Evaluating sustainable development policies in rural coastal economies

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Sustainable development (SD) policies targeting marine economic sectors, designed to alleviate poverty and conserve marine ecosystems, have proliferated in recent years. Many developing countries are providing poor fishing households with new fishing boats (fishing capital) that can be used further offshore as a means to improve incomes and relieve fishing pressure on nearshore fish stocks. These kinds of policies are a marine variant of traditional SD policies focused on agriculture. Here, we evaluate ex ante economic and environmental impacts of provisions of fishing and agricultural capital, with and without enforcement of fishing regulations that prohibit the use of larger vessels in nearshore habitats. Combining methods from development economics, natural resource economics, and marine ecology, we use a unique dataset and modeling framework to account for linkages between households, business sectors, markets, and local fish stocks. We show that the policies investing capital in local marine fisheries or agricultural sectors achieve income gains for targeted households, but knock-on effects lead to increased harvest of nearshore fish, making them unlikely to achieve conservation objectives in rural coastal economies. However, pairing an agriculture stimulus with increasing enforcement of existing fisheries' regulations may lead to a win–win situation. While marine-based policies could be an important tool to achieve two of the United Nations Sustainable Development Goals (alleviate poverty and protect vulnerable marine resources), their success is by no means assured and requires consideration of land and marine socioeconomic linkages inherent in rural economies.

coupled human and natural system | bioeconomic model | general equilibrium

Coastal and island nations are adopting "blue growth" sustainable development (SD) policies to alleviate poverty and conserve vulnerable ocean resources. Generally speaking, SD policies manage resources and direct investments in order to meet current and future human needs and aspirations, without endangering the natural systems (1). The feasibility and potential of SD has been the focus of decades of academic research; many regard the consideration of economic, social, environmental, and institutional needs and linkages as fundamental to successful policy design and implementation (2–6). Given their novelty, what constitutes a blue growth policy is not universal (7), but like traditional SD policies that focus on land-based sectors such as agriculture, manufacturing, and energy sectors (8, 9), blue growth policies seek to achieve social, economic, and environmental goals simultaneously (10). Blue growth policies attempt to achieve these goals by supporting marine-based industries such as offshore fishing, aquaculture, shipping, and tourism (11, 12). The marine focus has reinvigorated SD efforts of international organizations (including the Global Environmental Facility, United Nations Food and Agriculture Organization, the European Union, and The World Bank) that have collectively invested hundreds of millions of dollars into the development and monitoring of blue growth programs (12–16).

While small-scale artisanal fishers consider a variety of factors when making fishing decisions (17), evidence suggests allocation of time is, in part, based on relative returns to labor (18–21). Thus, some blue growth policies attempt to alter returns to fishing relative to alternative income-generating activities as a way to achieve both poverty alleviation and conservation objectives. For example, if poor fishing households are incentivized to participate in offshore fishing, it may lead to increased household incomes and reduced fishing pressure on overexploited nearshore fish stocks (22, 23). Policies enforcing and increasing the regulation of fishing activities are also considered important to achieving blue growth objectives (10, 24).

Many SD policies are designed to reduce upfront costs of switching to more sustainable livelihoods. Historically, large-scale fisheries receive the majority of subsidy benefits (25), arguably to the detriment of small-scale fisheries who are often outcompeted by industrialized operations (26). Recently, however, developing countries including Kenya, the Philippines, India, Tanzania, Vietnam, and Indonesia have been investing in programs that bolster the fishing capacity of small-scale and artisanal fishermen (27–33). These programs are designed to help small-scale fishers access larger or better vessels and gear, allowing them to reach more plentiful fishing grounds, compete

Significance

Support for marine-based "blue growth" policies derives from their potential to simultaneously address United Nations Sustainable Development (SD) Goals on poverty alleviation and marine conservation. Modeling the linkages between a rural coastal economy and local fish resources, this work provides a rigorous ex ante assessment of common strategies to achieve SD objectives. We find that most of the considered policies increase target household incomes, negatively impact some nontarget households, and further deplete nearshore fish stocks. The results underscore the importance of considering characteristics of local economies and household linkages to marine and land resources when designing SD policies to avoid unintended consequences.

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with commercial vessels, and relieve pressure on vulnerable nearshore fisheries.

Despite the recent surge in popularity, we lack evidence that these marine-based SD policies will achieve both poverty reduction and conservation objectives when implemented in rural economies. The complexity of coupled natural–human systems makes it difficult to measure the ex post performance of SD policies, especially in marine environments (34, 35). Additionally, local market failures due to high transportation costs and poorly developed marketing infrastructure (36) can lead to locally defined prices that fluctuate with changes in local supply and demand; local prices may distort household responses to policies, leading to unintended environmental consequences (37–40). Because local market failures are more common in rural economies in developing countries, methods and lessons learned from studies of industrialized fisheries in developed countries may not be relevant. Rather, management of fisheries in rural coastal economies may be more successful if market imperfections, alternative livelihood options, and ecological feedback are considered (20, 41–47).

Recent studies explore the causal impacts of land-based SD policy instruments in developing countries (48–56). A key finding of these studies is that community heterogeneity is an important factor in policy performance. However, findings from forestry research do not necessarily carry over to marine settings because fish resources are mobile and regenerate relatively quickly, and, typically, access rights to fisheries are not well defined. This study begins to address the need for research examining responses to SD policy in rural coastal economies.

We use a coupled natural–human modeling framework to estimate the ex ante impacts of common SD policies. Our ex ante mechanistic approach that includes a general equilibrium local economy model captures important dynamic feedback between the economy and health of the fish stocks. Indeed, other researchers have studied the correlations between markets and ecosystems in coastal communities in developing countries (44, 57–59). However, the theoretical structure of our analysis approach allows us to examine the causal mechanisms between policy and its outcomes. Our model captures the feedback between economic sectors and households within the economy (Fig. 1, details in *SI Appendix*). This broad scope is necessary to estimate the extent to which policies targeting poor households in a community also impact nontargeted households (knock-on effects). For example, a policy supporting a subset of fishing households could be detrimental to other households that harvest from the same fish stocks and compete in the same input and output markets.

