


CONTRIBUTED PAPER

Large-sample-size assessment of socioeconomic predictors of community-level resource management occurrence

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Abstract

Community-level resource management efforts are cornerstones in ensuring sustainable use of natural resources. Yet, understanding how community characteristics influence management practices remains contested. With a sample size of ≥ 725 communities, we assessed the effects of key community (i.e., socioeconomic) characteristics (human population size and density, market integration, and modernization) on the probability of occurrence of fisheries management practices, including gear, species, and spatial restrictions. The study was based in Solomon Islands, a Pacific Island country with a population that is highly dependent on coastal fisheries. People primarily dwell in small communities adjacent to the coastline dispersed across 6 island provinces and numerous smaller islands. We used nationally collected data in binomial logistic regression models to examine the likelihood of management occurrence, given socioeconomic context of communities. In contrast to prevailing views, we identified a positive and statistically significant association between both human population size and market integration and all 3 management practices. Human population density, however, had a statistically significant negative association and modernization a varied and limited association with occurrence of all management practices. Our method offers a way to remotely predict the occurrence of resource management practices based on key socioeconomic characteristics. It could be used to improve understanding of why some communities conduct natural resource management activities when statistical patterns suggest they are not likely to and thus improve understanding of how some communities of people beat the odds despite limited market access and high population density.

KEYWORDS

community-level resource management, fisheries, human population density, management institutions, modernization, probability of occurrence, socioeconomic development

Resumen

Los esfuerzos por manejar los recursos a nivel comunitario son pilares para garantizar el uso sustentable de los recursos naturales. Aun así, el conocimiento sobre cómo las características comunitarias influyen sobre las prácticas de manejo todavía está en discusión. Con un tamaño de muestra de ≥ 725 comunidades, evaluamos los efectos de las características (tamaño y densidad poblacional humana, integración del mercado y modernización) comunitarias (es decir, socioeconómicas) clave sobre la probabilidad de incidencia de las prácticas de manejo de las pesquerías, incluyendo el equipamiento, las especies y las restricciones espaciales. El estudio se ubicó en las Islas Salomón, un país isleño del Pacífico con una población altamente dependiente de las pesquerías costeras. En este país, las personas habitan principalmente en comunidades pequeñas adyacentes a la costa y dispersas en las seis provincias isleñas y en numerosas islas más pequeñas. Usamos datos recolectados en todo el país en unos modelos de regresión logística binomial para examinar la probabilidad

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de incidencia del manejo, dado el contexto socioeconómico de las comunidades. Contrario a las opiniones predominantes, identificamos una asociación positiva y estadísticamente significativa entre el tamaño poblacional humano y la integración del mercado y entre las tres prácticas de manejo. La densidad poblacional humana, sin embargo, tuvo una asociación negativa estadísticamente significativa y la modernización una asociación variada y limitada con la incidencia de las prácticas de manejo. Nuestro método ofrece una manera para predecir remotamente la incidencia de las prácticas de manejo de recursos con base en características socioeconómicas importantes. El método podría utilizarse para incrementar el conocimiento sobre cómo algunas comunidades llevan a cabo actividades de manejo de recursos naturales cuando los patrones estadísticos sugieren lo contrario y así mejorar el entendimiento de cómo algunas comunidades humanas superan todos los pronósticos a pesar del acceso limitado al mercado y la alta densidad poblacional.

Evaluación de Muestras de Gran Tamaño de Pronosticadores Socioeconómicos de la Incidencia del Manejo de Recursos a Nivel Comunitario

PALABRAS CLAVE

densidad poblacional humana, desarrollo socioeconómico, instituciones de manejo, manejo de recursos a nivel comunitario, modernización, pesquerías, probabilidad de incidencia, 社区资源管理, 渔业, 人口密度, 管理机构, 现代化, 社会经济发展, 发生概率

【摘要】

社区水平的资源管理工作是确保自然资源可持续利用的基础。然而,人们对于社区特征如何影响管理实践的认识尚存有争议。本研究利用超过725个社区的样本,评估了关键社区特征(即社会经济特征,包括人口规模与密度、市场一体化水平、现代化水平)对渔业管理实践(包括对渔具、物种及空间的限制)发生概率的影响。我们的研究地点位于所罗门群岛,这是一个居民高度依赖沿海渔业的太平洋岛国。该地区的人口主要分散在6个岛屿省及许多较小岛屿上邻近海岸线的小型社区中。我们利用全国数据,构建了特定社区社会经济背景下的二项式逻辑回归模型,以检验管理实践的发生概率。不同于主流观点,我们发现人口规模和市场一体化水平与所有三种管理实践之间均存在统计上显著的正相关关系。然而,人口密度与管理实践具有统计上显著的负相关关系,而现代化与三种管理实践之间则存在不一致且有限的相关性。我们的研究方法可作为一种基于关键社会经济特征远程预测资源管理实践发生概率的工具,有助于更好地理解为什么一些社区会在统计模型表明其不太可能开展自然资源管理活动时仍采取管理实践,从而深入理解一些社区的人们如何在进入市场的机会有限且人口密度高的情况下战胜不利条件。【翻译:胡怡思;审校:聂永刚】

