management to co-management (Chuenpagdee and Jentoft, 2007). Of the 17 case studies reporting positive results for stakeholder participation included here, 15 also reported positive results for other process and outcome indicators assessed, with 8 studies reporting positive results for 4 or more indicators. Stakeholders are more likely to comply with rules if they can participate in the management of the resource, reducing conflict and improving resource well-being as quotas are increasingly adhered to (Coffey, 2005, Pita et al., 2010). More importantly, participation in management develops trust and social capital between the various parties involved (Berkes, 2009).

The studies that report no difference or a negative impact of co-management on process indicators had the largest sample sizes, suggesting the most reliable results (Figures 3, A1). However, smaller sample sizes could also relate to smaller fisheries with fewer participants (Pimoljinda and Boonrakda, 2001; Pomeroy et al, 2005), resulting in higher participation in the management decisions and an increased influence over the decisions made. Interactions among control over the resource through reduced competition, increased influence over governance, compliance and reduced conflict suggest that as the number of stakeholders involved in the fishery decreases, the chance of decisions being reached that can be agreed by all increases, suggesting that co-management could benefit smaller fisheries but becomes difficult to successfully maintain when the number of groups participating in the fishery increases.

It is important to consider a range of response variables when assessing the effect of co-management arrangements. Fisheries that are experiencing difficulties are likely to report negative outcomes for more than a single factor (Nielson et al., 2004). This was true for most of the case studies examined here. In the quantitative method (*RR*), only two case studies reported a single negative outcome, compared to the other 14 studies that reported multiple negative outcomes. The most commonly reported negative indicators were outcome indicators: resource well-being, access to resource and household income. However not all studies reported values for all indicators assessed which in some cases made generalising findings difficult. For example, in the case of resource-wellbeing, 71% of the case studies included came from the Philippines. However, as co-management is often implemented as a final resort by governing bodies (Kaplan and McCay, 2004), it is not necessarily surprising that the majority of fisheries examined here report a decline in the fish stocks.

There was also a lack of consistency in the way that certain attributes were reported across studies. Fisheries yield, for example, could not be included in our second (quantitative) analysis, due to a lack of consistency in the way that data was reported, as well as a failure to report standard metrics. Yield data was reported in several ways; the most common being catch per unit area (35.3%) or perceived changes in catch over time as reported by fishermen (35.3%), with other studies reporting changes in catch per unit area or total landings. However, as all studies consistently reported these as a change in the metric over time, we combined them for comparison in our qualitative method, to show an overall effect of co-management on (different metrics of) fisheries yield reported in different studies. While it would clearly be preferable to analyse a single metric across all studies, this would have resulted in a significant reduction in sample size. While there were more reports of increased yield from the fishery following the implementation of co-management, four were reported as being significantly negative, yet only two were significantly positive (Fig. 1), highlighting the variable yield results associated with co-management and emphasising the need for quantitative data to be reported in a more consistent way for this crucial information.

The case studies from the Philippines dominated some of the indicators measured due to studies incorporating an existing framework first described by Pomeroy et al, (1997) to collect stakeholder perception data. Of the 17 studies used in the quantitative method, 10 came from the Philippines and 8 of these reported on all 8 of the indicators assessed (Table 2; Katon et al., 1998, 1999; Israel et al., 2004; Webb et al., 2004; Pomeroy et al., 2005; Maliao and Polohan., 2008), with the remaining two studies reporting results for seven indicators (Baylon, 2002). In contrast, studies from other areas, such as Sultana and Thompson's (2004) work in Bangladesh, only addressed three process indicators (Compliance, Control and Influence). These results highlight the difficulty in generalising across indicators or geographic regions, yet emphasise the lead that research conducted in the Philippines has taken on studying co-management. A consistent framework would address the need for a more standardized method of assessing fishery co-management schemes. We recommend future studies follow the reporting approach of Pomeroy et al (1997), to allow broader, consistent analysis and facilitate meaningful comparison.

4.3 Co-management attributes

Gutierrez et al. (2011) emphasize that fisheries co-management schemes appeared to be more successful in areas with strong government management, including attributes such as funding and marine protected areas, which our results support. There was a 40% overlap in the case studies included in their analysis and ours. However, we rejected a substantial number of case studies included by Gutierrez et al (2011) from our study due to the failure to report appropriate quantitative data. While sample sizes were too low (and in some cases confounded) to allow a formal analysis, the information we could include in our analyses suggests that successful schemes involved funding, dedicated project staff and the outside agencies (Table S1, Supplementary Information), as well as having had sufficient time to allow the co-management schemes to become established (Table2, Table S1).