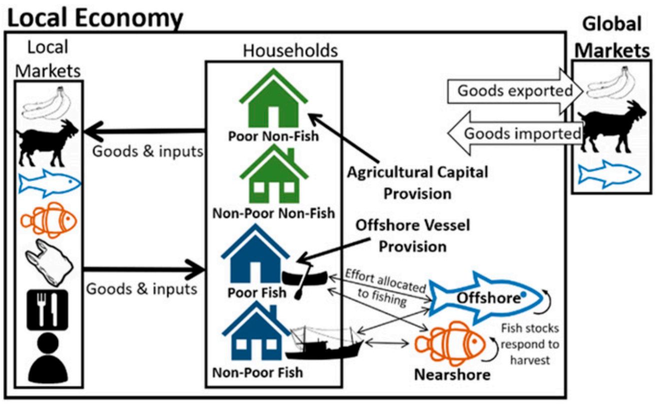

Fig. 1. A conceptual framework for the bioeconomic local general equilibrium model. Households are represented by four representative groups and may produce goods and services (e.g., agricultural, offshore and nearshore fish, retail, and restaurants) available in local, and possibly global, markets. The simulated policies provide different types of capital to poor households and may also restrict use of fishing capital.

Here, we estimate the impacts of two common marine fisheries policies (provision of offshore fishing vessels and increased enforcement of fishing regulations) and an alternative agricultural policy (provision of agricultural capital) in a rural coastal economy. To estimate the impacts of these SD policies in coastal economies, we use a modeling approach that has been developed using theory from development economics, natural resource economics, and marine ecology (37, 60). Introducing new features to the framework, we develop a model of a rural economy capable of disentangling fisher participation in two distinct fishing activities and household consumption of two fish goods. We use microeconomic data collected from household and business surveys to parameterize and calibrate our model, allowing us to realistically estimate policy impacts. An inherent strength to our methodology is the ability to adjust the structure of the model to represent alternative economies. We demonstrate how the model can be used to predict policy outcomes for a typology of rural coastal economies.

Although combining policies that simultaneously target marine and agricultural sectors is currently not part of the dialogue on the adoption of blue SD policies around the world (e.g., see The World Bank's strategy document for its Blue Economy Program and PROBLUE (13)), we find that pairing policy instruments that target both sectors—increased enforcement of vessel regulations and capital investments in the agricultural sector—is better able to achieve both conservation and poverty reduction goals.

Why is an agricultural policy combined with enforcement capabilities of marine fishing regulations able to achieve a win–win while marine-focused SD policies are not? Our coupled natural–human modeling framework highlights the mechanisms leading to this counterintuitive outcome. That is, investing in the agricultural sector increases the returns to agricultural labor, which in turn creates upward pressure on wages and encourages a reduction in labor allocated to nearshore fishing. At the same time, the increased wealth in the local economy due to greater agricultural productivity drives up demand for nearshore fish. Although higher prices of fish draw some labor back into the fishery, increased enforcement of vessel regulations prevents fishers from illegally using larger boats in the nearshore habitat as a means to increase harvests. Without coupling increased enforcement and agricultural subsidy, the higher demand for fish would lead to increased harvests in the nearshore environment and lower fish stocks over time.

Results

To understand the efficiency and distributional impacts of SD policies, we model four groups of households defined by their involvement in fishing activities (fishing/nonfishing) and income (poor/nonpoor) (Fig. 1). Heterogeneous economic impacts originate from differences in livelihood strategies, asset wealth (endowments), and linkages between economic sectors and natural resources (39, 61). To evaluate the conservation impacts of policies promoting alternative marine-based livelihoods, our model accounts for the dynamic relationship between a local economy and two fish stocks: offshore and nearshore fish. Measuring the environmental impacts and determining the success of SD policies is challenging and contentious (62–66). We have chosen to evaluate the conservation objective by estimating the policy's impact on the nearshore fish stock and the poverty alleviation objective by estimating the changes in real incomes expected for target and nontarget representative household groups.

An excellent setting to study the impact of SD policies is in rural coastal areas in Indonesia. Indonesia is at the forefront of blue economy initiatives and is the second-largest producer of

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marine capture fish in the world, with production dominated by small-scale fishermen (67, 68). The data used to inform our predictive modeling are from Selayar, a rural island in South Sulawesi, Indonesia. This island has many characteristics shared by communities targeted by blue growth initiatives. Its relative isolation from regional markets makes transport of inputs and goods expensive, market imperfections likely, and local general equilibrium and ecological feedback important determinants of policy success. Additionally, fish is a central part of the local diet, and many households participate in marine fishing activities as well as other household production activities.

While our framework represents an economy that has many quintessential characteristics of a rural coastal economy, other rural communities may have different market features. We therefore demonstrate how our framework can be used to estimate policy impacts across a topology of rural economies, exploring how results are affected by preferences for fish as a consumption good, characteristics of local labor supply, and specification of fish production.

We estimate the impacts of four policies over a 10-y period; each policy contains a subset of the three SD interventions. We simulate an offshore fishing vessel provision by increasing the poor fishing households' offshore fishing capital endowment by 40%, approximately equal to 45 five-gross-ton (5 GT) vessels. District governments have jurisdiction over vessels that are less than 5 GTs and fishing areas within four nautical miles of the shore, which is the location of most nearshore fisheries. We simulate increased enforcement capacity by preventing offshore fishing capital from being used for nearshore fishing. We consider an alternative to investment in the marine fisheries; an agriculture-focused intervention provides poor nonfishing households with agricultural capital, such as storage or processing equipment to reduce crop loss or facilitate postharvest activities, equal in value to the vessel provision (*SI Appendix*).