INTRODUCTION

Drivers of community resource management

There is growing concern that humanity does not possess institutions capable of mediating the effects of social and economic change on Earth's finite natural resources (Dietz et al., 2003; Walker et al., 2009). In developing countries, where much of the world's biodiversity exists and many people are directly dependent on natural resources (Donner & Potere, 2007; Ostrom, 1990), community-level resource management practices are vulnerable to the negative effects of social and economic drivers of change (Agrawal, 2001; Agrawal & Yadama, 1997; Kramer et al., 2009).

Although there is a significant literature on institutional design principles for collective action to manage natural resources (e.g., Ostrom, 2007), the effects of underlying social and economic drivers (i.e., human population size, human

population density, market integration, and modernization) on resource management remain contested and poorly understood. It has long been asserted that the number of people with access to a common resource (human population size) may affect management outcomes (Olson, 1965; Poteete & Ostrom, 2004). Effects vary across studies (Barcelo & Capraro, 2015; Hardin, 1968; Oliver & Marwell, 1988; Olson, 1965); however, consensus is emerging that intermediate-sized groups are more likely to work collectively than small or large groups (Agrawal & Goyal, 2001; Capraro & Barcelo, 2015; Yang et al., 2013). Population density (people per available resource) has, despite being recognized as a crucial predictor of collective action (Agrawal, 2001), been relatively overlooked in the literature on natural resource management practices. However, there is both sound theory and clear evidence that population density is negatively correlated with resource condition (e.g., Brewer et al., 2013; Newton et al., 2007). Indeed, population density has been applied as a proxy of Malthusian overexploitation, through

failure of resource management institutions. As with population size, there is also some evidence of an optimum population density for collective action (Pender & Scherr, 1999).

Evidence of the effect of market integration (commodification of natural resources) on the existence of management practices is equivocal. There is evidence that increased economic inequality, which could emerge through unequal market access, makes collective action more challenging (Baland & Platteau, 1999). In contrast, there is also strong evidence across diverse cultural and economic settings that increased market access enhances cooperative behavior (Epstein et al, 2021; Henrich et al., 2001), including the probability of institution occurrence (Meinzen-Dick et al., 2002).

The relationship between modernization (here analogous with socioeconomic development) and the presence of natural resource management practices is unclear. A hopeful perspective holds that with increased modernization, resource management institutions will fail, to a point, after which they will reemerge as societies can afford and demand environmental quality (Cinner et al., 2009; York et al., 2003). An alternative theory is that capacity for, and interest in, managing the environment declines as modernization increases (Pilgrim et al., 2008). One major limitation of theories of the effect of modernization on management of common property resources is the complexity of modernization itself (Kramer et al., 2009).

The theories outlined above frequently explain variation in resource conditions (e.g., fisheries, forest cover, and biodiversity), both within the study context (Brewer et al., 2013) and universally (York et al., 2003), so their effects on local resource systems are likely to be mediated by practices established by management institutions (Agrawal & Yadama, 1997). Additionally, understanding of their effects on resource management practices remains contested (Barcelo & Capraro, 2015; Yang et al., 2013). Parsing the effects of these drivers on the probability of management practice existence is critical to understanding the conditions required to bolster efforts to expand and strengthen community-based conservation to counter global ecological decline.

In outlining these theories, we acknowledge that there are additional factors that predict both existence and efficacy of natural resource management (Ostrom, 1990; Poteete & Ostrom, 2004). For example, group heterogeneity affects local management efforts (e.g. Poteete & Ostrom, 2004). Further, leadership qualities have long been considered important in determining management institution success (Epstein et al., 2021; Glowacki & von Rueden, 2015; Vedeld, 2000). We focused on a limited set of predictors, primarily because they encapsulate the dominant environmental sociology theories of human–environment interaction (York et al., 2003) and because the available data did not include proxies for a more complete collective action analysis. Details on each driver are in Appendix S1.

Context

Community-based fisheries management (CBFM) is central to sustainable coastal fisheries and ongoing food security in the Pacific. Such management is primarily enabled through existing

local customary tenure arrangements (customary marine tenure reviewed in Appendix S1). Scaling CBFM in the Pacific region is hampered, however, by the globally unrivalled challenges of the sheer number of small communities of diverse social, cultural, and economic contexts and dynamic and diverse nature of management activities, such as temporal, spatial, gear, and species restrictions. Obtaining a comprehensive understanding of existing CBFM in communities across the Pacific, let alone a single country, by conducting in-community interviews, is infeasible. For example, depending on definitions of “community,” Solomon Islands has roughly 3000 communities spread across hundreds of islands. Existing data, in the form of national surveys, such as household income and expenditure surveys, census, and village resource surveys, combined with other data sources, such as geographic information system layers, have the potential to radically transform understanding of the distribution of CBFM activities across the Pacific.