The more successful co-management schemes received funding, both for the implementation of the co-management and for providing some stakeholders with a wage as they develop co-management arrangements and links (Table S1). Studies of schemes where funding was not available or was limited, reported unstable arrangements due to a lack of compliance and the inability to enforce rules (Oberio et al., 2015). Providing funding for co-management implementation may increase the initial financial cost, however, the economic and social impact of collapsed fisheries could drastically increase government costs if appropriate intervention does not occur (Abdullah et al, 1998). Many of the fisheries in Asia, especially Bangladesh, are located in floodplains and provide seasonal work, so the fishery may not provide the only source of individual income. Co-management schemes may require a greater individual time investment, thus reducing the time that stakeholders have to pursue other income sources (Thompson et al, 2003), and without support from government or NGOs this could result in a decrease in income from outside of the fishery.

Many fisheries co-management schemes that were unsuccessful or faced difficulty in implementation lacked government involvement in the process or suffered from the governments' inability to delegate authority to the community (Ho et al., 2016). Several studies reported that a lack of government recognition led to inadequate community participation and the inability to enforce rules and regulations which had negative effects on the outcome of these schemes (Oberio et al., 2015; Cudney-Bueno and Basurto., 2009).

The most successful studies we included reported positive results in all (Katon et al, 1998), or all but one (a decline in household income; Katon et al 1999), process and outcome indicators, following the implementation of co-management. These Philippine fisheries shared important common features, including implementation by a private firm, restoration of coastal habitats and sufficient funding was provided to employ community members to promote awareness and engagement from local fishers' associations. Government input was minimal, providing legal advice and frameworks. Co-management is not an end-point but a process which evolves over time and therefore the time required for the initial developmental process may be quite substantial (Berkes, 2009). These and other successful schemes had been in place for at least six years, suggesting that co-management schemes need to be given time to establish before being assessed, a point that has not been previously taken into account

4.4 Future Opportunities

The geographic limitations mentioned above, with only four published case studies being found across Australasia, the Americas and Europe, suggest either that co-management schemes are not commonly employed in these continents, or that data is not being published or made available. While several countries within these continents have reported on fisheries co-management schemes, such as Australia (Carter and Hill, 2007) and Norway (Søreng, 2006), neither quantitative nor qualitative outcome results have yet been published from these schemes.

There was also a lack of consistency between studies in the way that certain attributes were reported across studies. Fisheries yield, for example, was reported as either catch per unit area, catch per boat or as perceived changes in catch over time as reported by fishers. This, along with resource well-being, could be argued to be one of the most important variables studied. To make this comparable across studies and allow it to be included in the quantitative method, it should be reported as catch per unit effort or catch per unit area, so yield can be monitored more robustly.

Publication bias towards significant results remains an important issue in scientific communication, including meta-analysis (Egger et al, 1997, Chase, 2013, Kotze et al. 2004). Both the process and outcome indicators analysed here indicated potential publication bias (Figs. 3 and A1; but see Lau et al, 2006, for further discussion of the use of funnel plots in this context). The majority of studies used in our analyses had relatively small sample sizes which often reflected the size of the fishery ($n < 100$), lacking power compared to the few studies that reported higher sample sizes.

Access to data was limited, presenting a number of challenges. Firstly, failure to report basic descriptive statistics such as means, sample size and variance, coupled with the difficulty in obtaining data sets from which published work had been produced, meant that a number of studies could not be included in our quantitative method. When *p*-values were not reported, results that could potentially have been significant in the qualitative (coded) analysis were classified as non-significant. This means that even though the coded method included more data, its results should be considered relatively conservative and the true results from this could be more pronounced than the results we reported. Secondly, unpublished data was often not easily visible and the organisations holding the data were often unwilling to release it for use (confidential personal communications). Where possible, studies should aim to maximise power during the design phase, but ultimately, we believe making all data available will have the most positive impact on improving effect size estimates and therefore fisheries around the world. This echoes calls made to maximise transparency and rigour through fuller reporting of trials carried out in clinical research (Goldacre, 2015).

5. Conclusions

Implementation of community co-management had a consistent, significant positive effect on social factors and mixed effects on bio-economic factors. The more successful schemes involve the community members from the start, establishing core groups from participants that could help guide the implementation as well as providing or securing funding to support this transition. The more successful schemes are community-based, where the government's role is to provide the rules and regulations with legal status, or a partnership between the community and the government where the management is shared equally. These schemes also involve external organisations, which are often responsible for co-ordinating the program as well as guiding the implementation. A standardised method for assessing the schemes should be introduced to assess and compare co-management more efficiently, with any published studies reporting a minimum set of descriptive statistics to allow incorporation in future meta-analyses and syntheses: effect sizes, sample size and variance estimates. This would not only facilitate comparison across studies but would aid in the design and improvement of current and future community co-management schemes.