Initial Impacts of SD Policies. We find heterogeneous income effects starting immediately after policy implementation. By design, the vessel provision increases the income of the poor fishing household group (~15%). Similarly, the agricultural capital provision increases the income of the poor nonfishing household, albeit to a lesser extent (~4%) (Fig. 2).

Our analysis uncovers several unintended consequences of the SD policies. A capital stimulus increases the productivity of the target household's labor, increasing the local wage rate. Fishing capital provisions increase the local wage rate ~0.9% above baseline levels, while the agricultural capital provisions increase the local wage rate ~2.8%. Increased productivity and capital endowment raise the target households' income, stimulate demand for all goods and services, and raise locally determined prices. In the first year, the consumer price index rises 0.4% under a vessel provision and 1% under an agricultural provision. While higher prices increase the costs of household purchases, they also increase returns to local production. While we find that the nonpoor nonfishing households who are the majority owners of nonfishing capital, benefit from increased prices, local price inflation negatively impacts other households; nonpoor fishing households' real income declines in all scenarios, and poor nonfishing households' real income declines after a vessel provision (Fig. 2). This latter result shows how policies targeting a subset of poor households, such as the vessel provision, can have negative consequences for other poor households.

Dynamic Impacts of SD Policies. In all scenarios, a higher local nearshore fish price increases the incentive to fish. When fishing vessel regulations are not enforced, both fishing households reallocate a small amount of their offshore fishing capital to nearshore fishing in response to the rising demand for fish (all changes are less than 0.5%, *SI Appendix*). Even when capital regulations are enforced, households can boost fish production by increasing labor allocated to nearshore fishing. Both fishing households increase labor allocated to nearshore fishing under a vessel provision policy but decrease labor allocated to nearshore fishing under agricultural capital provision. The policies that cause an increase in aggregate catch cause the nearshore stock to decline (Fig. 3 and *SI Appendix*).

Why can increased enforcement of regulations protect the nearshore fish stock from declining following an agricultural capital provision but cannot do so under a vessel provision?

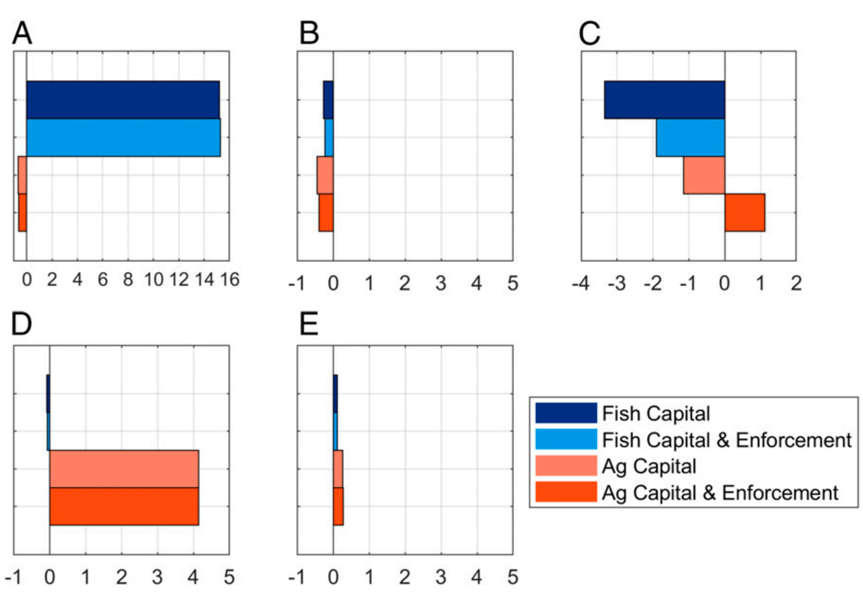

Fig. 2. Policy impacts 10 y after policy implementation. The percent of change in real income for poor fishing (*A*), nonpoor fishing (*B*), poor nonfishing (*D*), and nonpoor nonfishing (*E*) households and the percent of change in nearshore fish biomass (*C*) are shown. The results are presented for all four SD policy scenarios. Poor households are the recipients of targeted capital provisions. The enforcement of vessel regulations affects both fishing households. The impacts to the nontargeted households result from the GE impacts rippling through the local economy. The change in real income reflects changes in the value of productive assets after adjusting for inflation.

