

Social, institutional, and knowledge mechanisms mediate diverse ecosystem service benefits from coral reefs

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Edited by Anthony J. Bebbington, Clark University, Worcester, MA, and approved November 5, 2014 (received for review July 16, 2014)

Ecosystem services are supplied by nature but, by definition, are received by people. Ecosystem service assessments, intended to influence the decisions people make regarding their interactions with nature, need to understand how people benefit from different ecosystem services. A critical question is therefore, What determines the distribution of ecosystem service benefits between different sections of society? Here, we use an entitlements approach to examine how people perceive ecosystem service benefits across 28 coral reef fishing communities in four countries. In doing so, we quantitatively show that bundles of benefits are mediated by key access mechanisms (e.g., rights-based, economic, knowledge, social, and institutional). We find that specific access mechanisms influence which ecosystem services people prioritize. Social, institutional, and knowledge mechanisms are associated with the largest number and diversity of benefits. However, local context strongly determines whether specific access mechanisms enable or constrain benefits. Local ecological knowledge enabled people to prioritize a habitat benefit in Kenya, but constrained people from prioritizing the same benefit in Madagascar. Ecosystem service assessments, and their resultant policies, need to include the broad suite of access mechanisms that enable different people to benefit from a supply of ecosystem services.

access | capabilities | entitlements | coral reefs | ecosystem services | entitlements

The concept of ecosystem services (ES) refers to the many ways that people benefit from nature (1). This concept emerged amid a growing realization, in both sustainability science and environmental policy, that practical solutions to environmental degradation must explicitly link people with nature (e.g., refs. 2–4). Much of the subsequent research and policy in ES has focused on increasing benefits to people through enhancements to the supply of one, or a few, ecosystem goods and services (5–8). However, the social, economic, and institutional mechanisms that mediate interactions between people and their environments (e.g., refs. 9–11) can create unequal and inefficient distributions of benefits, meaning an increase to the supply of ES does not necessarily translate into benefits being received by people (12).

Conceptualizing unequal distributions of benefits has an established history within the social sciences on which ES approaches can draw. For example, Sen's (13) entitlements approach to the analysis of famines highlighted how starvation is about people not having enough food rather than there not being enough food (14). Although the latter may cause the former, many famines occur where there is in fact sufficient food supply, and in this context, improving yields or shipments of food aid do little to reduce famine (13, 14). Entitlements therefore describe the range of possibilities of what people can have (14–16). Subsequent developments in this area have focused on examining people's capabilities—or the freedoms they have to choose what they want to have, be, and do (17). Together these approaches provide the tools to challenge conventional distribution paradigms. Rather than assuming an increase in supply

will automatically benefit everyone equally, these approaches acknowledge that due to differences in their capabilities, certain individuals—often the local elite—can capture the majority of benefits, leading to the continued marginalization of others. Despite some critiques (16, 18, 19), Sen's entitlements approach has had significant influence on poverty scholars and practitioners, who now question the paths of influence rather than simply the direct antecedents of poverty and starvation. Indeed, Sen's entitlements approach, starting from the insight that availability does not necessarily mean access, has influenced research far beyond the analysis of famines (16) and has been used to examine the following: gender dynamics (14, 20), the influence of economic or social reform (21, 22), the relationship between fisheries and poverty (23), and challenges facing environmental governance (15, 24, 25). However, an entitlements approach has yet to be applied empirically to the analysis of ES.