6. Acknowledgements

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8. Tables

Table 1: Process and Outcome Indicators evaluated in this study, their definitions and groupings.

Indicator	Definition	Grouping
Participation	User's perceived participation in the co-management arrangement.	Institutions and governance
Influence	User's perceived influence over decisions made regarding the fishery under co-management.	
Control	User's perceived control over resource.	
Conflict	User's perceived levels of conflict between stakeholders and government.	
Compliance	If the user perceives that stakeholders are adhering to rules and regulations decided under co-management.	
Fish yield	Fisheries yield reported as catch per unit area, catch per boat or perceived changes in fish yield.	Natural Systems
Resource Well-being	Number of fish present within fishery, as well as the condition of fish caught, as perceived by the user.	
Household income	Stakeholders income	People and livelihoods
Access to resource	Perceived changes in the stakeholders' access to the fishery resource after co-management implementation.	

Table 2: A Summary of Case-studies used in the Meta-analysis. Those highlighted in grey were used in method 2 (Quantitative Studies).

Case Study	Country	Study period or year co-management was implemented	Type of co-management arrangement	Reference	P-values Reported
B1	Bangladesh	2002 - 2004	Partnership	Sultana and Abeyasekera, 2008	No
P1	Philippines	1996 - 2002	Partnership	Baylon 2002	Yes
P2	Philippines	1996 - 2002	Partnership	Baylon 2002	Yes
B2	Bangladesh	1995 - 2012	Community Control	Chowdhury et al 2012	No
S1	Spain	1994 – 2001	Advisory	Domingues-Torreiro et al, 2004	No
CL1	Chile	2008 - 2010	Co-operative	Fernandez and Friman, 2011	No
CL2	Chile	2002 - 2004	Co-operative	Gelcich et al, 2006	Yes
B3	Bangladesh	1998 - 2006	Community Control	Halder and Thompson, 2006	No
B4	Bangladesh	1998 - 2005	Community Control	Halder and Thompson, 2006	No
B5	Bangladesh	1998 - 2006	Community Control	Halder and Thompson, 2006	No
I1	Indonesia	1996 - 1997	Community Control	Harkes, 2006	Yes
B6	Bangladesh	1994 – 2005	Community Control	Islam and Dickson, 2007	No

B7	Bangladesh	1994 – 2005	Community Control	Islam and Dickson, 2007	No
B8	Bangladesh	1994 – 2005	Community Control	Islam and Dickson, 2007	No
B9	Bangladesh	1994 – 2005	Community Control	Islam and Dickson, 2007	No
P3	Philippines	Early 1990`s - 2002	Co-operative	Israel et al, 2004	Yes
P4	Philippines	Early 1990`s - 2002	Co-operative	Israel et al, 2004	Yes
BR1	Brazil	1996	Consultative	Kalikoski, 2002	No
P5	Philippines	1989 – 1997	Community Control	Katon et al, 1998	Yes
P6	Philippines	1988 – 1998	Community Control	Katon et al, 1999	Yes
B10	Bangladesh	1995 - 2006	Community Control	Khan et al, 2012	No
K1	Kenya	2001 (1 year)	Partnership	Kundu et al, 2010	No
P7	Philippines	+10 years	Partnership	Maliao and Polohan, 2008	Yes
I2	Indonesia	10 years	Advisory	Novaczek et al, 2001	No
Z1	Zimbabwe	1993 – 1998 (5 years)	Partnership	Nyikahadzoi and Songore, 1999	No
T1	Thailand	1995 – 1999	Community Control	Pimoljinda and Boonraksa, 2001	Yes
T2	Thailand	1995 – 1999	Community Control	Pimoljinda and Boonraksa, 2001	Yes

