Unintended Consequences of Alternative Income Programs: The Implications of Non-Monetary Benefits from Traditional Livelihoods for Fisheries Conservation

Sheila M. Walsh[a,b], Theodore Groves[c], and Sriniketh Nagavarapu[d]

a. The Nature Conservancy, 4245 North Fairfax Dr., Arlington VA, 22203,
swalsh@tnc.org

b. Environmental Change Initiative, Brown University, Box 1951, Providence, RI
02912, Sheila_Walsh@brown.edu

c. Department of Economics, University of California-San Diego, 9500 Gilman Dr, La
Jolla, CA 92093-0508, trgroves@ucsd.edu

d. Department of Economics and Center for Environmental Studies, Brown
University, Box B, Providence, RI 02912, ssn@brown.edu

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Corresponding Author: Sheila M. Walsh, The Nature Conservancy, 4245 North
Fairfax Dr., Arlington VA, 22203, swalsh@tnc.org, Phone: 202-674-484

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Abstract

The labor decisions and welfare of poor households may be strongly influenced by non-monetary benefits from traditional livelihoods and the health of ecological stocks. Understanding these factors may shed light on why alternative income programs have had mixed results. We develop a model of a fishing-agricultural household with non-monetary benefits from fishing. We show that increases in agricultural prices have ambiguous effects on fishing labor that depend subtly on households' landholdings and value for fishing. Using this model to frame our econometric analysis, we examine a government program in the Republic of Kiribati that increased agricultural output prices. First, using household survey data we find that the program likely *increased* fishing labor for households with little land. Second, using novel ecological data, we estimate the negative impact of increased fishing on fish stocks and other coral reef ecosystem services. These unintended consequences may counteract long-term improvements in income from the program.

Keywords: integrated conservation and development program; alternative income program; fishing; copra; agriculture; ecosystem services; coral reef; household production; non-monetary benefits

1. Introduction and Literature Review

1.1 Introduction

The majority of the world's ecosystems, which provide life supporting services, are degraded and over 1 billion people live in poverty (Millenium EcosystemAssessment, 2005). These problems are inextricably linked because ecosystems provide the majority of wealth for poor people (Dasgupta, 2004). The hundreds of millions of dollars spent on integrated conservation and development programs (ICDPs) over the past three decades reflect a growing understanding of this connection, as well as a moral imperative to conserve natural resources using strategies that do not exacerbate poverty (Hughes and Flintan, 2001; WPC, 2003; Andam *et al*., 2010). To this end, ICDPs use a variety of strategies to try to align economic incentives with conservation (Berkes, 2007). One common strategy is to create or enhance alternative incomes (OECD, 1996; Wilkie and Godoy, 2000; Bennett, 2002). This strategy has been motivated by the expectation that, given standard economic assumptions, increasing alternative income opportunities should decrease resource extraction and increase human welfare (Wells *et al.*, 1992; Worah, 2000). Yet, reviews of ICDPs have found mixed or unclear results (Wells *et al.*, 1992; Smith *et al.*, 1998; Wells *et al.*, 1999; UNDP, 200; Hughes and Flintan, 2001). This may be due to program designs that take a one-size fits all approach and do not incorporate evaluation (Pullin and Knight, 2001; Brooks *et al.*, 2006).

Studies of household natural resource use decisions under different market conditions, property rights regimes, and with different household attributes and objectives provide important insights into how to design ICDPs for specific settings (Angelsen, 1999; Bluffstone, 1995; Pendleton and Howe, 2002; Muller and Albers, 2004); while, recent advances in program evaluation help guide practitioners on how to evaluate their success (Andam *et al.*, 2010, Ferraro and Pattanayak, 2006). Designing and evaluating alternative income programs for fisheries highlight two generally interesting and under addressed challenges. First, anthropological studies show that fishermen's decisions may be strongly influenced by the non-monetary benefits of their livelihood (Smith, 1981; Apostle *et al.*, 1985; Pollnac and Poggie, 1988; Gatewood and McKay, 1990). This suggests that alternative income programs focused on increasing wages or output prices may not be successful. Instead, considering household preferences in program design may help match different strategies to different groups or cultural contexts (Weiss 2009). Second, measurements of ecological outcomes are either uncommon or rely on proxy measurements based on resource extraction (e.g. fish catch rather than fish stocks). Measuring ecological outcomes in terms of changes in stocks rather than extraction is important because stocks (i.e. natural capital) are better indicators of long-run changes in wealth (Arrow *et al.*, 2004). Deforestation studies have partially overcome this challenge through the use of satellite technology to detect changes in forest cover (e.g. Pfaff, 1999). Catch per unit effort (CPUE) may provide an indication of fish stocks under certain conditions (Leiss *et al.*, 2007); however, CPUE is often a biased measure of resource stocks (Bannerot and Austin, 1983). In addition, measuring changes in the stocks of other resources that are indirectly affected by fish harvest and provide other important ecosystem services may be important to assess impacts on welfare.