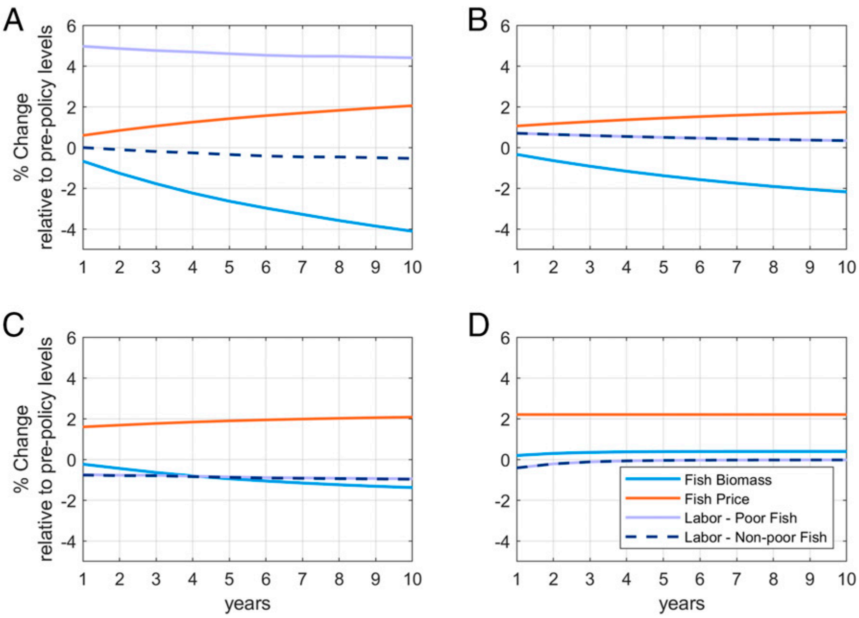

Fig. 3. The percent change in nearshore fish biomass (bright blue), price (orange), and labor (light and dark blue) over time, relative to prepolicy levels (year 0). Results are presented for the fishing capital provision without (*A*) and with (*B*) increased enforcement and the agricultural capital provision without (*C*) and with (*D*) increased enforcement. All stimulus policies increase the wealth of targeted households, increasing demand for, and price of, nearshore fish. Scenarios *A* and *B* increase the local fishing capacity, allowing supply to increase and dampen price rise. The enforcement of vessel restrictions limits increases in nearshore fish production. Over time, changes in nearshore fish biomass affects fishing productivity and local supply.

Following the agricultural capital infusion, poor nonfishing households' land becomes more productive, increasing demand for agricultural labor and decreasing labor allocated to nearshore fishing activities. When vessel regulations are enforced, increased demand for agricultural labor temporarily reduces nearshore fish harvest, allowing the nearshore fish stock to recover. On the other hand, under the vessel provision, fishing activities are more productive, drawing labor into both offshore and nearshore fishing regardless of whether the larger boats illegally enter nearshore waters. The increased labor allocated to fishing results in higher catches in the short run and lower nearshore fish stock.

Although many of the locally defined prices stay relatively constant over the 10-y simulation period, fish prices may be volatile. Following a fishing capital provision without additional enforcement of vessel regulations, the price of nearshore fish rises from a ∼0.5% increase in year one to a ∼2% increase in year 10 (Fig. 3). In this scenario, increased fishing capacity allows supply to adjust to increased demand, which acts to buffer the price change in year one. As the nearshore stock declines, fishing is less productive, harvests decline, and prices increase. The enforcement of vessel restrictions limits fisher response to rising demand, and we observe a larger initial increase in price.

Under both agricultural capital provision scenarios, fishing capacity in the local economy does not change, and demand for labor in the agricultural sector increases, limiting the ability for local supply to meet rising demand. As a result, the initial increase in local fish price is higher than in the scenarios with a fishing capital provision (Fig. 3). When vessel restrictions are enforced, the recovering nearshore fish stock can sustainably support increased harvests, and prices decrease slightly.

The Role of Fish Consumption Preferences and the Labor Market. During data collection, households reported reluctance to consume relatively more offshore fish, even when the price of nearshore fish rises, suggesting offshore and nearshore fish are imperfect substitutes. We model this preference with inelastic substitution between the two fish goods (details in *SI Appendix*). This inelasticity causes a large increase in nearshore fish prices after a capital provision increases wealth and demand for fish. However, other economies may not have this same reluctance to adjust fish consumption when prices change. We consider two alternative model specifications: 1) an economy with households more reluctant to change fish consumption and 2) an economy with households more willing to change fish consumption. In the first alternative, the two fish goods are very poor substitutes (characterized by more inelastic substitution). The price of nearshore fish rises more dramatically in response to increased demand, so much so that the nearshore fish stock is expected to decline in all four policy scenarios. In the second alternative, the nearshore and offshore fish are good substitutes (characterized by elastic substitution). The price of nearshore fish does not increase as much, dampening the incentive to increase nearshore fish harvest. Here, the enforcement of the vessel regulation may protect the nearshore fish stock in both capital provision scenarios.

The household interviews revealed few instances of migration into or out of the island, suggesting the economy is best represented by a very inelastic labor supply. This specification implies increases in the local wage will not attract additional labor into the economy. This is critical, as nearshore fish harvest is limited by the amount of available labor. Because migration may be more common in other rural economies, we consider alternative degrees of labor supply elasticity. If local labor supply is sufficiently elastic, increasing productivity of labor leads to a large expansion of the labor supply and ability to increase nearshore harvests to meet demand. This increased capacity leads to a decline in the nearshore fish stock in all four policy scenarios (*SI Appendix*).

The Role of Fishing Production. Our preferred model specification assumes fishing production functions exhibit constant returns to scale with respect to labor, capital, and fish stock. We believe this is representative of Selayar and, more generally, of a small-scale artisanal fishery. This assumption is also consistent with the local general equilibrium literature. It implies increasing labor and capital causes a less-than-proportional increase in harvest, holding fish stock constant. In our household surveys, the most-used fishing gear were spears, handlines, and small nets. With this gear, increasing fishing effort would lead to fatigue or inefficiencies caused by congestion. This specification additionally implies that production of output increases less than proportionally with increases in fish stock, holding fishing effort fixed, which would be expected when fish school or aggregate in patchy habitats. Again, this is consistent with the conditions of the small-scale fisheries off Selayar: the offshore fish stock is primarily small, schooling pelagics, while the nearshore fish stock congregates around patches of reefs and sea grass.

We explore two alternative specifications of fish production to demonstrate further how our model can be used to provide ex ante analysis for economies with different fishery characteristics. The first alternative differs from the preferred specification in that stock output elasticity is set to one, implying harvest increases proportionally with fish stock, holding fishing effort constant. This specification represents a situation where excess capacity allows fishers to adjust to increased biomass or when fish biomass is spread out evenly across demersal habitat. We additionally consider a production function similar to what would be expected in an industrialized fishery—production increases proportionally with increases in labor and capital as well as with increases in the fish stock. In this scenario, additional labor and capital can easily and efficiently be used to take advantage of increased biological stock.