We link ES and an entitlements approach (13, 15) (Fig. 1) through the lens of coral reef fisheries to examine how people perceive multiple ES benefits. We examine two key components of an entitlements approach: first, the rights and resources people have, and second, given these rights and resources, the benefits they are able to harness. Endowments are the rights and resources that people have available to them—essentially their potential to access resources (15). We have expanded Sen's (14) original concept of endowments to encompass capabilities (16) and examine this through the lens of access (26). Endowments are therefore the combination of access mechanisms that shape the processes and relations that enable people to benefit (14, 15). We measure indicators for nine categories of access, as identified

Significance

Ecosystems provide a range of services that can benefit people. However, the extent to which people are able to harness those benefits depends not only on the supply of ecosystem services but also on their capacity to access them via a range of social, economic, and institutional mechanisms. Here, we examine how people perceive ecosystem service benefits across 28 coral reef fishing communities in four countries. We quantitatively show that bundles of benefits are mediated by key access mechanisms (e.g., rights-based, economic, knowledge, social, and institutional). Interestingly, social, institutional, and knowledge mechanisms were associated with the greatest number and diversity of benefits. Resource managers can focus on these access mechanisms to maximize ecosystem service benefits while minimizing human–environment impacts.

Author contributions: C.C.H. and J.E.C. designed research; C.C.H. performed research; C.C.H. analyzed data; and C.C.H. and J.E.C. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1413473111/-DCSupplemental.

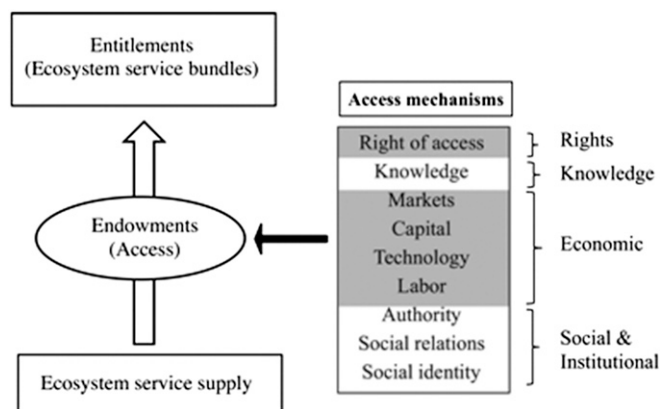


Fig. 1. ES entitlements framework. Data collection and analysis framework used to investigate how different social actors benefit from ES. Access mechanisms, or institutions, mediate the relationship between the supply of ES and the ability of actors to benefit from them (modified from ref. 15).

by Ribot and Peluso (26): rights, technology, capital, labor and labor opportunities, markets, authority, social relations, knowledge, and social identity, which we further grouped into four types of access (rights-based, economic, knowledge, and social and institutional) (Table 1 and Fig. 1). Entitlements are the “alternate commodity bundles” over which, given their endowments, people have command—essentially, the endowments that people can realize or leverage within existing sociocultural constraints (14–16). In an ES context, this reflects “ES bundles” that may include any combination of provisioning (e.g., food), regulating (e.g., coastal protection), cultural (e.g., spiritual reflection), and supporting services (e.g., nutrient cycling) (1), or just a single ES (Fig. 1). We apply this approach to 28 coral reef fishing communities, across four countries in the western Indian Ocean, and ask the following research questions: (i) What ES bundles (entitlements) do resource users in the western Indian Ocean perceive? (ii) Which access mechanisms (endowments) are associated with these ES bundles? (iii) How does the distribution in ES bundles, and their associated access mechanisms, vary across countries?

Results

Ecosystem Service Bundles. We identified nine coral reef ES: two provisioning (identified as fishery and materials), two regulating (identified as coastal protection and sanitation), one supporting (identified as habitat control), and four cultural services (identified as culture, education, recreation, and bequest). Across the western Indian Ocean, these ES co-occurred in four bundles (representing distinct entitlements) (Fig. 2). Each ES bundle represented a greater tendency of resource users to prioritize specific ES benefits. Each ES bundle was associated with a different country, suggesting communities within a given country were generally more similar to each other than to communities in other countries in the way they prioritized ES benefits (Fig. 2A).