The purpose of this paper is to address these theoretical and methodological challenges by 1) developing a household model that incorporates direct benefits from labor, 2) using this model as a framework for an econometric analysis of labor decisions that result from an alternative income program, and 2) estimating the effect of these labor decisions on interacting ecological stocks in the Republic of Kiribati (Figure 1). The Republic of Kiribati is a small Pacific island nation with a simple economy where almost all households are engaged in fishing and coconut agriculture (copra). Recent increases in the government controlled price of copra were thought to decrease pressure on the fishery and increase welfare (Sauni *et al.*, 2005). Our model shows that the effect of an increase in the copra price on fishing labor depends on the complementarity of direct benefits from fishing with other goods and land holdings. Consistent with the predictions of an intuitively reasonable parameterization of this model, we find that the majority of households actually increased fishing, with the largest increases for households with little land. Almost all households increased copra labor; however, the largest increases were for households with large land holdings. We estimate the effect of the change in fishing labor on four important and ecologically interacting coral reef stocks using data collected with SCUBA-based surveys. We show that the increase in the copra price may negatively impact fish stocks and coral reef builders, which may result in declines of other coral reef ecosystem services. These results suggest that the design of alternative income programs needs to consider that households respond to benefits other than those from wages when making labor decisions and that these decisions may have far-reaching implications for welfare due to the ecology of resource stocks. In the context of conservation-development project evaluation, this study makes a substantive contribution to the theory of household decision-making as well as a methodological contribution by directly measuring interacting ecological stocks, and in doing so reveals unintended consequences of an alternative income program.

1.2 Literature Review

Overfishing has radically transformed marine ecosystems and threatens the livelihoods of millions (Pauly *et al.*, 1998; Jackson *et al.*, 2001; Smith *et al.*, 2010). Studies of overfishing in the conservation literature have primarily focused on population growth as the key driver (e.g. Jackson *et al.*, 2001) (except see Cinner *et al.*, 2009). However, economic incentives and market conditions may play an even more important role in driving natural resource use than population growth (Angelsen, 1999). For instance, even though large population centers are often associated with degraded resources, more developed areas may provide alternative income opportunities that reduce resource use (Liese *et al.*, 2007). This is the general logic behind most conservation-development strategies; however, studies of resource extraction (focusing primarily on forests) suggest that the success of these strategies will depend on household attributes and objectives, market conditions, and property rights regimes (Bluffstone, 1995; Angelsen, 1999; Pendleton and Howe, 2002). Although the modeling frameworks used in studies of deforestation are not directly applicable to fishing, they provide important insights into conditions influencing household decisions (Liese *et al.*, 2007). For instance, in general, households with greater existing capital assets (e.g. land and education (a proxy for human capital)) may be better able to take advantage of alternative income opportunities and reduce resource extraction, while the commons may be an asset of last resort for poor households (Baland and Francois, 2005; Pendleton and Howe, 2002). Interestingly, Angelsen (1999) and Bluffstone (1995) show the development of labor markets may reduce deforestation by providing alternative employment even without privatizing the commons. In contrast, Pendleton and Howe (2002) show that the development of product markets may increase deforestation. In the context of an open access fishery, Liese *et al.* (2007) shows that the development of labor and product markets have counteracting effects on catch per unit effort due to the opposing effects of increases in the shadow wage of fishing labor and resource prices.

These studies highlight important conditions that may influence artisanal fishing household's labor decisions. However, none of these studies address the substantial body of empirical evidence suggesting that fishermen are influenced by non-monetary benefits from their livelihood – i.e. utility is derived directly from time spent fishing. The recognition that non-monetary benefits influence labor allocation decisions is not new, but to our knowledge has not been formally incorporated into an economic analysis of resource extractive decisions. For example, Adam Smith (1776, pgs. 100–101) observed that fishing and hunting may be labor activities in developing economies and leisure activities in developed economies[1]. Marshall (1920) suggested that, in order to better reflect the role of job attributes in labor decisions, wages should be thought of as multidimensional (Weiss, 2009). Anthropologists have similarly conceived of labor allocation decisions and suggested that the enjoyment of fishing explains why fishermen often choose fishing over other jobs with higher wages (Pollnac and Poggie, 1988; Gatewood and McKay, 1990). For example, attitudinal surveys of fishermen in the Philippines report that fishermen will not give up fishing for other occupations because they enjoy the income and lifestyle associated with fishing (Pollnac *et al.*, 2001; CRC, 2000)[2]. This empirical evidence is consistent with the concept of the compensating wage differential , which reflects the amount a person is willing to accept in terms of a wage reduction to be employed in an enjoyable job or the additional wages a person must be paid to be employed in an unpleasant or risky job (Rosen, 1986).