Our qualitative findings are robust to the specification of the fishing production functions. Quantitative differences provide some useful insight into the mechanisms driving results. A larger output elasticity on the fish stock (as in the two alternative specifications) will lead fishers to respond faster to changes in fish stocks. Here, fish stock has a larger influence on input productivity and encourages fishers to exit a declining fishery (and enter an improving fishery) faster. As a result, the impacts to the nearshore fish stock are muted. Larger output elasticities on labor and capital, as in the second alternative, mean fisheries yield higher returns on factor inputs. As a result, households receiving capital experience larger increases in real income. Additionally, fishing households move labor and capital more aggressively, amplifying changes expected in fish production and nearshore fish biomass. Additional details and full results are found in the *SI Appendix*.

Discussion

We find that policies that encourage alternative livelihoods (both fishing and nonfishing) will increase recipients' income, but multiple market failures in a rural economy will lead to unintended consequences. Vulnerable, nontarget households will be negatively impacted, and the increased price of nearshore fish will lead to increased fishing pressure that may exacerbate overharvest. Investing in nonfishing alternative livelihoods while simultaneously increasing the enforcement of fisheries' regulations may successfully conserve vulnerable nearshore fisheries, depending on how households view the consumption of offshore and nearshore fish (price elasticity) as well as how fast the labor supply responds to changes in wages (labor elasticity). Given the importance of these elasticities, evaluation of local market conditions will be a critical part of successful policy design.

The results presented in this analysis assume the offshore fish stock is held constant throughout the 10-y simulation period, unaffected by harvest from local fishermen. This assumption is plausible if we imagine a vessel provisioning policy implemented in just a few locations throughout a country. However, we can use our findings to predict the impacts of more expansive policies. If hundreds of villages were to receive large numbers of offshore fishing vessels, the offshore fish stock would likely decline under increased fishing effort, reducing fishing households' return on labor and fishing capital allocated to offshore fishing activities. This would dampen the increase in recipients' income over time and increase fishers' incentive to reallocate capital and labor to nearshore fishing to the detriment of the nearshore fish stock.

We have not considered other types of blue growth policies that address absent or incompletely enforced individual- or community-based rights to fish stocks, such as the establishment and enforcement of quotas, marine reserves, or territorial use rights for fishing areas (69–71). Many environmental nongovernmental organizations advocate for these policies as a way to protect vulnerable fish stocks and simultaneously improve returns to fishing. When carried out in rural areas, these policies are also likely to have unintended heterogeneous impacts on households, economic sectors, and natural resources.

Our structural approach to ex ante policy analysis has four key advantages. First, our methodology can be applied in data-poor settings because it takes advantage of economic and ecological theory and only requires one-time data collection. This is important because frequent data collection efforts are expensive, and therefore policymakers often lack the necessary data when designing, implementing, and evaluating SD policies for rural economies. Second, the structure allows us to study the mechanistic response and quantify both direct and indirect impacts of SD policies. Third, we can estimate the environmental impacts to renewable natural resources because our model captures the dynamic linkage between the economy, households, and natural resources. Finally, as we demonstrated, our model can be used to predict impacts in similar coastal economies that face different market conditions. This enables policymakers and aid organizations to target communities that are more likely to achieve all SD goals.

Policies supporting household production are expected to benefit recipients and targeted sectors, but these policies have unintended impacts on nontarget economic sectors and households. Distortions caused by local market failures affect fishing incentives so that even policies targeting nonfishing households and nonfishery sectors can impact marine ecosystem health. Emphasizing local market connections, our framework highlights both direct and indirect impacts of SD policies and permits a full assessment of SD policies in rural coastal economies.

Materials and Methods

We use a computable general equilibrium model of a rural economy, parameterized with site-specific data from household and business surveys. The model contains representative households engaged in multiple production activities, connected by input and output markets. The model includes four representative households, defined by livelihood and poverty status. Households are involved in many small-scale production activities, including agriculture (e.g., cashews, coconut, spices, and grain), animal husbandry (e.g., goats, chicken, and cattle), and enterprise (e.g., restaurants, retail, and services). In addition, many households participate in marine fishing activities for their own consumption and sale. Inputs to production activities include labor and capital. Credit constraints limit households' ability to accumulate capital, which is assumed to be fixed in our simulations. Local labor supply is also fixed, implying migration into or out of the economy does not occur. As a result, all inputs have locally determined prices. Survey data indicated that household producers (in all economic sectors) compensated labor in a variety of ways (share of revenue, share of profit, wage, etc.). All of these payment methods imply a marginal value of labor, which we refer to as wage (see *SI Appendix* for additional detail).

Households consume five produced goods (agriculture, retail, restaurants, other services, and a composite fish good) and exogenous goods. All output goods have locally determined prices, except for offshore fish and agricultural goods, which are frequently traded with markets outside the local economy. Our model accounts for some degree of substitutability between offshore and nearshore fish; households consume a composite fish good, which combines offshore and nearshore fish according to a constant elasticity of substitution aggregation function. Because we cannot estimate the elasticity of substitution from data, we choose a plausible value and run a sensitivity analysis (see *SI Appendix* for additional detail).

Offshore and nearshore fish have been separated into two distinct goods and production activities to capture market structure and disentangle households' allocation of their time and fishing capital more accurately. Nearshore and offshore fishing activities target different groups of fish species in different locations. We assume that each produce one aggregate output: nearshore fishing yields nearshore fish (e.g., snapper, grouper, emperor, and fusiliers), and offshore fishing yields offshore fish (e.g., tuna, mackerel, and jacks). Each fishing production activity has three factor inputs: labor (number of person hours), fishing capital (e.g., boats, engines, nets, lines, and spears), and fish stock (biomass). Because households are engaged in small-scale artisanal fishing activities, fishers implement generalized fishing strategies, using similar vessels and fishing gear in both fishing activities (see *SI Appendix* for additional detail). Fishing households can choose how much labor and capital to allocate to each activity. However, the fish stock is taken as given in each period. Fish stocks are independent from one another so that the size of one does not directly affect the growth of another.