Associated Access Mechanisms. Importantly, each ES bundle was associated with distinct access mechanisms. The greater coastal protection, sanitation, and habitat benefits were associated with better access to markets and access to knowledge (Fig. 2A). The greater recreation benefits were associated with higher levels of access to knowledge, to labor and labor opportunities, via the negotiation of social relations, and through social identity (Fig. 2A). The greater fisheries and materials benefits were associated with increased access via the negotiation of social relations (Fig. 2A). Finally, the greater education, culture, and bequest benefits were associated with increased access through social identity (Fig. 2A).

Analyses conducted at a country scale, however, revealed a different suite of ES bundles and access mechanisms associated with them (Fig. 3 and Fig. S1). There were some commonalities

across countries in the access mechanisms that mediated bundles containing specific ES. For example, in Kenya, Seychelles, and Tanzania, communities with higher reported levels of social identity were more likely to prioritize fishery benefits (Fig. S1 and *SI Results*). Similarly, in Kenya and Madagascar, communities with limited rights-based access and higher reported levels of access through social relations were more likely to prioritize recreation benefits (Fig. S1 and *SI Results*). Our country-scale analyses highlight the importance of context, particularly where one access mechanism enabled a benefit in one context but constrained the same benefit in a different context. For example, communities with higher reported levels of knowledge (specifically local ecological knowledge) were more likely to prioritize habitat benefits in Kenya and less likely to prioritize habitat benefits in Madagascar. Similarly, communities with higher reported levels of knowledge (specifically years of education) were more likely to prioritize material benefits in Madagascar and less likely to prioritize material benefits in Tanzania (for further details, see Fig. S1 and *SI Results*).

Influence of Different Types of Access Mechanisms. Overall, social and institutional (e.g., social relations and identity) as well as knowledge mechanisms mediated the greatest number and diversity of ES bundles (Fig. 3). At the regional and country scales, respectively, social and institutional mechanisms were associated with 75% and 70% of the ES bundles and knowledge mechanisms with 50% and 44% of the ES bundles (Figs. 2 and 3 and Fig. S1). Economic and rights-based mechanisms, overall, explained the lowest number and diversity of ES bundles; economic mechanisms were associated with 50% of the identified ES bundles at both the regional and country scales and rights-based with 13% at a country scale (Figs. 2 and 3 and Fig. S1). Interestingly, the rights-based and economic access mechanisms always acted in combination with other mechanisms (i.e., they were not exclusively related to any ES bundles), whereas the social and institutional access mechanisms were exclusively associated with 50% of the ES bundles at a regional scale and 25% at a country scale. Likewise, knowledge mechanisms were exclusively related with 13% of the ES bundles at a country scale (Figs. 2 and 3 and Fig. S1).

Controlling for differences in the number of individual variables measured within each type of access mechanism (Table 1), 63% and 59% of the social and institutional variables, 100% and 89% of the knowledge variables, 50% and 54% of the economic variables, and 0% and 50% of the rights-based variables were used to explain the overall variation in ES bundles at the regional and country scales, respectively.

Discussion

An entitlements approach has been applied to a diversity of fields to uncover the processes through which different people benefit from a supply of food, environmental, or economic resources (14, 15, 20). We present an entitlements approach for assessing ES that explicitly acknowledges that people access and benefit from ecosystems in diverse ways (11, 26–28). Our comparative study of 28 communities across four countries revealed three key findings. First, we demonstrated that people perceive ES benefits in bundles that are mediated by specific access mechanisms. Second, we showed that across scales, social and institutional as well as knowledge (rather than rights-based or economic) access mechanisms were associated with the greatest number and diversity of ES bundles. Third, we found that the directionality of these relationships—that is, whether specific mechanisms enable or constrain perceived benefits—changes depending on context.