Non-monetary benefits may be associated with other types of traditional livelihoods and explain, in part, why development programs have limited success in rural communities (Uphoff *et al.*, 1998; Bebbington, 2000). The majority of the work on development and natural resources has been in terrestrial environments, particularly tropical forests (Oates, 1999). There are few examples examining the effect of alternative incomes on marine resources (Wilcox, 1994) and they show mixed results. For example, alternative income programs associated with marine

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[1] Adam Smith (1776, pgs. 100–101): “Hunting and fishing, the most important employments of mankind in the rude state of society, become in its advanced state their most agreeable amusements, and they pursue for pleasure what they once followed from necessity.” (Weiss 2009)

[2] This attitude is not particular to developing countries. North American fishermen have high levels of job satisfaction that are attributed to factors that represent “self-actualization,” suggesting that fishing relates to individuals’ need to fulfill rather than merely sustain themselves (Smith, 1981; Apostle *et al.*, 1985; Pollnac and Poggie, 1988)

protected areas (MPAs) have increased compliance with MPA regulations (Pollnac *et al.*, 2001; Thiele *et al.*, 2005) and measures of MPA success, including coral mortality (Pollnac *et al.*, 2001). However, the alternative livelihoods have also been associated with lower perceived quality of life (Thiele *et al.*, 2005). Studies of seaweed farming programs showed that fishermen rarely gave up fishing and even invested extra income in new fishing gear; however, outcomes varied across villages (Sievanen *et al.*, 2005; Hill *et al.*, In press). In addition, it is difficult to draw strong conclusions about alternative income programs, despite the variability of outcomes, because many programs were not designed with evaluation in mind or did not measure relevant economic and ecological outcomes (Kremen *et al.*, 1994; Ferraro and Pattanayak, 2006).

Here, we aim to advance our understanding of the effect of alternative incomes on fishing by incorporating the role of non-monetary benefits of livelihoods into labor decisions and measuring both direct and indirect ecological and economic outcomes from a significant policy change in the Republic of Kiribati (Fig. 1). The paper is organized as follows. First, we describe the policy change and the data. Second, we present the models of the fishing-agricultural household and the coral reef ecosystem. Third, we present our empirical strategy. Fourth, we describe the results. Fifth, we consider alternative explanations. We conclude by discussing the results in light of the previous literature and management decisions.

2. Study System and Data

In 2003 and 2004, the government of Kiribati increased its buying price of copra, a coconut product that is sold almost exclusively for export, as part of a social welfare program. This program resulted in a 9% increase in the copra price in the main Gilbert Islands and a 17% increase in the Line Islands (Table I). The spatial variation in the price change is due to the fact that the copra price in the Line Islands had been historically lower than in the Gilbert Islands because of their greater distance from the capital, Tarawa[3]. In 2004, the copra price was increased by another 21% in all islands (Table I). The program had limited potential for selection bias because the price increase was unexpected, it did not target specific areas based on fish stocks, and the majority of households engage almost exclusively in fishing and copra (Table II).

The Ministry of Fisheries expected that the increases in the copra price would help relieve pressure on the coral reefs by increasing labor in copra and decreasing fishing (Sauni *et al.*, 2005). To test this general hypothesis, we conducted a household survey to collect retrospective data covering the period from 2001 to 2006. The spatial and temporal variation in the copra price, as well as variation in household land, allowed us to identify changes in labor in fishing and copra, which may be mediated by household's preferences for fishing. In order to predict the effect of estimated changes in fishing labor on ecological stocks, we conducted detailed fishing surveys and underwater visual surveys to collected data on fishing labor and ecological stocks across an extreme spatial gradient in fishing labor on one island, Kiritimati (Figure 1) (Walsh, 2011). This use of spatial variation in fishing labor was necessary because we could not collect retrospective data on ecological stocks and changes in ecological stocks may lag changes in fishing labor by many years.

2.1 Household Data

We collected retrospective data (2001-2006) from 277 households on four islands in May and June 2007 (Figure 1). The survey instrument was developed with input from officers from the Ministry of Finance and Ministry of Fisheries and pre-tested on 85 households on two islands in December 2006. Households from every village of the study islands were surveyed and

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[3] Subsidies used to increase the buying price of copra are a form of social welfare in Kiribati (Tarakia 2009). These large increases followed a presidential election where promises for increases were made during the campaign.

selected randomly with sample sizes proportional to the island population. After obtaining oral consent, surveys of heads of households were conducted by one of the authors and a trained field assistant with translation by local Fisheries Assistants.

We used publicly available data on rainfall and coral reef area to control for changes in the marginal productivity of labor across years and islands. We calculated annual rainfall for the one degree cell associated with each island using daily rainfall estimates from the Global Precipitation Climatology Project (Huffman *et al.*, 2001). Rainfall summed over the two previous years was used to control for changes in copra productivity because the maturation time of coconuts results in a two year lag between droughts and copra production (NRC, 1951; Catala, 1957). Current rainfall was used to control for changes in the available number of days to dry coconut meat (one step in the copra production process) and bad weather days that may decrease the likelihood of going fishing. The total coral reef area associated with each island was calculated as the sum of the lagoon and reef area queried from the Millennium Coral Reef Mapping Project validated maps provided by the Institute for Marine Remote Sensing, University of South Florida and Institut de Recherche pour le Développement, Centre de Nouméa, with support from NASA.