Without clearly defined or enforced formal or informal property rights, many small-scale artisanal nearshore fisheries are most appropriately described as open-access resources (72, 73), causing households to overallocate factors of production until economic profits in the sector are dissipated. Following the methodology described by Manning et al. (60), we assign a proportion of the share of value added attributable to the fish stock to each of the remaining factor inputs based on their relative contribution to total value added. We adapt this methodology, permitting the exploration of the sensitivity to production function assumptions (see *SI Appendix* for additional detail).

A key difference between the two fish stocks is how they respond to changes in fishing pressure. Offshore fish are migratory pelagic fish species with a large available biomass relative to local harvest, while nearshore fish stocks are comparatively sedentary, coral-reef–associated species subject to continued overfishing. Therefore, our model assumes that the offshore fish stock is unaffected by changes in local fishing pressure, while the nearshore fish stock is sensitive to changes in fishing pressure. We use the estimated production function to calculate the fishable offshore biomass at baseline. The dynamics of the nearshore fish stock is characterized by a delay-difference model with larvae recruitment (74, 75). The simulations are based on annual time step, with each year t beginning with a spawning event, followed by the recruitment of young fish into adult populations and the subsequent growth of both prerecruits and adults. The harvest of nearshore fish includes many families of fish commonly found in coral reef and sea grass habitats. The most common families in local harvest are emperors (32.85%), parrot fish (16.65%), rabbit fish (12.94%), and surgeon fish (11.83%). Our preferred specification of the model uses biological parameters corresponding to a representative species (*Lethrinus miniatus,* Trumpet emperor). Qualitative findings are robust to assumed parameter values (details of sensitivity analyses are in the *SI Appendix*).

We parameterize our model using a microeconomic dataset assembled from surveying a random sample of households and businesses throughout the island. The baseline of the economic model is calibrated to match initial economic and market conditions defined by survey data, and the bioeconomic model of the nearshore fishery is calibrated such that baseline harvest is equal to net changes in biomass (i.e., steady state). The bioeconomic and local general equilibrium models are linked to capture the direct and indirect impacts of policies over time. Each period (year), market clearing prices and demands are calculated (i.e., the local economy reaches equilibrium) given a fixed biomass level. Between periods, fish stocks are updated, accounting for the harvest over the past period, growth, natural mortality, and adult recruitment.

A full model description, model code, description of data collection, and necessary data inputs are provided in the *SI Appendix* and Datasets S1 and S2.

Data Availability. All study data are included in the article text and supporting information. Aggregate data are available in the supporting information. The household-level and business-level data are protected by data-sharing agreements with the participating respondents. The aggregate data provide all estimations and information required to run simulations using General Algebraic Modeling System (GAMS) software. The syntax necessary to replicate results are available in the supporting information. The model is coded in GAMS.

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SUSTAINABILITY SCIENCE

1. G. H. Brundtland, *Our Common Future: Report of the World Commission on Environment and Development* (United Nations Commission, 1987), vol. 4, p. 300.
2. N. Salafsky, E. Wollenberg, Linking livelihoods and conservation: A conceptual framework and scale for assessing the integration of human needs and biodiversity. *World Dev.* **28**, 1421–1438 (2000).
3. M. Jänicke, "Green growth": From a growing eco-industry to economic sustainability. *Energy Policy* **48**, 13–21 (2012).
4. J. Robinson, J. Tinker, "The cornerstone of development: Integrating environmental, social, and economic policies" in *Surviving Globalism: The Social and Environmental Challenges*, T. Schrecker, Ed. (St. Martin's Press, 1997), pp. 71–94.
5. J. Robinson, J. Tinker, *The Concept of Policy Integration: Reconciling Ecological* (Economic and Social Imperatives, 1998).
6. J. H. Spangenberg, Reconciling sustainability and growth: Criteria, indicators, policies. *Sustain. Dev. (Bradford)* **12**, 74–86 (2004).
7. A. M. Eikeset *et al*., What is blue growth? The semantics of "sustainable development" of marine environments. *Mar. Policy* **87**, 177–179 (2018).
8. OECD, "Towards green growth: A summary for policy makers" in *Meeting of the Council at Ministerial Level* (Organization for Economic Cooperation and Development, 2011).
9. World Bank, *Inclusive Green Growth; The Pathway to Sustainable Resource Management* (World Bank, 2012).
10. FAO, *Achieving Blue Growth: Building Vibrant Fisheries and Aquaculture Communities* (The Food and Agriculture Organization of the United Nations, 2018).
11. FAO, *The State of World Fisheries and Aquaculture 2016: Contributing to Food Security and Nutrition for All* (The Food and Agriculture Organization of the United Nations, 2016).
12. FAO, *The State of Fisheries and Aquaculture in the World 2018–Meeting the Sustainable Development Goals* (The Food and Agriculture Organization of the United Nations, 2018).
13. The World Bank, The World Bank's Blue Economy Program and PROBLUE: Supporting integrated and sustainable economic development in healthy oceans. https://www.worldbank.org/en/topic/environment/brief/the-world-banks-blue-economy-program-and-problue-frequently-asked-questions. Accessed 17 March 2019.
14. DG Maritime Affairs and Fisheries, Joint Research Center, The 2018 Annual Economic Report on EU Blue Economy (European Union, 2018).
15. OECD, *The Ocean Economy in 2030: The Ocean as a Sustainable Source of Economic Growth* (Organization for Economic Cooperation and Development, 2016).
16. FAO, *FAO Working for SDG 14: Healthy Oceans for Food Security, Nutrition, and Resilient Communities* (The Food and Agriculture Organization of the United Nations, 2017).
17. K. E. Abernethy, E. H. Allison, P. P. Molloy, I. M. Côté, Why do fishers fish where they fish? Using the ideal free distribution to understand the behaviour of artisanal reef fishers. *Can. J. Fish. Aquat. Sci.* **64**, 1595–1604 (2007).
18. C. Liese, M. D. Smith, R. A. Kramer, Open access in a spatially delineated artisanal fishery: The case of Minahasa, Indonesia. *Environ. Dev. Econ.* **12**, 123–143 (2007).
19. J. E. Cinner, T. Daw, T. R. McClanahan, Socioeconomic factors that affect artisanal fishers' readiness to exit a declining fishery. *Conserv. Biol.* **23**, 124–130 (2009).
20. T. M. Daw *et al*., To fish or not to fish: Factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery. *PLoS One* **7**, e31460 (2012).
21. J. K. McElroy, The Java Sea purse seine fishery. A modern-day "tragedy of the commons"? *Mar. Policy* **15**, 255–271 (1991).
22. J. D. Bell *et al*., Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories. *Mar. Policy* **51**, 584–591 (2015).
23. J. D. Bell *et al*., Adaptations to maintain the contributions of small-scale fisheries to food security in the Pacific Islands. *Mar. Policy* **88**, 303–314 (2018).
24. M. Nielsen, L. Ravensbeck, R. Nielsen, Green growth in fisheries. *Mar. Policy* **46**, 43–52 (2014).
25. U. R. Sumaila, V. Lam, F. Le Manach, W. Swartz, D. Pauly, Global fisheries subsidies: An updated estimate. *Mar. Policy* **69**, 189–193 (2016).
26. A. Schuhbauer, R. Chuenpagdee, W. W. L. Cheung, K. Greer, U. R. Sumaila, How subsidies affect the economic viability of small-scale fisheries. *Mar. Policy* **82**, 114–121 (2017).