Having reliable and comprehensive data on the presence or absence of CBFM at the community scale could unlock significant efficiency gains in CBFM scaling efforts by enabling more targeted interventions, such as focusing efforts on communities, that would be expected to, but do not, practice CBFM. Reliable and comprehensive data could also act as a repository of regional knowledge against which ongoing progress toward scaling CBFM could be measured. These data would provide information on, for example, total number of communities conducting CBFM by geopolitical scale (region, subregion, country, province, ward, enumeration area).

Study aims

Using an unprecedented sample size (725–1026 communities, varying across specific analysis), we tested the effect of the described drivers of community-level management practice occurrence in a single model; thus, we accounted for interactive effects and nonlinearity. Our broad aim of, and framing for, this analysis was not to fully account for all factors that predict management (Cinner et al., 2012; Epstein et al., 2021; Ostrom, 2007), but to compare established and contested environmental sociology theories and observed patterns across a limited set of dominant variables and a large numerical gradient. We used coral reefs as our study system because they are greatly affected by human disturbance (Cinner et al., 2018) and are renowned for supporting biodiversity and livelihoods in developing countries. Coral reef fisheries are often collectively managed at the community level, particularly in the Pacific region, where the overwhelming majority of people live close to the coast (Andrew et al., 2019). We based our study in a developing country, Solomon Islands, because it is reflective of other economically disadvantaged regions of the world in having high community-level dependence on natural resources (Bell et al., 2009), is experiencing market- and population-driven fishery decline (Brewer et al., 2013), and has ubiquitous community-level common property systems (detailed contextual background in Appendix S1). Specifically, we tested the effects of human population size, human population density,

market integration, and 4 dimensions of modernization (public infrastructure, health and education, economic, social) on the occurrence of 3 common fisheries management practices: temporary spatial closures, species restrictions, and fishing gear restrictions. We included 2 additional variables due to their availability in the data and sound grounds for inclusion. Distance from community to the resource (nearest coral reef) is included, based on the assumption that closer proximity enables enforcement (Crawford et al., 2004). Coral reef area is included, based on the assumption that either communities with greater reef area are more likely to have management practices or less likely to have management practices due to increased cost of enforcement (Wade, 1987).

METHODS

Data sources

We primarily used survey data collected by the Solomon Islands Government using established survey protocols (e.g., <https://microdata.pacificdata.org/index.php/catalog/396/study-description>). All villages recorded in the 2007–2008 Solomon Islands Village Resource Survey (VRS) (Solomon Islands Government, 2008) were spatially referenced using the 1999 Population and Housing Census (PHC) (Solomon Islands Government, 1999) locations, which was deemed to be the more accurate of the 2 sources. The VRS and PHC sample included all 6 provinces of Solomon Islands. Villages (hereafter communities) that did not have latitude and longitude recorded in the PHC or were incorrectly allocated to a ward (local political constituency) in the VRS were considered potential errors and omitted from the data set ($n = 191$). It is plausible that there was further error in the data, such as communities with a total population of 1 inhabitant, as is expected with large-scale survey data. However, it was not feasible to systematically ground truth possible errors. If error was retained, then it is expected that this effect would be outweighed by the benefits of a large sample, compared with a field survey, which can be prone to selection bias (e.g., Lorant et al., 2007), across a proportionately smaller sample.

Spatial boundaries between communities were measured using Thiessen polygons (Figure 1). Thiessen polygons are generated such that each community boundary is equidistant from the location of each adjacent community location, following Muller and Zeller (2002). This method for determining boundaries has been applied and validated in other contexts and found to be acceptably reliable (Butler et al., 2014; Wilebore & Coomes, 2016). Ground-truthing a representative sample of resource boundaries could provide triangulation on the accuracy of Thiessen polygons. This was not feasible, however, for a number of reasons. First, boundaries are dynamic, so ground-truthing would have been required when the VRS was conducted. Second, representative sampling would have required in-field assessment across a large number of communities across population, market, and socioeconomic gradients, a time and cost-inhibitive exercise, given the remote and inacces-

sible nature of the majority of communities in Solomon Islands. Coral reef area (Andrefouet et al., 2006) was overlaid with population data and Thiessen polygons to derive a measure of coral reef area available to each community. Communities that did not have a coral reef area in their Thiessen polygon boundary ($n = 1546$) were subsequently removed from the data set.