Observations of households with no land or with values for land, household size, number of working aged (15-60 yrs) men, and education levels greater than three standard deviations beyond the mean were excluded from the dataset, which resulted in a total of eighteen observations being dropped and a remaining total sample of 274 households (Table II). Households on average spent half of their time fishing and slightly more than half of their time producing copra (Table II). A minority of the average household’s time was spent in other occupations (Table II). In a given year, 5 to 10% and 34 to 39% of households did no fishing or no copra, respectively. Between 2 and 6% of households did neither fishing nor copra in a given year.

Using reported income from 2001 and assuming no change in labor, we calculated that the copra price increase could have resulted in a 6.2% increase in total annual income ($580/year (2001 AUD)) for households with land holdings in the bottom quartile and a 15.2% increase ($766/year (2001 AUD)) for households with land holdings in the top quartile. These potential increases in income are similar in magnitude to the average annual household expenditure on fish ($363/year (2001 AUD)) and rice ($708/year (2001 AUD)).

Based on a simple comparison of household copra and fishing labor before (2001) and after (2006), only 8.9% of households' behavior is consistent with the standard prediction that increasing the copra price should decrease fishing and either increase or cause no change in copra labor. However, a substantial percentage of household reported increasing fishing labor and non-decreasing copra labor (23.0%). The fact that about 40.5% of households reported no change in fishing and copra labor suggests that this pattern may subject to recall bias.

2.2 Ecological Data

We conducted ecological and fishing surveys in Kiritimati during July and August 2007 at 37 reef sites and with 145 additional households, respectively, to estimate the effect of changes in fishing labor on coral reef ecological stocks using spatial variation in fishing. Fishing effort on Kiritimati ranged from 947 hrs/km/wk at some reef sites near the largest villages to no reported fishing on reefs along the unpopulated coast (Table III). This estimate of fishing effort corresponds to approximately 50 households fishing one kilometer of coastline for about 20 hours per week in the most heavily fished areas. The total range of biomass of fish observed across this fishing gradient was from over 8 mT/ha to less than a quarter of a metric ton per hectare, which is approximately the range observed between the few pristine coral reefs in the Pacific to the heavily degraded coral reefs in the Caribbean (Knowlton and Jackson, 2008) (Table III). Similarly, the reefs ranged from being almost totally dominated by reef building organisms (corals and crustose corraline algae) (91%) to reefs that have been almost entirely overgrown by algae (macroalgae and turf algae) (80%) (Table III).

3. Model

3.1. Household

In this section, we develop a simple model to demonstrate that the direction of the response in fishing labor to a change in the copra price is ambiguous and provide a framework for our empirical analysis. Using a few examples, we discuss how one aspect of preferences, namely for non-monetary benefits associated with fishing, can critically determine the direction and the magnitude of the response. In the last example, we show one parameterization of the model that yields predictions consistent with the empirical results below.

For the sake of transparency, we adopt a simple household model with limited availability of product and labor markets. In the case of Kiribati, consumption and labor supply opportunities are severely limited, making our simplified model a reasonable starting point. We assume that households are endowed with A units of land and T units of time. Households maximize a utility function defined over rice (c_r), fish (c_f), leisure (l), and time spent fishing (L_f). Income is produced through labor in copra L_c and time spent fishing L_f, with the production functions for copra and fishing being $g(A, L_c)$ and $f(L_f)$, respectively. Copra is by and large exported, so we abstract from domestic consumption of copra. We normalize the price of rice to one, while the price of fish is p_f and the price of copra is p_c. With no opportunities for hiring labor from outside the household, or supplying own labor outside of the household, we have $l + L_f + L_c = T$.

Intuitively, an increase in the government-set copra price (p_c) has two main effects: first, it increases the marginal revenue product of copra labor at any given level of copra labor; second, it increases household income. The former effect increases the shadow price of leisure and the shadow price of fishing effort. This encourages households to increase labor in copra and reduce leisure and time spent fishing. The latter effect will increase consumption of all normal goods, including time spent fishing. Because of these countervailing effects, the net effects on copra labor and time spent fishing are theoretically ambiguous. For some sets of preferences and production functions, an increase in the copra price can increase time spent fishing. For this effect to emerge, the fact that L_f directly enters the utility function is a necessary, but not sufficient condition[4].

To illustrate the logic clearly, we can examine specific choices of the utility function and production functions. Suppose the household's problem from above is given by:

$$\max_{c_r, c_f, l, L_f, L_c} \left[\alpha_1 L_f^{\sigma} + (1-\alpha_1)(c_f^{\beta_1} c_r^{\beta_2} l^{1-\beta_1-\beta_2})^{\sigma} \right]^{1/\sigma}$$

subject to:

$$c_r + p_f c_f = p_f f(L_f) + p_c g(A, L_c)$$

$$l + L_f + L_c = T$$

$$f(L_f) = L_f^{\gamma}$$

$$g(A, L_c) = A^{1-\delta} L_c^{\delta}$$

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[4] It is also possible the increase in the copra price could increase time spent fishing if higher incomes led to an increase in the demand for fish and an increase in the local market price of fish. The trends in the price of fish; however, do not suggest that general equilibrium effects have occurred (Table I).

and the standard non-negativity constraints on consumption, leisure, and labor supplies.