27. Business Daily Africa, Mombasa eyes bigger catch in Sh250m fishing project. *Business Daily Africa*, 9 June 2020. https://www.businessdailyafrica.com/bd/corporate/shipping-logistics/mombasa-eyes-bigger-catch-in-sh250m-fishing-project-2292278. Accessed 4 December 2020.
28. J. Alipala, Feeding fishers for life through boat distribution program. *Inquirer.net*, 24 September 2016. https://newsinfo.inquirer.net/818536/feeding-fishers-for-life-through-boat-distribution-program. Accessed 8 January 2020.
29. L. Mishra, Govt to help fishermen buy trawlers, explore deep seas. *The Hindu*, 22 March 2016. https://www.thehindu.com/news/cities/mumbai/business/govt-to-help-fishermen-buy-trawlers-explore-deepseas/ article8383664.ece. Accessed 8 January 2020.
30. K. Suneja, Fish subsidies rise 23%, but India feels it won't be an issue. *Economic Times*, 5 November 2018. https://economictimes.indiatimes.com/news/economy/agriculture/fish-subsidies-rise-23-but-india-feels-it-wont-be-anissue/articleshow/66505071.cms?from=mdr. Accessed 8 January 2020.
31. M. Masato, Zanzibar turns focus to untapped blue economy. *Tanzania Daily News*, 5 January 2020. https://dailynews.co.tz/news/2020-01-075e149d264be27.aspx. Accessed 8 January 2020.
32. R. Jennings, Vietnam advances plan to protect disputed maritime claims with stronger fishing fleet. *Voice of America*, 13 November 2019. https://www.voanews.com/east-asia-pacific/vietnam-advances-plan-protect-disputed-maritime-claims-stronger-fishing-fleet. Accessed 8 January 2020.
33. D. A. Sinaga, Poor fishermen made to wait for free boats from Indonesian government. *JakartaGlobe*, 9 November 2017. https://jakartaglobe.id/context/poor-fishermen-made-wait-free-boats-indonesian-government. Accessed 8 January 2020.
34. P. J. Ferraro, J. N. Sanchirico, M. D. Smith, Causal inference in coupled human and natural systems. *Proc. Natl. Acad. Sci. U.S.A.* **116**, 5311–5318 (2019).
35. S. Polasky *et al*., Role of economics in analyzing the environment and sustainable development. *Proc. Natl. Acad. Sci. U.S.A.* **116**, 5233–5238 (2019).
36. A. de Janvry, M. Fafchamps, E. Sadoulet, Peasant household behaviour with missing Markets : Some paradoxes explained. *Econ. J. (Lond.)* **101**, 1400–1417 (1991).
37. T. E. Gilliland, J. N. Sanchirico, J. E. Taylor, An integrated bioeconomic local economy-wide assessment of the environmental impacts of poverty programs. *Proc. Natl. Acad. Sci. U.S.A.* **116**, 6737–6742 (2019).
38. D. T. Manning, J. E. Taylor, J. E. Wilen, Market integration and natural resource use in developing countries: A linked agrarian-resource economy in Northern Honduras. *Environ. Dev. Econ.* **19**, 133–155 (2014).
39. S. T. Holden, J. E. Taylor, S. Hampton, Structural adjustment and market imperfections: A stylized village economy-wide model with non-separable farm households. *Environ. Dev. Econ.* **4**, 69–87 (1999).
40. S. F. Muhibat, Indonesia's new ocean policy: Analysing the external dimension. *Marit. Aff.* **13**, 50–61 (2017).
41. E. H. Allison, F. Ellis, The livelihoods approach and management of small-scale fisheries. *Mar. Policy* **25**, 377–388 (2001).
42. N. L. Andrew, C. Béné, S. J. Hall, Diagnosis and management of small-scale fisheries in developing countries. *Fish Fish.* **8**, 227–240 (2007).
43. J. E. Cinner, Social-ecological traps in reef fisheries. *Glob. Environ. Change* **21**, 835–839 (2011).
44. J. E. Cinner *et al*., Comanagement of coral reef social-ecological systems. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 5219–5222 (2012).
45. T. M. Daw *et al*., Elasticity in ecosystem services: Exploring the variable relationship between ecosystems and human well-being. *Ecol. Soc.* **21**, 11 (2016).
46. D. Finnoff, J. Tschirhart, Linking dynamic economic and ecological general equilibrium models. *Resour. Energy Econ.* **30**, 91–114 (2008).
47. Z. D. Hughes, E. P. Fenichel, L. R. Gerber, The potential impact of labor choices on the efficacy of marine conservation strategies. *PLoS One* **6**, e23722 (2011).
48. J. M. Alix-Garcia, E. N. Shapiro, K. R. E. Sims, Forest conservation and slippage: Evidence from Mexico's national payments for ecosystem services program. *Land Econ.* **88**, 613–638 (2012).
49. J. M. Alix-garcia, K. R. E. Sims, P. Yanez-pagans, *Only One Tree from Each Seed? Environmental Effectiveness and Poverty Alleviation in Mexico's Payments for Ecosystem Services Program* (American Economic Association, 2018), vol. 7.