P8	Philippines	1994 – 2003	Community Control	Pomeroy & Ahmed, 2006	Yes
P9	Philippines	10+ years	Community Control	Pomeroy et al, 2005	Yes
P10	Philippines	9 years	Community Control	Pomeroy et al, 2005	Yes
B11	Bangladesh	2000 – 2001	Partnership	Sultana and Thompson, 2004	Yes
V1	Vietnam	2000 – 2001	Partnership	Sultana and Thompson, 2004	Yes
B12	Bangladesh	5 years	Community Control	Thompson and Choudhury, 2007	No
B13	Bangladesh	5 years	Community control	Thompson and Choudhury, 2007	No
B14	Bangladesh	3 years	Community control	Thompson and Choudhury, 2007	No
SK1	South Korea	2002 – 2007	Advisory	Uchida et al, 2012	Yes
P11	Philippines	10 years	Community control	Webb et al, 2004	Yes
SA1	South Africa	1993 – 2003	Partnership	Wilson et al, 2010	Yes
NZ1	New Zealand	1999 - 2001	Partnership	Yandle, 2003	No
UK1	Scotland	10 years	Consultative	Butler et al, 2015	No
V2	Vietnam	2002 - 2014	Partnership	Ho et al, 2016	No
M2	Mexico	1997 - 2004	Community control	Cudney-Bueno and Basurto, 2009	No
K2	Kenya	3 years	Partnership	Obiero et al, 2015	Yes

9. Figure Captions

Figure 1: Coded meta-analysis results for the effect of fisheries co-management schemes on a range of outcome (indicator) variables. Nine indicators were analysed for a total of 41 different co-management schemes. The different shades represent positive and negative results and whether these have been reported as significant or non-significant. A number of studies did not report p-values and therefore a number of insignificant results could be significant. This is a conservative method of coding the studies.

Figure 2: Quantitative meta-analysis of the effect of fisheries co-management schemes on a range of outcome variables, using the response ratio effect size. Eight indicators were analysed for a total of 17 different co-management schemes. The mean weighted effect-size for each indicator was calculated for each indicator and the error bars represent 95% confidence intervals. No observed change is indicated by the dashed line at Response Ratio = 1. The results show that co-management increased the process indicators (Compliance, control, conflict, influence and participation) but a decrease was observed in the outcome indicators (Access to resource, household income and resource well-being). Sample size (n) of the number of studies included in each outcome variable is given on the right-hand side of the plot.

Figure 3: Funnel plot for the Participation indicator. The effect size of each study is plotted against the sample size used to generate that effect size. The mean effect size (red line) and 95% CIs (dashed black lines) are also indicated. This plot illustrates that large sample sizes have a greater impact on overall effect size than those studies with lower sample sizes, indicating publication bias.