Following the data reduction process, human population size was measured as the total number of people living in each Thiessen polygon. Data on human population size were not available from the VRS, so population data and locations were derived from the PHC. Change in population size between the time of the PHC and the time of the VRS was corrected for all communities assuming an annual growth rate of 2.8% (World Bank, 2018). Although this method of associating resource user groups with resource does not account for intra- or intercommunity resource ownership or primary and secondary use rights (Aswani, 1999), it was appropriate because the management questions related specifically to community-level practices and because natural resource management is primarily conducted at the community level (Appendix S1). In doing so, we equated community population size with group size as discussed in collective action literature under the assumption that all members of the community have association with the resource and are required to adhere to management practices. Human population density was measured as the derived human population size divided by coral reef area in each Thiessen polygon. Market integration was measured as whether members of the community sold key coral reef fishery resources, including finfish, bêche-de-mer (Holothuridae), and trochus (*Tectus niloticus*), at local or wholesale markets. The data for market integration were derived from the VRS and measured as a binary variable (i.e., if any of the key commodities were sold, then a community was given a score of 1). Modernization was measured from 13 infrastructure and amenity items detailed in the VRS. Modernization items were measured as either present or absent in each community. Distance to resource was measured as the distance from each community in the VRS to the nearest coral reef.

Data on the presence of management practices was derived from the VRS. Specifically, community leaders were surveyed to identify the presence of management practices. Community leaders included elders, chiefs, school teachers, or community pastors. Community leaders are generally responsible for enforcing marine harvest restrictions, particularly in the traditional context (Hviding, 1998). Enumerators were chosen to survey specific communities because of their affiliation with the communities. Enumerator training was conducted over 3 weeks prior to enumeration. During the enumeration field period, communities were defined as a large settlement, encompassing smaller satellite communities within 15-min walking distance. The satellite communities were likely to include many of the additional communities recorded in the PHC that were not recorded in the VRS (Figure 1). The enumerators grouped settlements in a single polity (e.g., under the jurisdiction of a single chief) where possible. The Thiessen polygon method, as used to define human populations and coral reef area, was deemed more compatible with the definition used during the VRS enu-