50. J. Alix-Garcia, A. De Janvry, E. Sadoulet, The role of deforestation risk and calibrated compensation in designing payments for environmental services. *Environ. Dev. Econ.* **13**, 375–394 (2008).
51. K. S. Andam, P. J. Ferraro, K. R. E. Sims, A. Healy, M. B. Holland, Protected areas reduced poverty in Costa Rica and Thailand. *Proc. Natl. Acad. Sci. U.S.A.* **107**, 9996–10001 (2010).
52. P. J. Ferraro, M. M. Hanauer, K. R. E. Sims, Conditions associated with protected area success in conservation and poverty reduction. *Proc. Natl. Acad. Sci. U.S.A.* **108**, 13913–13918 (2011).
53. P. J. Ferraro, M. M. Hanauer, Protecting ecosystems and alleviating poverty with parks and reserves: "Win-win" or tradeoffs? *Environ. Resour. Econ.* **48**, 269–286 (2011).
54. P. Ferraro *et al*., More strictly protected areas are not necessarily more protective: Evidence from Bolivia, Costa Rica, Indonesia, and Thailand. *Environ. Res. Lett.* **8**, 025011 (2013).
55. K. R. E. Sims, J. M. Alix-Garcia, Parks versus PES: Evaluating direct and incentive-based land conservation in Mexico. *J. Environ. Econ. Manage.* **86**, 8–28 (2017).
56. P. J. Ferraro, M. M. Hanauer, Quantifying causal mechanisms to determine how protected areas affect poverty through changes in ecosystem services and infrastructure. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 4332–4337 (2014).
57. T. D. Brewer, J. E. Cinner, R. Fisher, A. Green, S. K. Wilson, Market access, population density, and socioeconomic development explain diversity and functional group biomass of coral reef fish assemblages. *Glob. Environ. Change* **22**, 399–406 (2012).
58. J. E. Cinner, N. A. J. Graham, C. Huchery, M. A. Macneil, Global effects of local human population density and distance to markets on the condition of coral reef fisheries. *Conserv. Biol.* **27**, 453–458 (2013).
59. J. E. Cinner, T. R. McClanahan, Socioeconomic factors that lead to overfishing in small-scale coral reef fisheries of Papua New Guinea. *Environ. Conserv.* **33**, 73–80 (2006).
60. D. T. Manning, J. E. Taylor, J. E. Wilen, General equilibrium tragedy of the commons. *Environ. Resour. Econ.* **69**, 75–101 (2018).
61. J. E. Taylor, M. J. Filipski, *Beyond Experiments in Development Economics: Local Economy-wide Impact Evaluation* (Oxford University Press, United Kingdom, 2014).
62. K. Rennings, H. Wiggering, Steps towards indicators of sustainable development: Linking economic and ecological concepts. *Ecol. Econ.* **20**, 25–36 (1997).
63. H. E. Daly, Toward some operational principles of sustainable development. *Ecol. Econ.* **2**, 1–6 (1990).
64. S. Batie, Sustainable development: Challenges to the profession of agricultural economics. *Am. J. Agric. Econ.* **71**, 1083–1101 (1989).
65. R. Costanza, H. E. Daly, Natural capital and sustainable development. *Conserv. Biol.* **6**, 37–46 (1992).
66. D. Tilman, K. G. Cassman, P. A. Matson, R. Naylor, S. Polasky, Agricultural sustainability and intensive production practices. *Nature* **418**, 671–677 (2002).
67. D. S. Adhuri, L. Rachmawati, H. Sofyanto, N. Hamilton-Hart, Green market for small people: Markets and opportunities for upgrading in small-scale fisheries in Indonesia. *Mar. Policy* **63**, 198–205 (2016).
68. California Environmental Associates, *Trends in Marine Resources and Fisheries Management in Indonesia: A 2018 Review* (California Environmental Associates, 2018).
69. H. S. Gordon, The economic theory of a common-property resource: The fishery. *Source J. Polit. Econ.* **62**, 124–142 (1954).
70. G. Hardin, The tragedy of the commons. *Science* **162**, 1243–1248 (1968).
71. E. Ostrom, "Tragedy of the commons" in *New Palgrave Dictionary of Economics*, M. Vernengo, E. P. Caldentey, B. J. Rosser Jr., Eds. (Palgrave Macmillan, London, 2008), pp. 360–362.
72. J. E. Wilen, The challenges of pro-poor fisheries reform. *Mar. Resour. Econ.* **28**, 203–220 (2013).
73. J. E. Kirkley, D. Squires, M. F. Alam, H. O. Ishak, Excess capactity and asymmetric information in developing country fisheries: The Malaysian purse seine fishery. *Am. J. Agric. Econ.* **85**, 647–662 (2003).
74. R. Hilborn, C. J. Walters, *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty* (Springer US, 1992).
75. N. C. Krueck *et al*., Marine reserve targets to sustain and rebuild unregulated fisheries. *PLoS Biol.* **15**, e2000537 (2017).