The parameter σ in the CES utility function indexes the degree of substitutability between L_f and the other goods. When σ is close to 1, the sets of goods are close to perfect substitutes. In this case, when the price of copra increases, households will tend to reduce time spent fishing: the shadow price of fishing increases, and utility gains can come easily from spending the additional income on consumption and leisure. In contrast, low values of σ indicate greater complementarity, with especially negative values producing Leontief-like preferences. In this case, spending additional income on consumption and leisure while reducing fishing is not necessarily optimal, as a low level of fishing constrains the gains from increasing consumption and leisure.

We illustrate these ideas in Figure 2. Each panel examines the effect of changing the price of copra from a baseline ($p_c = 1$) to a higher level ($p_c = 1.5$). For all figures, we use the following values for the parameters: $T = 7$, $p_f = 1$, $\beta_1 = \beta_2 = \frac{1}{3}$, $\gamma = 0.3$, $\alpha_1 = 0.3$, and $\delta = 0.7$. Depending on the figure, we choose a different value of σ. In every case, we find the optimal choices of L_f and L_c numerically, and graph the elasticity of both labor choices with respect to the copra price change at each value of land ownership (see Appendix). To compute this elasticity, we simply calculate the relative change in the labor choice, and divide by 0.5 (for a 50% change in the copra price). We examine $A \in [1, 6.5]$.

The top panel of Figure 2 shows the case of $\sigma = 0.1$, which is close to standard Cobb-Douglas preferences over the sets of goods. With this degree of substitutability, we obtain elasticities that take the “conventional” signs likely expected by proponents of the copra price increase. Across the range of land ownership, an increase in the copra price results in more labor in copra production and less labor in fishing production. The magnitudes of these changes are smaller at larger values of land ownership. Intuitively, larger landowners see a larger income effect from a given price change. Since we almost have Cobb-Douglas preferences, increased income tends to increase both leisure and fishing labor. This income effect makes the fishing labor declines smaller and the copra labor increases smaller for larger landowners.

The second panel of Figure 2 shows the case of $\sigma = -2$, where the two sets of goods are more complementary. As before, an increase in the copra price is associated with an increase in copra labor, with a higher magnitude at low levels of land ownership. But here, across the range of land ownership considered, the impact of a copra price increase on fishing labor is actually positive and increasing with land ownership. As the copra price increases, every household experiences an income effect, with the largest landowners having the largest income effects. Since fishing labor provides utility and is complementary with the other goods, part of the extra income is “spent” on consuming more fishing labor.

Thus far, we have simplified the setting by ignoring preference heterogeneity. One distinct possibility is that the people who have a small amount of land and are not invested heavily in copra production are the people who care about fishing most. In the third panel of Figure 2, we consider a specific version of this type of selection.

Specifically, we allow σ to increase in a linear manner from −1.7 to 0.05 as land increases. That is, those with lower landholdings also see fishing as a stronger complement to consumption and leisure. The resulting elasticities show a different pattern from the two panels above. The impact of the copra price on fishing labor is non-linear, with a positive elasticity for values between 1 and 4.4, and negative values thereafter. The impact of the copra price on labor in copra is still positive, but the magnitude is now highest at large levels of land ownership. Intuitively, larger landowners still see the larger income effects, but they also care less for fishing time. The relatively lower “need” for fishing time produces a fall in fishing effort and an increase in copra labor.

To summarize, Figure 2 demonstrates that the sign of the effect on fishing labor is ambiguous. The first two panels show that the substitutability of fishing labor with other goods is a critical determinant of the sign. The third panel considers preference heterogeneity and a plausible sort of selection, where those who see fishing labor as more complementary invest in lower landholdings. As we see below, our empirical results show patterns that have a flavor very similar to the third panel.

3.2. Ecosystem

In order to determine the success of this program, it is important to estimate how changes in fishing labor, that result from an increase in the copra price, affect resource stocks. Here, we measure the impacts of changes in fishing labor caused by the program by estimating simple models of a coral reef ecosystem with fishing (Figure 3). Overfishing has been implicated as a major cause of the shift from coral dominated to algal dominated reefs (Hughes, 1994; Newman *et al.*, 2006; Sandin *et al.*, 2008; Smith *et al.*, 2010). In these models, fishing may directly affect fish stocks and indirectly affect corals, and hence coral reef ecosystem services, through reductions in herbivorous fish stocks or stocks of all fish species. Herbivorous fish help maintain the balance between corals and their algal competitors through grazing (Hughes, 1994; McCook *et al.*, 2001; Smith *et al.*, 2010). In addition, fishing of any species may increase the nutrients available to algae because fish are important sinks for nutrients (Kitchell *et al.*, 1979). These mechanisms are not mutually exclusive. However, if changes in grazing are more important than changes in available nutrients caused by fishing any fish, we would expect fishing to have larger negative effects on corals because the effect is not diffused through the entire fish community.