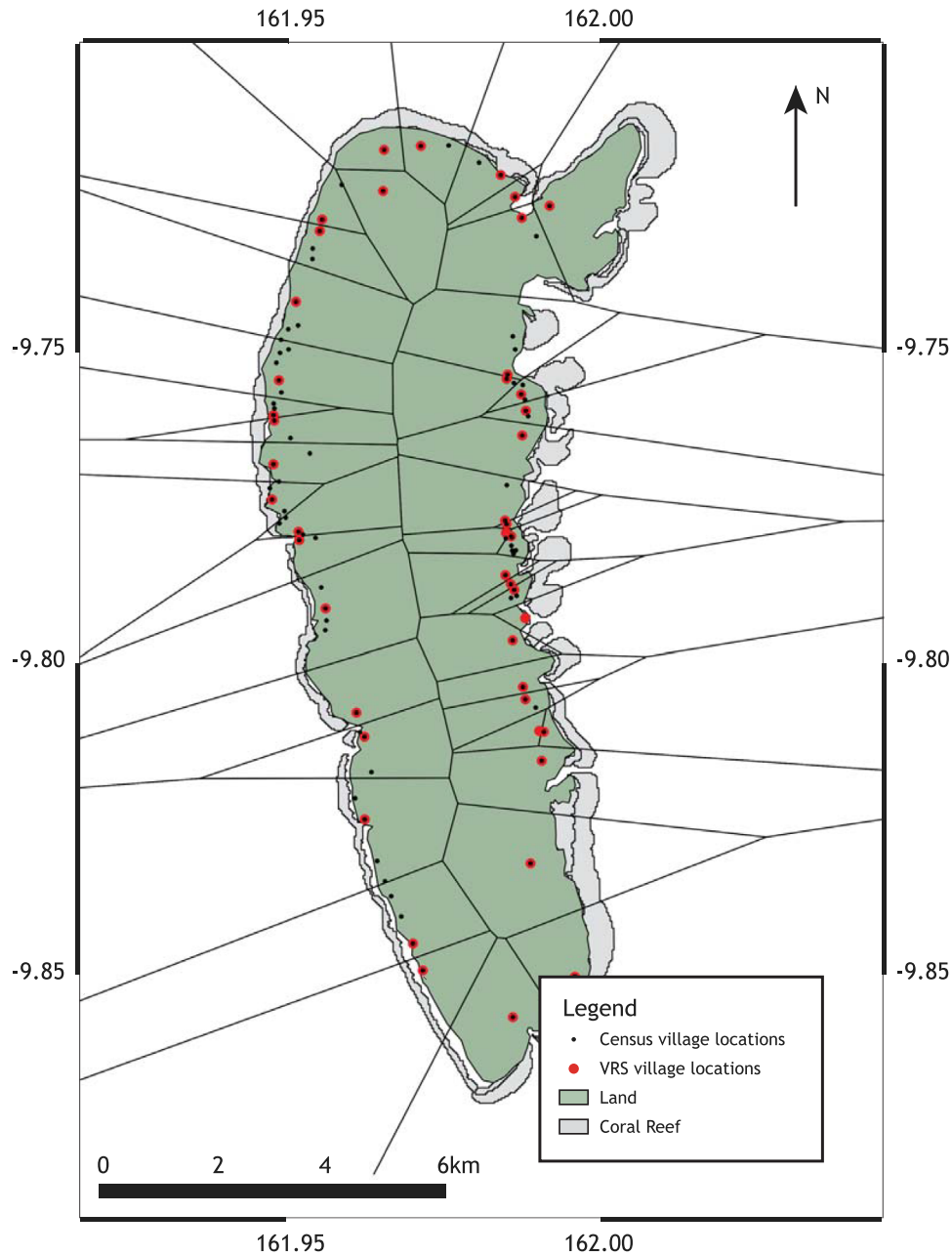


FIGURE 1 Geographical information system layers used to measure population size and population density at a sample location in Solomon Islands (red circles, communities participating in the Solomon Islands Village Resource Survey [VRS]; black circles, communities measured in the 1999 Population and Housing Census; black lines dividing communities, Thiessen polygon boundaries)

meration compared with alternate methods of remotely defining spatial boundaries, such as radial distance. The question used in the study pertaining to current management practices was developed (T.B. in collaboration with Solomon Islands National Statistics Office) to be intentionally general so as to capture the diversity of practices that exist in Solomon Islands and broader Melanesia (Cinner & Aswani, 2007). Specifically, community leaders were asked whether their villages had any of the following community fishing regulations: reef area closed on and off (yes or no), particular species restrictions (yes or no), and fishing gear restrictions (yes or no).

Data on permanent spatial closures were also elicited, but subsequently omitted because of possible misinterpretation. Specifically, it was possible that many of the recorded permanent closures represented false positives, including, but not limited to, sacred sites with no explicit resource management intent.

Analyses

We used categorical principal components analysis (CATPCA) (IBM Corp., 2019) with varimax rotation and Kaiser normal-

TABLE 1 Categorical principal components analysis (CATPCA) of binary (0 or 1) modernization variables based on a varimax rotation and Kaiser normalization in the assessment of modernization components across communities^a

Modernization item ^b	Modernization component					Occurrence (%) ^c
	Health and education	Public infrastructure	Economic	Social	Component 5	
Primary school	0.89	0.06	0.10	0.10	0.00	21.38
Preschool	0.88	0.04	0.13	0.18	0.03	18.99
Kindergarten	0.77	0.03	0.12	0.21	0.03	23.60
Clinic	0.49	0.14	0.38	-0.04	-0.06	13.93
Administrative center	0.04	0.87	0.06	0.02	0.06	1.06
Postal service	0.06	0.83	0.08	0.03	0.06	1.06
Airport	0.07	0.75	0.04	-0.02	-0.05	1.42
Fuel depot	0.14	0.04	0.81	0.09	0.04	19.25
Markets	0.11	0.13	0.70	0.04	-0.03	37.18
Trade store	0.14	-0.02	0.68	0.25	0.15	10.20
Village hall	0.11	0.04	0.12	0.82	0.03	21.92
Church	0.23	-0.02	0.15	0.77	-0.06	56.88
Credit facility	0.01	0.06	0.09	-0.02	0.98	1.95
Eigenvalue	2.54	2.07	1.84	1.42	1.01	
Variance explained (%)	19.54	15.91	14.19	10.95	7.76	

^aAll communities included in CATPCA ($n = 1137$) had responses for all modernization variables. Larger values for the items, whether positive or negative, represent a greater contribution of the item to the respective component.

^bDefinitions: administrative center, administrative provincial center and administrative substation; postal service, post offices and post agencies; trade store, trade stores and supermarkets; credit facility, credit facilities and banks (all as defined in the village resource survey).

^cPercentage of communities in which each item existed.

ization to generate components of modernization from the set of 13 infrastructure and amenity items derived from the VRS. We included infrastructure and amenity items based on a trade-off between coverage of modernization, as it is conceptually defined, and maximizing response rate in the VRS. The principal component analysis generated 5 components with eigenvalues >1 (Table 1), which explained 68.4% of the variance. Only the first 4 components were retained for predicting occurrence of management activities because the fifth component was largely composed of a single variable, credit facility, which alone has limited theoretical application. The 4 retained modernization components were health and education, public infrastructure, economic, and social. Where appropriate, explanatory variables were transformed so they would have an even spread across their ranges. Human population size, human population density, distance to nearest reef, and public infrastructure modernization were transformed to the $\log_{10}(+offset)$. The offset was set to half the second-lowest value next to zero. Coral reef area was transformed to the lognormal. Health and education, economic, and social dimensions of modernization were not transformed.