9. Figures

Figure 1

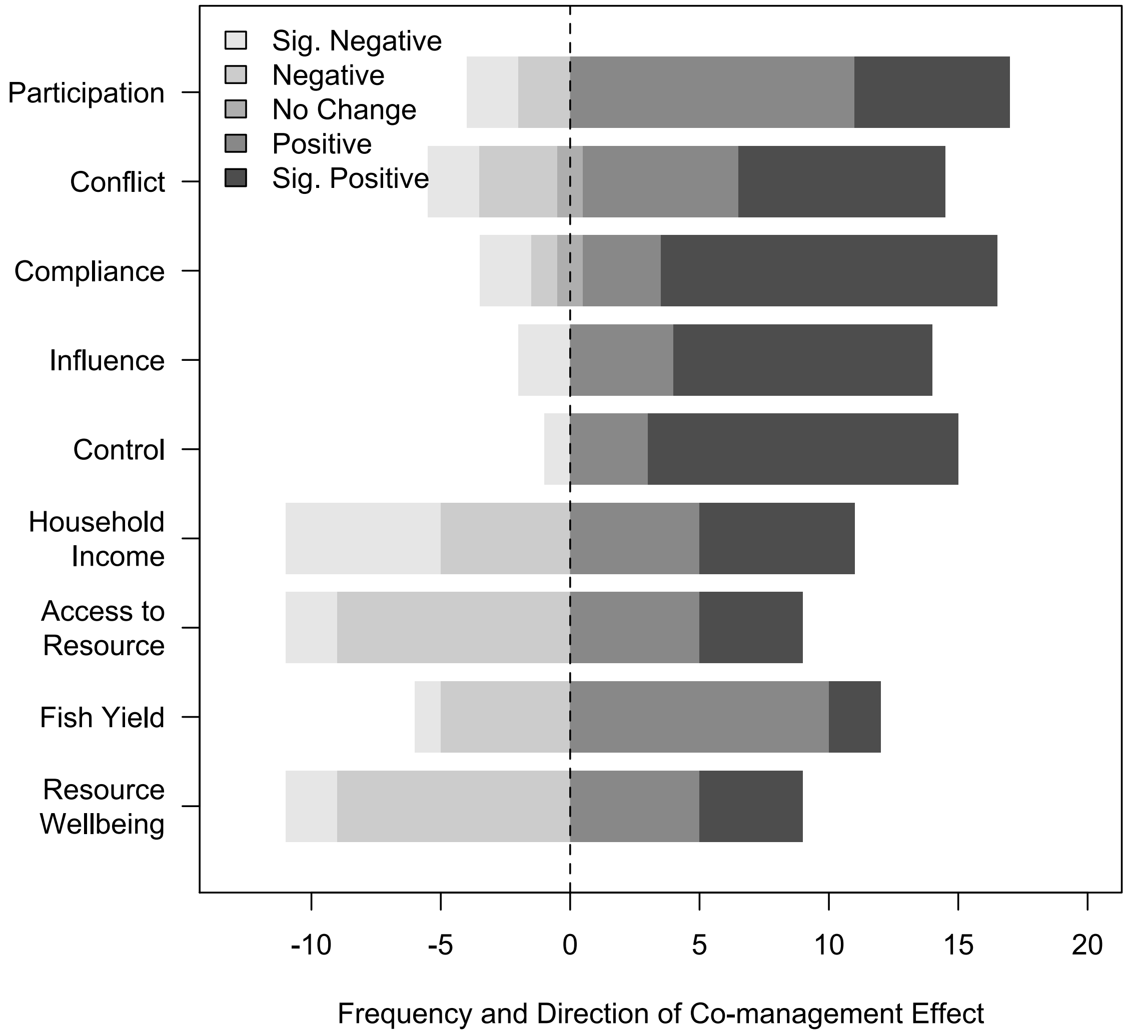