The first key finding highlights that the benefits people perceive from a supply of ES tend to occur in bundles, mediated by specific access mechanisms. This suggests people do not always distinguish between different benefits, making conceptualizing, separating, and measuring individual services problematic. Indeed, most fishers are motivated to go fishing as much by income

Table 1. Access mechanisms determined in the focus groups, guided by Ribot and Peluso (26)

Type	Mechanism	Description	Response	Analysis (PCA % explained)
Rights-based	Rights-based access*	The formal (de jure), or informal but adhered to (de facto), rights and restrictions on fishing	Open access, 0; restricted access, 1	Rights, NA
Social and institutional	Access to authority**	Levels of trust in, and participation with, local and national authorities, based on (i) how much they trusted relevant members of authority and (ii) whether they engaged with members of authority in any groups or organizations	(i) 5-point Likert scale (ii) yes, 1; no, 0	Authority, one factor (42%)
Social and institutional	Access through social identity**	Social identity was measured as (i) meanings, how strongly respondents identified with seven statements conveying the meanings associated with being a fisher; (ii) heritage, whether respondents grew up in a fisher family; and (iii) attachment, how attached the respondent was to the marine environment [as (a) occupational connections, (b) occupational importance, and (c) dependents] (48).	(i) 5-point Likert scale (ii) True, 1; false, 0 (iii) (a) number of connections, 0–3; (b) order of importance, 1–3; (c) dependents, 0–9	Meanings resulted in two factors, place-based (26%) and identity (20%) Heritage, NA Attachment, one factor (31%)
Social and institutional	Access via the negotiation of social relations**	Social relations were measured through levels of (i) trust [in (a) fishers and (b) community members] and (ii) participation [in (a) community events and (b) resource management decisions (37)]	(i) 5-point Likert scale (ii) (a) yes, 1; no, 0 (b) no attendance, 0; passive, 1, participation, 2	Three factors, trust in fishers (18%), trust in community (25%), and participation (15%)
Knowledge	Access through knowledge**	We assessed knowledge about (a) ecological processes, (b) local knowledge transfer, (c) species, (d) weights at maturity, and (e) years at school	(a and b) 5-point Likert scale (c and d) true, 1; false, 0; (e) years at school	Two factors, local ecological knowledge (35%) and education (16%)
Economic	Access to markets*	Markets were measured by the average price of fish as sold in the nearest market	\$/kg	NA
Economic	Access to technology**	Technology was measured as capital invested in the gears owned by the fisher (49)	Scale 1–4 investment required. Spear guns, US\$4.6; line, US\$6.9; trap, US\$33.9; net, US\$200.6	Technology, NA
Economic	Access to capital**	Capital was measured to include (i) income, (ii) expenditure, and (iii) a material style of life index (MSL). MSL calculates a wealth score based on material possessions. Our MSL index examined 15 items: types of walls, roof, and floor in house; how they cooked (gas, charcoal, or firewood); lighting (e.g., light bulbs, hurricane, or kerosene lantern); any transport (car, motorcycle, bicycle); and whether they had piped water, a generator, electricity, a fan, a refrigerator, a television, a DVD, a radio or cassette player, and a mobile phone (37).	(i and ii) \$/fortnight (iii) presence, 1; absence, 0	Capital, one factor (59%)
Economic	Access to labor and labor opportunities**	Occupations were measured to include occupational diversity, and household occupation multiplicity, determined from the activities (i.e., jobs) that people did that brought food or income into their homes (50). We calculated the number of (i) jobs in which respondents were engaged, (ii) jobs in which members from their household were engaged, and; (iii) different types of jobs in which people in the household engaged.	Number of (i) personal jobs, 0–5; (ii) household jobs, 0–5; (iii) different jobs in the household, 0–5	Occupations, one factor (72%)

Access mechanisms fall into a broad type, a description is given, response scale used, and PCA.

* $n = 28$ communities.