Correlation analysis was subsequently performed to test for collinearity among explanatory variables (Table 2). Correlations of $|r| > 0.7$ may distort model estimations and subsequent prediction (Dormann et al., 2013). The correlation between coral reef area and human population density of 0.82 exceeded the recommended threshold. Coral reef area was excluded from fur-

ther analyses following variable exclusion rationale outlined in Dormann et al. (2013).

We calculated a variance inflation factor (VIF) for models of each response and all potential explanatory variables. All explanatory variables had a VIF of <2 , so they were retained for all models (Hair et al., 1998). All predictor variables, covering existing theory of linear and curvilinear responses, were included in all 3 models with binomial logistic regressions in a backward-stepwise manner until a minimum Akaike's information criterion score was achieved, representing the minimum adequate model for explaining variance in each of the response variables. All remaining explanatory variables were included in all 3 models because there was no rationale for assuming different drivers of management practices across the 3 management practices we included. There are concerns with the application of stepwise-regression approaches for model selection, including failure to rank the relative importance of explanatory variables and type 1 error (false positives) (Mundry & Nunn, 2009; Taylor & Tibshirani, 2015). However, given the nature of conflicting theory and evidence regarding predictors of management practices it was necessary to consider all plausible predictors and present results showing which predictors had the strongest effect on response variables. For clarity and transparency, we present outputs of both full and final models and diagnostic plots (Appendix S2) and graphs of all effects in final models. Generalized linear models were performed using the R statistical software package (R Core Team, 2019), and in R we

TABLE 2 Pearson correlation matrix of transformed explanatory variables from across communities included the study

	Human population size	Human population density	Market integration	Distance to nearest coral reef	Health and education	Economic	Social	Public infrastructure
Human population density	0.417							
Market integration	0.061	-0.093						
Distance to nearest coral reef	-0.015	0.145	-0.029					
Health and education	0.291	0.076	0.032	0.019				
Economic	0.084	0.015	0.181	0.028	-0.004			
Social	0.262	0.083	0.004	0.016	0.016	-0.031		
Public infrastructure	0.084	0.044	-0.01	0.01	0.071	0.121	0.170	
Coral reef area	0.176	-0.821*	0.14	-0.167	0.103	0.038	0.077	0.005

*Collinearity resulting in exclusion of coral reef area.

used the `glm` function for the generalized linear regression analysis and the `step` function for the stepwise backward selection procedure from the base package.

RESULTS

Overall, 34% ($n = 424$) of communities had temporary spatial closures, 23% ($n = 287$) had species restrictions, and 19% ($n = 236$) had fishing gear restrictions. Of the 1168 communities that provided responses to all management questions, 12% indicated that they employed all 3 management practices, 9% employed 2 management practices, 17% employed a single management practice, and 61% employed no management practices. Average community size was 165 people, the median population density was 292 people/km² of coral reef, and 82% ($n = 1271$) of communities traded marine resources.

Human population size was positively associated with the probability of all restrictions (Figure 2a & Appendix S2). The range of probability of occurrence across the population size gradient (setting values of the other predictors to their mean) was 0.08–0.7, 0.04–0.65, and 0.05–0.72 for temporary closures, gear restrictions, and species restrictions, respectively.

Human population density had a dramatic negative association with the probability of occurrence across all management practices (Figure 2b & Appendix S2). Indeed, there was no evidence that management response to increased population density is nonlinear (Gebremedhin et al., 2003). The range of probability of occurrence across the human population density gradient (setting values of the other predictors to their mean) was 0.05–0.76, 0.02–0.84, and 0.03–0.66 for temporary closures, species restrictions, and gear restrictions, respectively.

Market integration had a strong positive association with the probability of occurrence of all management practices (Figure 2c & Appendix S2). The probability of temporary closures existing (setting values of the other predictors to their mean) was 0.15 when market integration was absent and 0.36 when market integration was present. The probability of species

restrictions existing (setting values of the other predictors to their mean) was 0.13 when market integration was absent and 0.31 when market integration was present. The probability of gear restrictions existing (setting values of the other predictors to their mean) was 0.06 when market integration was absent and 0.28 when market integration was present.

Components of modernization had limited association with management practices, and when the association was observed, the range of probability of occurrence was far less than for population and market effects. Economic modernization had a marginal negative association with temporary closures and a marginal negative quadratic association (inverse U) with gear and species restrictions. The range of probability of occurrence across the economic modernization gradient (setting values of the other predictors to their mean) was 0.19–0.39 for temporary closures (Figure 2d & Appendix S2). Distance to coral reef did not explain occurrence of any management practice in the models.