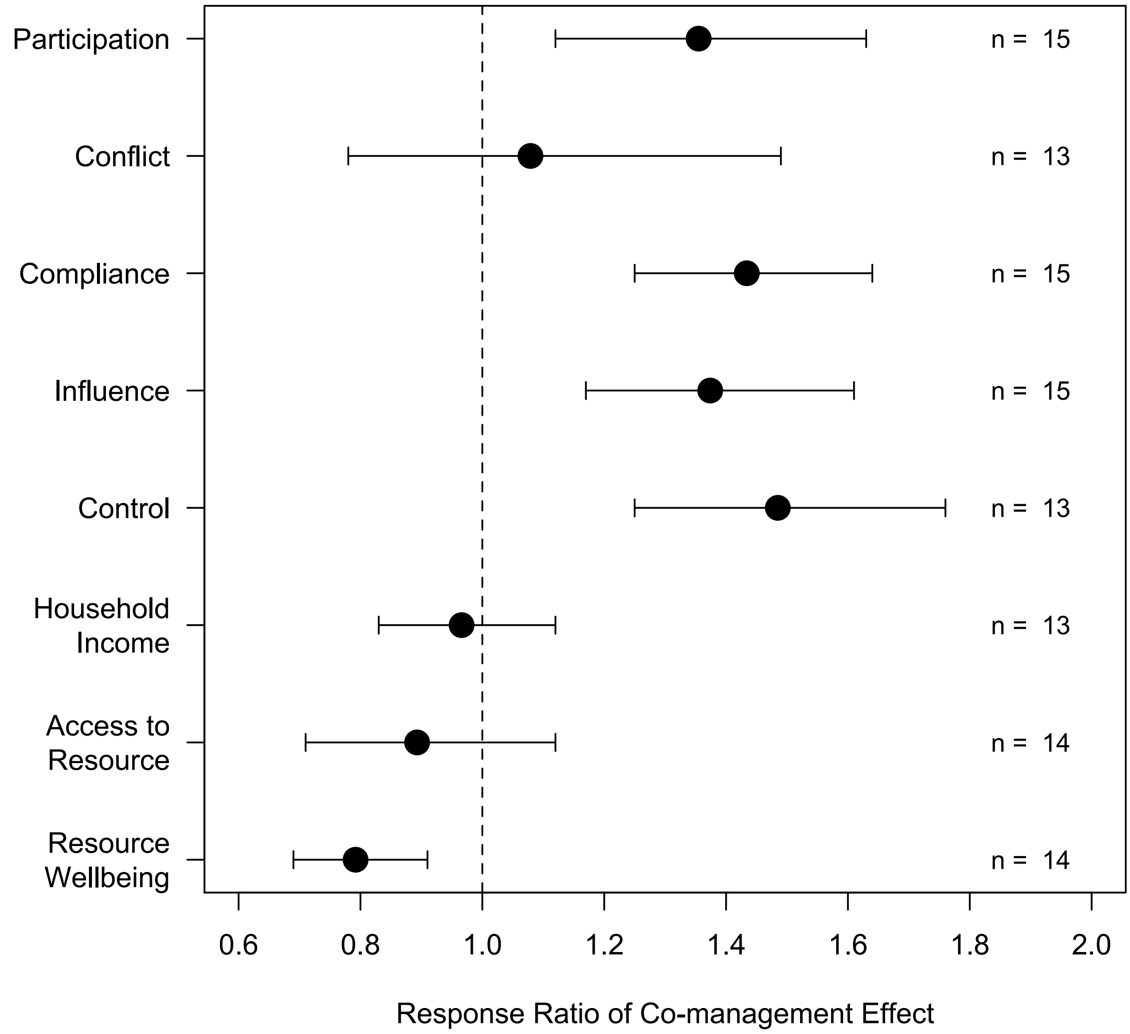
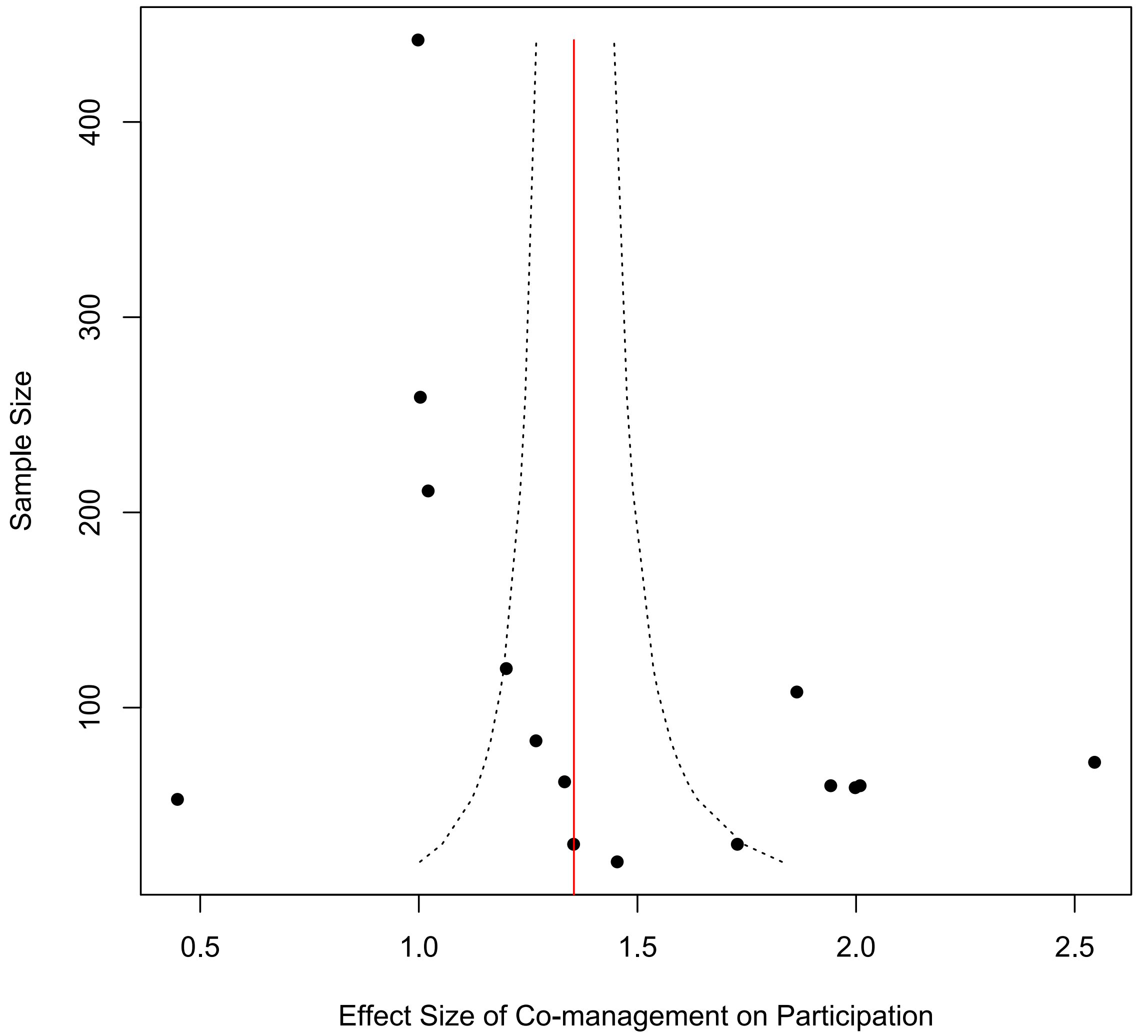