** $n = 374$ individual interviews sampled.

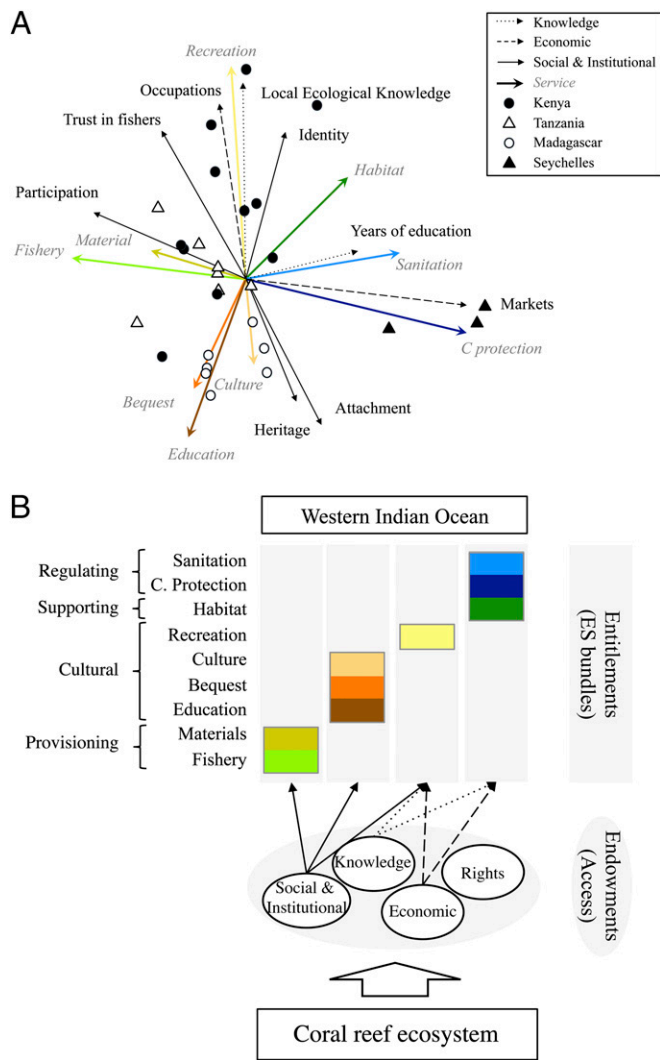


Fig. 2. WIO ES entitlements. (A) RDA showing variation in community priorities for ES benefits associated with distinct access mechanisms. (B) Schematic entitlements framework showing ES bundles and their associated access mechanisms derived from the RDA.

(a provisioning service) as many nonincome-related factors such as tradition and pleasure (cultural services) (29), and they tend not to cognitively distinguish between these types of benefits (30). ES assessments that measure one or two ES at a time are therefore basing decisions on partial information with the potential to generate unexpected tradeoffs (12, 31, 32). An entitlements approach differs from a conventional ES approach in that it starts with the assumption that people receive benefits in bundles rather than as discrete individual commodities (12, 14, 15). ES bundles have conventionally involved biophysical measures (5, 33) but are emerging as an important way of approaching preference-based ES assessments (31, 34, 35). We add to this growing body of literature by demonstrating that the bundles of benefits people perceive from a supply of ES can be understood from the access mechanisms people have available to them (26). Access can therefore be seen to give people the rights and resources they need to benefit from a supply of ES. Because people are unlikely to respond to policy in the ways an ES approach intends until they perceive a benefit, ES science would be advanced by an inclusion of access in the assessments of bundles.

Our second key finding identified social and institutional as well as knowledge access mechanisms to be related to a wider range of ES bundles than rights-based or economic mechanisms.