4. Empirical Methodology

4.1 Labor Allocation

To test the predictions of our economic model, we considered reduced form models of copra and fishing labor:

$$\ln(L^c_{i,t}) = \alpha^0_i + \alpha^1 \ln(p^c_{k,t}) + \alpha^2 \ln(p^f_{k,t}) + \alpha^3 A_{i,t} + \alpha^4 \ln(p^c_{k,t}) * A_{i,t} + \alpha^5 D_{i,t} + \alpha^6 R_{k,t-1+t-2} + Z_i + I_k + \varepsilon_{i,t}$$

$$\ln(L^f_{i,t}) = \beta^0_i + \beta^1 \ln(p^c_{k,t}) + \beta^2 \ln(p^f_{k,t}) + \beta^3 A_{i,t} + \beta^4 \ln(p^c_{k,t}) * A_{i,t} + \alpha^5 D_{i,t} + \alpha^6 R_{k,t} + Z_i + I_k + \delta_{i,t}$$

where island ($k = 1$ to 4) and year ($t = 2001$ to 2006) specific prices for copra, $p^c_{k,t}$, and fish, $p^f_{k,t}$, adjusted for inflation, and the interaction between copra prices and land ($A_{i,t}$) predict labor allocation. The simplest specifications of these models also include other variables, in addition to prices, that may affect the shadow wage rate: basic household demographic and socioeconomic variables ($D_{i,t}$), household land ($A_{i,t}$), and island-specific rainfall summed over the two previous years ($R_{k,t-1+t-2}$). For instance, households with more adult males and higher education levels may have a greater opportunity cost for copra labor. In contrast, when previous rainfall was high and households have lots of land, the opportunity cost of labor in fishing may be high. To control for fixed unobservable heterogeneity across households and islands, household fixed effects, Z_i, and island fixed effects, I_k, are included. Results for models estimated without household fixed effects are also presented. Models were estimated using clustered standard errors, where clusters were village-years[5], and probability weighted $w_i = (N_i / N) / (n_i / n)$ data, where N is the population across islands, N_i is the population within island i, n is the sample across islands, and n_i is the sample within island i (MaCurdy 2007).

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[5] Clustering by village-year allowed for a large number of clusters (greater than 50), which are required for the use of statistical methods based on asymptotic theory (Angrist and Lavy, 2002).

Two additional model specifications were estimated to verify the robustness of the results. To test whether our results were sensitive to the possibility that land is endogenously chosen, we estimated the above model with land from the first year only. We also estimated models that included additional household and island-specific variables that may affect the shadow wage rate, including fishing capital, current year rain, house type (concrete versus traditional hut), and reef area.

4.2 Ecological Stocks

The relationship between fishing labor (standardized for gear type) and key coral reef ecological groups was investigated using path analysis. In our models, fishing was expected to indirectly affect reef-building (C) organisms by reducing the total abundance of fish (F_T) and, specifically, herbivorous fish (F_H) that feed on algae (S). These pathways are represented graphically and by the following set of equations (Figure 3 a, b):

$$F_j = \gamma_1 + \gamma_2 L_f + \varepsilon_f$$

$$S = \eta_1 + \eta_2 F_j + \eta_3 L_f + \varepsilon_s$$

$$C = \phi_1 + \phi_2 S + \phi_3 F_j + \phi_4 L_f + \varepsilon_c$$

where j is either T (all fish) or H (herbivorous fish). These models were estimated using ordinary least squares and parameter estimates from these models were used to estimate the effect of the change in fishing labor due to the copra price increase on reef-builders.

We argue that this is a valid approach because the location of fishing effort is determined exogenously by the government through village planning and fishing effort is restricted to reefs near their villages because few households own canoes or automobiles (for detailed methods see Walsh 2011). In addition, although corals and algae may have some effect on fish abundance, empirical evidence shows that top-down effects of fish on corals and algae dominate (Newman *et* *al.*, 2006; Sandin *et al.*, 2008). The lack of correlation between the error terms and the independent variables in the equations above support this claim.

5. Results

5.1 Labor Allocation

The fixed effect estimates of fishing and copra labor (Table IV) are consistent with the predictions of our household model. Copra price alone predicted significant increases in fishing labor (Table IV) but did not predict changes in copra labor. However, household land area mediated the relationship between copra price and both fishing and copra labor (Figure 4 (a), (b); Table IV). Households with small land holdings had the largest increases in fishing labor (Table IV, Figure 4 (a)). Using elasticities from this model and household land, we estimated that 70% of households increased fishing labor compared to 30% that showed no significant change. In contrast, households with large land holdings had the largest increases in copra labor in response to increases in the copra price (Table IV, Figure 4 (b))[6]. The vast majority of households (89%) increased copra labor with only 11% having no significant change. The mean price elasticity of fishing labor evaluated at the initial household land area for each house was 1.288 (*SE*=0.030, p<0.0001) and the mean price elasticity of copra labor was 1.076 (*SE*=0.081, p<0.0001). Based on these sample mean elasticities, we can estimate that a 29.7% increase in the copra price led to a 38.2% increase in aggregate fishing labor and a 31.7% increase in aggregate copra labor. Importantly, we determined that our results are most likely not being affected by endogenous

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[6] The same model was used to estimate copra production; however, we found no effect of copra price on copra production. Alternative model specifications were tested, including models with one and two year lags in the copra price and instrumental variables regression with copra labor instrumented by the price of copra, land, and their interaction. We found no effects of copra price or the instrumented copra labor. We attribute this to substantial measurement error in copra production. This seems like a reasonable explanation given that households often reported production by number of bags (which was then used to estimate kilograms) rather than kilograms.

land area investment decisions because a model specification using land in the first year in place of current year land resulted in almost identical estimates (Table IV). In addition, the results were robust to the inclusion of additional variables that may affect the shadow wage rate, including reef area, house type, rain in the current year, and fishing capital (Table IV). It should be noted, however, that 63% and 56% of households reported no change in copra labor and fishing labor, respectively, over this time period, which means that these patterns in labor are being identified off of less than 200 households.