Figure 2



Participation
Conflict
Compliance
Influence
Control
Household Income
Access to Resource
Resource Wellbeing
n = 15
n = 13
n = 15
n = 15
n = 13
n = 13
n = 14
n = 14
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Response Ratio of Co-management Effect

Figure 3


Sample Size
100
200
300
400
0.5
1.0
1.5
2.0
2.5
Effect Size of Co-management on Participation

Supplementary Material A

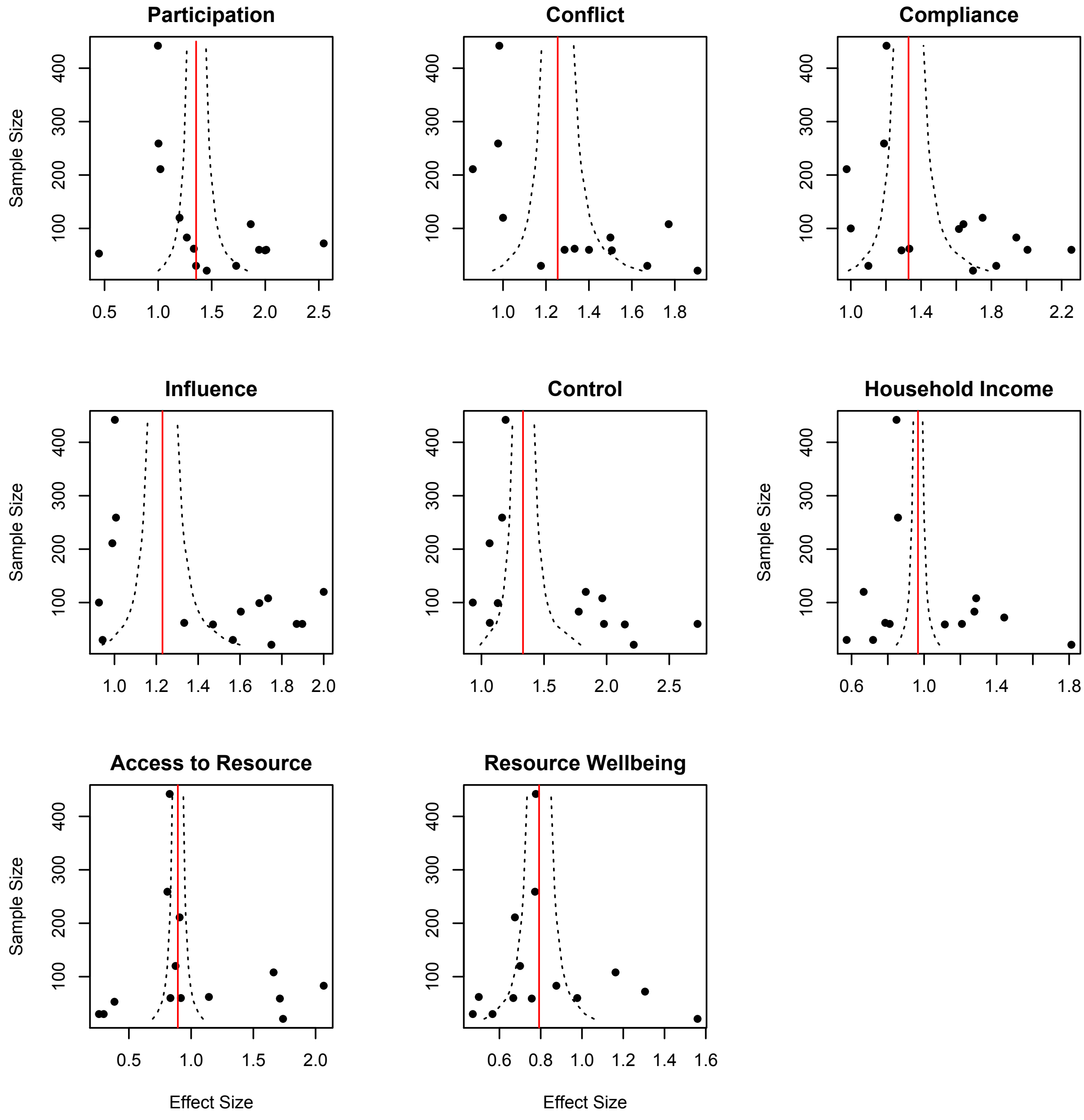


Figure A1: Funnel plots for each process and outcome indicator included in the quantitative meta-analysis. The sample size in each study was plotted against the corresponding effect size (log Response Ratio) to assess publication bias in each indicator analysed in the meta-analysis. The solid red line shows the overall effect size and the dotted black lines show the confidence intervals for the overall effect size.