This finding holds across the scale and is in line with critiques of Sen's early focus on economically mediated entitlements (16, 18, 19). For example, social and institutional mechanisms were associated with all entitlements containing fishery benefits: Access through authority was associated with fishery benefits in Madagascar, access through social relations in Kenya, and access through social identity in Kenya, Tanzania, and Seychelles. These patterns support the need for appropriate conflict resolution mechanisms (10, 36), trust (37), and attachments (38) in achieving benefits in natural resource settings. However, there is a tendency within fisheries and development more broadly to focus capacity-building efforts more narrowly. For example, rights-based approaches to fisheries management attempt to institute more secure fishing rights (39), and wealth-based approaches attempt to connect fishers to more efficient markets (40). A governance approach that creates the conditions within which people are able to benefit from their environment in diverse ways is likely to enhance people's ability to live better (14, 41). In line with these arguments, we suggest an ES approach that enables people to perceive a diversity of benefits is likely to enhance both human well-being and ecosystem quality. Such an approach should aim to enhance the social and institutional as well as knowledge-based mechanisms that we found associated with the greatest number and diversity of ES benefits. Examples of this could include co-management approaches that focus on generating and mobilizing knowledge (42) and welfare-based approaches that recognize the importance of maintaining social mobility in a fishery (43).

Our third key finding highlights significant differences across context that cannot be overlooked in determining how people perceive ES benefits. The regional analysis identified broad country-specific access mechanisms and bundles; however, care should be taken to nest locally appropriate policies within this context. Although the country-specific analyses identified some commonalities, all country-scale ES bundles were distinct, suggesting the way people benefit from ES is influenced by local context. Critically, a specific access mechanism may enable people to benefit from a certain ES in one context but may constrain the ability of people to benefit in a different context. For example, communities that reported greater levels of ecological knowledge were more likely to prioritize habitat benefits in the fishery in one context and a desire to learn more about the habitat in a different context (44). Baseline levels of knowledge or cultural differences may influence how these mechanisms play out. Evidently, broader assessments can help in building theories and making generalizations about the relative importance of different categories of mechanisms, but more fine-scale assessments will need to be conducted before developing specific policy recommendations.

Conclusion

The concept of ES seeks to illustrate the importance of biodiversity to humans through the benefits they gain. In doing so, it is hoped that people will become aware of the importance of biodiversity and therefore develop more environmentally responsible behaviors. By integrating an entitlements approach with ES, this article developed an understanding of how different people are likely to be affected by changes in ES supply. In the western Indian Ocean, we found people perceive ES benefits in bundles rather than as discrete individual benefits and that access mechanisms are strongly related to which ES benefits people perceive. We show that the greatest opportunities to diversify and improve the flow of ES benefits people receive may be by enhancing a range of social, institutional, and knowledge access mechanisms. Although there are broad similarities in how different people are able to benefit from specific ES, context is a key determinant of how these mechanisms play out and whether they ultimately increase or decrease the options people have available to them. These findings highlight a growing recognition