DISCUSSION

The prevalence of management practices highlights the extent and importance of community-level natural resource management, which is underreported in global accounting. Our large sample size, which provided significant statistical power, enabled the testing of numerous and divergent theories in a single study, resulting in clear trends within the study context. Replication of this approach in different contexts would determine whether there are universal patterns in the effects of social and economic conditions on resource management practices and consequent universally applicable theories. For example, comparable data from other Pacific countries could be used to identify whether the observed patterns hold in different nations. The broad value in this research lies in both the application of extant data across a large scale and sample size to reveal generalized patterns in socioeconomic factors that explain the existence of various natural resource management practices. It adds

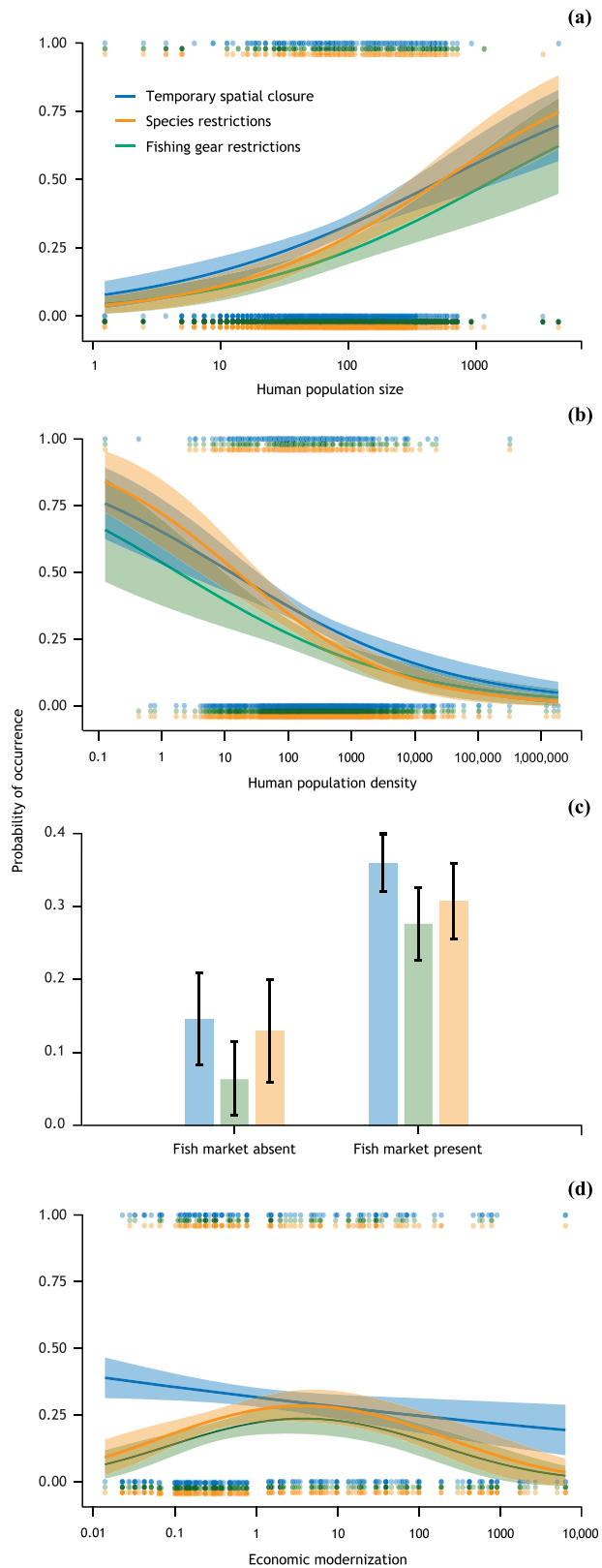


FIGURE 2 Statistically significant effects of (a) human population size, (b) human population density, (c) market integration, and (d) economic modernization on the probability of occurrence of management practices (lines in panels [a], [b], and [d], mean trend; shading or error bars, 95% CI; dots, position of communities, with or without management practices, along the x-axis gradient). Model outputs and diagnostics are in Appendix S2

to the existing literature on the subject of drivers of resource management practices by offering a method for testing theories at a scale not previously assessed with a large sample size.

Likelihood of occurrence of all management practices responded similarly to all explanatory variables deemed significant in the models: human population size and density, market integration, and economic modernization. Response similarity suggests that no single practice is likely to respond to any specific manifestation of social and economic change, but that they are likely complementary. Importantly, the broad range in mean probability of management practice occurrence across the statistically dominant explanatory variables provides strong evidence that some social and economic factors can have a dramatic effect on the probability of management occurrence.