Supplementary Material B: Quantitative Meta-analysis Methods

Here we show how heterogeneity among studies was assessed and incorporated into our quantitative meta-analyses, based on effect sizes calculated as the log transformed Response Ratios for individual studies ($\ln(RR_i)$, eqn. 1 in main text), weighted mean effect size across studies ($\overline{\overline{\ln(RR)}}$, eqn. 3) and the weighting factor ($w_i = v_i^{-1}$, eqn. 2).

Calculating Heterogeneity

Cochran's Q test determines whether there is true heterogeneity among studies (Medina et al. 2006) and can be defined as (Maliao et al. 2009):

$$Q = \sum w_i \left(\ln(RR_i) - \overline{\overline{\ln(RR)}}\right)^2, \qquad \text{(eqn. S.1)}$$

based on the assumption that a fixed-effects model is used. The Q statistic follows the χ^2 distribution with k-1 degrees of freedom, where k equals the number of studies in the meta-analysis. A low Q value indicates significant heterogeneity across the results from different studies. However, one problem associated with Q is that its statistical power depends on the number of studies. When the number of studies is small, Cochran's Q test has low power, while higher power is associated with a larger number of studies. The Q statistic determines whether there is true heterogeneity among studies, however the I^2 index can quantify the extent of heterogeneity by comparing the Q value to its expected value assuming homogeneity ($k-1$). Therefore, the I^2 index was calculated, describing the percentage of variation across studies that are due to significant heterogeneity rather than random chance. I^2 is calculated as:

$$I^2 = \begin{cases} 100\left[Q - \frac{(k-1)}{Q}\right], & if\ Q \geq (k-1) \\ 0, & otherwise \end{cases} \qquad \text{(eqn. S.2)}$$

I^2 is interpreted as a percentage of heterogeneity and, unlike Q, it does not inherently depend upon the number of studies considered (Medina et al, 2006). When the Q statistic is smaller than its degrees of freedom then I^2 is reported as zero.

2.5.1 Between Experiment Variance Component

The null hypotheses that the between-experiment variance component is zero (H_0: $\sigma_\lambda^2 = 0$), can be rejected whenever Q exceeds the 100×(1 – α) percentage point of the χ^2 distribution with $k - 1$ degrees of freedom (Huedo-Medina et al, 2006). If the I^2 value is high, then H_0 can also be rejected and a random effects model is used to take into account the study-level sources of random error (Cooper, 2009). The between experiment variance component is calculated as;

$$\sigma_\lambda^2 = \frac{Q-(k-1)}{\sum w_i - \frac{\sum w_i^2}{\sum w_i}}. \qquad \text{(eqn. S.3)}$$

This then allows a new weighting to be calculated which takes into effect the variance within an individual study as well as the variance between multiple studies:

$$w_i^* = 1/\left(v_i + \sigma_\lambda^2\right). \qquad \text{(eqn. S.4)}$$

A new weighted effect size can therefore be calculated as:

$$\overline{\overline{\ln(RR_\iota)}} = \frac{\sum_{i=1}^{n} w_i^* \ln(RR_i)}{\sum_{i=1}^{n} w_i^*} \qquad \text{(eqn. S.5)}$$

The 95% confidence intervals were then calculated for the individual study effect sizes and weighted effect sizes. The standard error (s.e.) of the overall effect size was calculated from the sum of the weightings as:

$$s.e.\left(\overline{\overline{\ln(RR)}}\right) = \sqrt{\frac{1}{\sum w_i^*}} \qquad \text{(eqn. S.6)}$$

2.6 Fixed Effects and Random Effects Models

The I^2 index was used to describe the percentage of variation across studies that was due to significant heterogeneity rather than random chance. Fixed effects models are used with low values of I^2 (<50%) as they assume that the true effect size of all the studies is identical and the only reason differences may be observed is due to random error (Borenstein et al, 2007). However, if $I^2 > 50\%$ a random effects model must be used to take into account the variation between studies as well as the variance within the single studies, and an estimate of the mean distribution of the effect is calculated (Borenstein et al, 2007). Both fixed and random effect models were used in this study.

Supplementary Material C

A list of studies considered for inclusion in the meta-analyses. Not all studies listed were used in the final analyses (see Table 2 for those articles) but are included here to allow replication of our methods is possible for any future work that may build on this method.

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Aburto, J., et al. (2013) Territorial user rights for artisanal fisheries in Chile - intended and unintended outcomes. Ocean & Coastal Management, 71Jan, pp.284-295.

Adrianto, L., Matsuda, Y. and Sakuma, Y. (2005) Assessing local sustainability of fisheries system: a multi-criteria participatory approach with the case of Yoron Island, Kagoshima prefecture, Japan. Marine Policy, 29(1) Jan, pp.9-23.

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