Ordinary least squares estimates did not show copra price or its interaction with household land to be significant predictors of labor. The OLS estimate of fishing labor showed that larger households, with more working aged men and lower levels of education had higher levels of fishing labor (Table IV). The OLS estimate of copra labor also showed that larger households had higher levels of copra labor (Table IV), but no other household attribute predicted copra labor. Of the household demographic variables, only household size and working age men remained as significant predictors of fishing in the fixed effects models. Rain over the two previous years predicts lower levels of fishing labor in the fixed effect model (Table IV) but was not a significant predictor of copra labor in either of the OLS models.

5.2 Fishing and Ecosystem Effects

The results of the ecological path analysis support the hypothesis that changes in fishing that resulted from an increase in the copra price may have indirect negative effects on coral reef-building organisms (Figure 3). Unsurprisingly, we find that fishing negatively affects the total biomass of fish (Figure 3 (a)). The effect of fishing on herbivorous fish biomass; however, is smaller than the effect on total fish biomass (Figure 3 (b)). Total fish biomass has direct negative effects on algae (Figure 3 (a)) and small positive direct effects on reef-builders (Figure 3 (a)). No effect of herbivorous fish on algae was detected but herbivorous fish did have a positive effect on reef-builders (Figure 3 (b)). Algae had negative effects on reef-builders in both models (Figure 3 (a),(b)). The integrated elasticity of reef-builders with respect to fishing from the first model, where the effects of fishing on all fish were considered, was smaller than the integrated elasticity from the second model, where only effects on herbivores were considered (Figure 3). Combining the results from the path analysis and the econometric analysis, we predict that the 29.7% increase in the copra price may result in a 19.9% in total fish stocks and a 6.9% decrease in herbivorous fish stocks. The copra price may also indirectly result in between a 4.5% and 6.2% decrease in reef-builders due to changing ecological interactions.

6. Alternative Explanations

Of course, the greatest concern in our analysis is that the changes in prices may have occurred at the same time as other major changes that affected fishing and copra labor, or that the changes in price occurred because the government was concerned about predicted changes in fishing and copra labor. We believe these concerns, while valid, cannot explain the patterns we see here. First, these alternative stories would have to explain not only a general increase in fishing and copra labor, but also the specific form of heterogeneous effects across the land distribution. Our model provides a simple way to generate these heterogeneous effects. Second, the robustness of our results to the inclusion of additional variables and the use of island fixed effects gives us confidence that the patterns in fishing and copra labor are not subject to omitted variables bias.

We will briefly discuss how we addressed potential biases associated with potential unobserved changes in copra and fisheries productivity or the cost of consumer goods and the government's potential responses to these changes. One concern may be that the government increased the price of copra to protect citizens from low productivity in copra, which could explain the increase in fishing. Our indicator of copra productivity (rainfall summed over the two previous years) suggests that the productivity of copra increased over the study period. This pattern is inconsistent with the expectation that the government is shielding citizens from shocks to productivity, unless there is a lag in policy. In addition, this potential trend in copra productivity would not explain the increase in fishing. Another possible explanation for the increase in fishing labor would be a declining fish stock. If there is limited substitution between fish and other foods, lower fish stocks would lead to increases in fishing labor to maintain fish consumption levels. Although there is some evidence that the fish stocks in Kiribati are declining, we have no reason to believe that the pattern of decline across years and islands corresponds to the changes in the copra price. Alternatively, an increase in the price of copra could increase incomes, enabling people to buy more fishing capital, increasing the marginal productivity of fishing, and drawing labor into fishing. We did not, however, observe any significant changes in fishing capital due to the copra subsidy. Lastly, it is unlikely that increases in the price of consumer goods explains the increase in copra and fishing labor because the trend in food prices showed the opposite trend to the copra price over the study period: increasing by 10% in 2002, remaining steady through 2005, and declining by 4% in 2006 (GOK, 2006). Beyond the potential trends discussed, we are unaware of any other government programs or policies (e.g. infrastructure development or fishing gear subsidies/supplies) that could explain the observed patterns in labor allocation (ADB, 2003; ADB, 2004).