On aggregate, we found no evidence of an optimum population size for collective action across a large population size gradient. Our results, instead, support existing evidence that larger populations are more likely to act collectively (Epstein et al., 2021; Oliver & Marwell, 1988). The stark contrast in the probability of management occurrence between small and large population size, across all management activities, offers some optimism in the context of population growth. Understanding why larger groups are more likely to have management practices in Solomon Islands will, however, require further detailed investigations across a representative subset of the communities we analyzed. Human population density had a dramatic negative effect on all tested management practices. Communities with more people per coral reef area were less likely to have spatial, gear, or species management practices. This result supports, rather than refutes, a Malthusian interpretation that common property practices are absent in the face of excessive competition (Hardin, 1968). Future analyses, including a more representative suite of explanatory variables, would contribute evidence for or against this interpretation. The independent and inverse effects of population size and population density are, to our knowledge, a novel finding that warrants further investigation. For example, the strong correlation between population density and coral reef area suggests that some of the variance explained by population density could be an artifact of reef area effects. It is also plausible that locations with high population densities are less dependent on marine resources and so have less incentive for management.

Market integration was positively associated with all management practices. It is likely that the observed effect is, in part, explained by the establishment of management practices in response to market-driven fishery decline (Brewer et al., 2013). Irrespective of the underlying causes of the observed effect, the finding suggests that market integration provides an opportunity for the establishment of management practices where they do not exist. The effect of the various dimensions of modernization was weaker and more variable. There was no evidence to support ecological modernization theory, or other modernization theories, across any of the modernization components tested. However, economic modernization had some overall negative association with likelihood of management occurrence at higher levels of economic modernization. Further analyses focused on a more detailed understanding of

economic development within the context, such as stakeholder interviews, could shed light on the mechanism of this observation. Although these results are robust for the context of this study, it is possible that the relatively constrained modernization gradient was inadequate to test the theories in a universal sense.

The use of Thiessen polygons to estimate resource boundaries was not informed by local knowledge of tenure arrangements. As outlined in the methods, however, the approach has been validated in other contexts. Additionally, tenure arrangements in Solomon Islands are historically fluid and not codified; therefore, it was not feasible to identify spatial boundaries across the sample (Appendix S1). Further, other researchers have applied more coarse approaches of estimating population and population density in assessments of resource pressures and management (e.g., Cinner et al., 2009; McClanahan et al., 2016). Finally, there is no apparent reason why this method would generate bias toward a particular type of community or management practice, so we would expect that, if boundaries were measured with greater precision, it would strengthen the observed effects.

Both national and local governance institutions in Solomon Islands establish and enforce regulations on marine resource use. It is possible, therefore, that despite the lead questions on management practices being “Does your village have any of the following community fishing regulations?” some of the data on management we used pertain to national restrictions. National laws against the use of explosives for fishing, for example, could explain some of the gear-restriction observations. Nongovernmental organizations (NGOs) also operate across Solomon Islands on coastal resource management initiatives. It is possible that some of the response data are a consequence of the presence or absence of NGOs. Including NGO presence in future analysis would determine potential effects. Similarly, coastal marine resources in Solomon Islands, as in most coastal locations globally, are highly diverse and varied in terms of their ecological, social, economic, and cultural functions. Different resources are therefore likely to be managed differently (Ostrom, 2003). It is also plausible that different communal resources could exhibit different responses to predictor variables, including group size. Determining which resources are the focus of specific management practices could provide greater model explanatory power, particularly regarding the species and gear restriction models. Additionally, here the response variable is binary, with management either existing or not. Other research focuses on only communities that have management and determines model response efficacy as, for example, the level or quality of monitoring and enforcement occurring (e.g., Agrawal & Goyal, 2001; Epstein et al., 2021). It is possible that this difference in varied analyses could influence observed trends across predictor variable gradients.

A number of supporting analyses would assist with a more nuanced interpretation of our results. A revised version of our analyses based on contemporary data would be enhanced by conducting in-field assessments at a subset of communities. Benefits of doing so would include assessment of the accuracy rate of data collection and detailed localized understanding of

the reasons for management presence or absence, such as the historical events and trends that occurred prior to current management arrangements. Additionally, identifying whether specific geopolitical regions (e.g., provinces or wards) had measurably higher or lower likelihood of management occurrence could add insight to understanding preconditions for management. Inclusion of additional variables associated with natural resource management collective action, such as human, social, and financial capital and the heterogeneity thereof (Poteete & Ostrom, 2004), could provide a more complete understanding of the existence of CBFM practices. Finally, testing different approaches to estimating resource use boundaries, such as radial distance and controlling for population size, would elucidate the effect of different approaches on the effect size of different drivers.

Our results offer windows of opportunity for increasing natural resource management occurrence. Where it does not already occur, management is more likely to be enacted in contexts of large population size, low population density, and the presence of market integration. Conversely, in instances where management practices are unlikely to occur (primarily contexts of small population size, high population density, absence of market integration), but do, there is opportunity to gain knowledge of why communities have management practices despite assumed adverse conditions (Cinner et al., 2016).

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