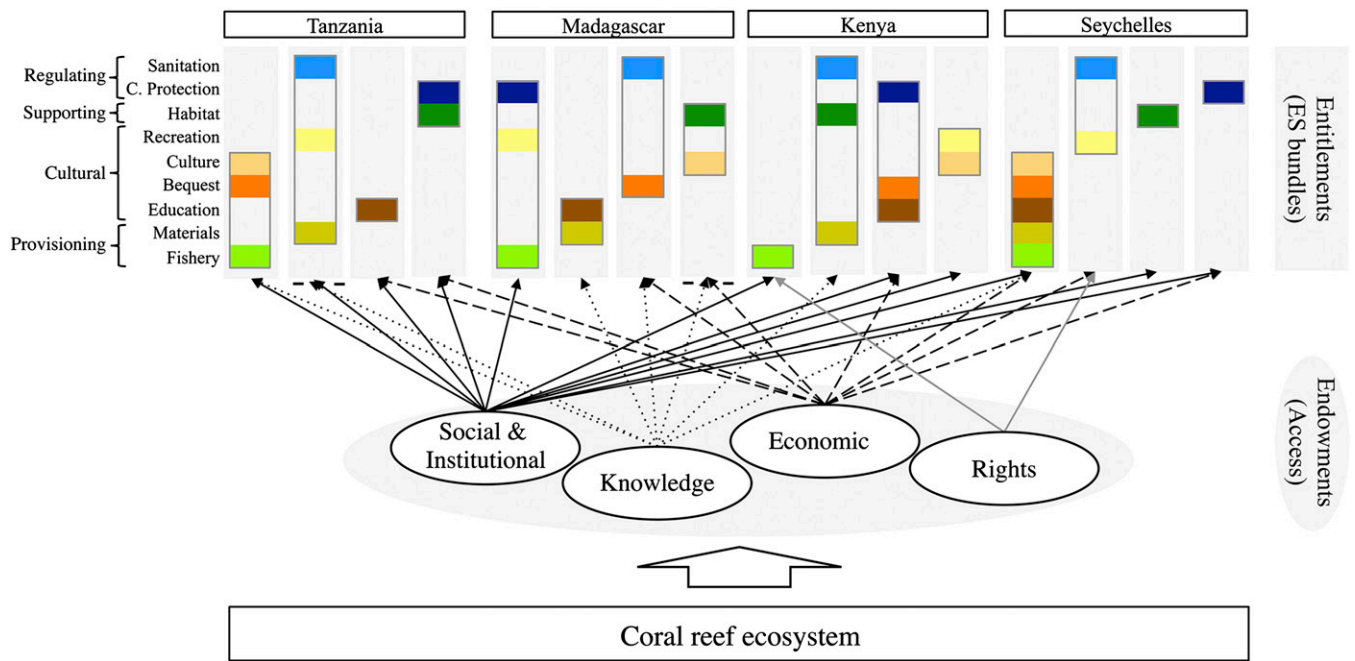


Fig. 3. Country-scale ES entitlements. Schematic entitlements framework showing ES bundles and their associated access mechanisms derived from the RDA analysis (Fig. S1 and SI Results).

of the need to broaden the way ES is considered (45). ES assessments, and their resultant policies, should take into consideration the mechanisms by which different people benefit from a supply of ES. By doing so, an ES approach will be better equipped to mediate inherent issues of inequality (1, 12).

Methods

We used both qualitative and quantitative approaches to examine the ES benefits people perceive from a coral reef ecosystem and the access mechanisms that enable them to benefit (Fig. 1).

Qualitative Approach. We gathered qualitative data through five focus groups with relevant managers and scientists, followed by 30 focus groups with fishers from 28 coastal communities across Kenya, Tanzania, Madagascar, and Seychelles.

ES benefits. To conceptualize the ES benefits, we first used the focus groups with managers and scientists to identify relevant coral reef ES benefits, appropriate wording to describe them, and a picture to convey each benefit (31). Second, we refined the chosen list, descriptions, and photographs of ES through the 30 fisher focus groups (31). Identified ES benefits were classified into provisioning (e.g., food), regulating (e.g., coastal protection), cultural (e.g., spiritual reflection), and supporting services (e.g., nutrient cycling) (1). **Access mechanisms.** We used three of the manager and scientist focus groups to determine the local access mechanisms by exploring factors that enabled, or constrained, the ability of fishers to benefit from ES. We categorized the identified factors into Ribot and Peluso's (26) nine access mechanisms (Table 1). Because complex and multidimensional components of access through knowledge and social identity were identified, we used 10 of the fisher focus groups to further explore knowledge and identity. The discussions sought to first determine knowledge that is common to both the scientific literature and the local ecological knowledge of the communities we visited. Second, they sought to describe some of the meanings and aspects of attachment associated with being a fisher. The outcome of the focus groups was a set of questions eliciting suitable indicators for the following access mechanisms: rights, technology, capital, labor and labor opportunities, markets, authority, social relations, knowledge, and access through social identity (Table 1).

Quantitative Approach. We gathered quantitative data through 374 individual semistructured questionnaires with fishers from the 28 coastal communities. We obtained information from local fisher organizations, or the fisheries department, on the age, primary gear used, and place of residence for all registered fishers. We used this information to randomly select

20–40% of fishers from each community, across the age, gear, and geographic range of all involved in the coral reef fishery for the quantitative surveys. We piloted the quantitative surveys in each country.

ES prioritization. We used individual semistructured interviews to estimate perceived importance of the identified ES (i.e., perceived ES benefit) (31). Respondents were provided with a photograph, a brief description of each ES (developed in the qualitative section), and 20 matchsticks to be used as “counters.” The services were discussed with the respondents to establish a common understanding. We then asked the respondents to rate the services by distributing the 20 counters across the nine ES as they saw fit, according to how important it is that they continue to benefit from each ES. For example, fishers could place all matches on one particular service or distribute them among several services. Any additional information on how the services were conceptualized, challenges arising in assigning preferences, or the rationale behind the respondents' scoring were recorded. The rating responses were weighted and normalized to a common scale of 0–1 (31).

Access mechanisms. We used the individual semistructured interviews to measure respondents' levels of access to nine mechanisms identified by Ribot and Peluso (26) (Table 1). Rights-based access and access to markets were determined at the site level ($n = 28$). All other access mechanisms were calculated at the individual level ($n = 374$) through a questionnaire (Table 1). We categorized Ribot and Peluso's (26) structural and relation access mechanisms according to the type of mechanism they represent: rights-based (rights-based), economic (technology, capital, markets, and labor), knowledge (knowledge), and social and institutional (authority, social identity, and social relations).

Data Analysis. Where multiple indicators were developed that related to individual access categories (e.g., income, expenditures, and material style of life all comprise access to capital), we used a principal component analysis (PCA), with a varimax rotation, to reduce the number of explanatory variables (37, 46). We normalized data to a common scale of 0–1 to allow comparisons across different types of variables to be made. The PCA reduction resulted in 15 final explanatory variables for the nine access mechanisms (26) (one rights-based, two knowledge, four economic, and eight social and institutional) (Table 1 and Table S1).

We used a redundancy analysis (RDA) (47) to examine how the distribution in perceived ES benefit was explained by access. An RDA allowed us to simultaneously identify which ES are prioritized together—that is, bundle (entitlements)—and what access mechanisms (endowments) are associated with the bundles. ES bundles were determined based on the angle between the ES vector and the variance explained by the closest canonical axes. We used a Monte Carlo permutation test (499 permutations) to forward select

variables (i.e., variables were added to the model one by one, with variables explaining the largest amount of variation added first) until no further variation was explained. Inflation factors give an indication of how correlated a variable was with other variables. Where variables reported inflation factors greater than 20, we removed variables by backward selection until all variables were within an inflation index score of 20 (47). Access mechanisms were determined to explain ES bundles based on the angle between the access mechanism vector and the strength of the closest canonical axis. To examine how access varied by context and scale, we ran an RDA on the whole dataset and on each country individually (Kenya, Tanzania, Madagascar, and Seychelles).

Influence of Each Types of Access. We calculated the influence that each type of access mechanism (i.e., knowledge, economic, rights-based, and

social and institutional) had on the perceived ES bundles at both the regional and country scales in three ways: (i) the proportion of bundles associated with each type of access individually, (ii) the proportion of bundles associated with each type of access both individually and in combination, and (iii) to control for differences in the number of variables used to measure each type of access mechanism, the proportion of available variables in each type of access mechanism associated with all ES bundles.

ACKNOWLEDGMENTS. Carol Abunge, Rogers Charo, Danny Julie, and Ravo Solovo helped in the field. We thank the fishers, who gave up their time and knowledge, and Nick Graham for comments on the manuscript. Wildlife Conservation Society Madagascar and the Seychelles Fishing Authority provided logistical support. This work was funded by the Western Indian Ocean Marine Science Association's Marine Science for Management scheme.

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