In addition, it is possible that other assumptions about household preferences over consumer goods could explain our results; however, we argue that this is unlikely. For instance, an increase in fishing labor in response to an increase in copra price could be observed if rice and/or leisure are inferior goods. In this case, increases in income due to an increase in the copra price would lead to higher consumption of fish relative to rice and/or leisure. Rice, however, is clearly not an inferior good in Kiribati because eating rice is associated with wealth and status (Thomas, 2002). We also believe that leisure is not an inferior good because time spent with family or friends appears to be highly valued (Borovnik, 2005). However, as we have already suggested, fishing itself has a leisure component.

7. Discussion

We found that households increased copra *and* fishing labor in response to the increased copra price, but that these responses depended on household land. Evidence of large increases in fishing for households with little land is consistent with our modeling framework in which we suggest that households that enjoy fishing more will be less invested in land. For these households, increases in income due to the copra price increase may be "spent" on fishing because non-monetary benefits from fishing may be more complementary to other consumer goods. We estimated that the increase in fishing labor may have significant negative consequences for the fish stock and reef builders, which provide important goods and services such as food or protection from storms and sea-level rise. This suggests that declines in the fishery and ecosystem services may off-set any gains in income from the program. In sum, the conservation-development program not only failed to reduce fishing and protect ecosystem services but may have actually exacerbated the problem.

The patterns we observed in labor allocation, which were strikingly similar to those predicted by a reasonable parameterization of our household model, we argue are not easily explained by measurement error. Although the sample of households was small, it covered substantial variation at the island and village level. The large number of households reporting no in copra or fishing labor (40%); however, suggests that recall bias may be an issue. Yet, households that reported no change in fishing did not have significantly different sizes of land holdings (5.02 acres, *SE*=0.19) from households that reported changes in fishing (5.10, *SE*=0.27) (Mann-Whitney Test, z=-1.30, *p*=0.19), which gives greater confidence in our results. In contrast, groups that reported no change in copra had smaller land holdings (4.20, *SE*=0.15) than those that reported changes in copra labor (7.14, *SE*=0.35) (Mann-Whitney Test, z=8.34, *p*<0.0001). This pattern in recall bias is consistent with the prediction from our model that households with small land holdings would experience the smallest changes in copra labor because small changes or less intense experiences are more likely to be forgotten (Lee, 2005).

The potential issues previously discussed give us greater confidence in our estimates of changes in fishing labor and hence our predictions of ecological outcomes. We argue that our use of spatial variation in fishing pressure to estimate effects of increases in fishing labor was valid because fishing patterns were exogenously determined by the government. The location of villages was originally influenced by the location of historic government-owned copra plantations, which no longer exist but were located primarily over the thickest part of the freshwater lens. To some extent this corresponded to the leeward side of the island, an area that has more nutrient rich waters due to upwelling of waters in the lee of the island (Walsh, 2011). These nutrient rich waters may have supported a higher abundance of fish, which suggests that our results may underestimate the negative effect of fishing on the fish population. Although historic differences in fish abundance may have coincided with the location of villages, reports of the location of fishing trips revealed that households usually fished very close to their villages.

Households are limited in their ability to seek out more productive reefs because very few households own canoes, boats, or automobiles. Even with motorized transportation, it takes a minimum of 3-6 hours for a boat or 1-3 hours for a automobile traveling from the largest village to reach the reefs near the smaller villages or along the unpopulated coastline. Often boat trips are impossible because of large waves and high winds.

The results of our ecological path analysis supported the prediction that fishing has direct effects on fish and indirect effects on reef-builders. These effects are greatest when acting primarily through changes in herbivorous fish. However, we did not find significant effects of herbivorous fish on algae, the competitors of reef-builders. This result may be due to mis-measurement of some algal groups through the use of percent cover as a measure of abundance (Burkepile and Hay, 2006). We did find significant negative effects of algae on reef-builders and of herbivorous fish on reef-builders. In fact, the estimate of losses in reef-builders is probably conservative because reef-builders are slower to respond to changes than algae. On historically over-fished reefs, sudden and almost complete losses of reef-builders have been observed following disturbances, such as hurricanes (Knowlton, 1992). Overall, our results suggest that increases in fishing due to the copra price increase may have negative effects on coral reef ecosystem services.

In general, our results contradict previous evidence suggesting that alternative incomes will reduce resource extraction or that the commons are an asset of last resort for poor households (e.g. Bluffstone, 1995; Angelsen, 1999; Pendleton and Howe, 2002; Baland and Francois, 2005; Liese *et al.*, 2007). Our results, however, are consistent with previous findings that households with greater assets are better able to take advantage of new or alternative income activities (Rosen, 1986). Under standard assumptions, we would expect households with the largest land holdings to have relatively smaller increases in copra labor because of diminishing marginal productivity of labor. However, we find that these households had the greatest increases in copra labor, which is consistent with preferences that result in additional income being spent on regular consumption goods or leisure, rather than enjoying fishing. We make the largest contribution by integrating previous findings from anthropological (Pollnac and Poggie, 1988; Gatewood and McKay, 1990) and economic or fisheries studies (Smith, 1981; Apostle et al. 1985) of non-monetary benefits from livelihoods and job satisfaction into an analysis of household resource use decisions. Our results suggest that this hard to measure factor has important effects on labor allocation decisions with unexpected negative consequences for the effect of alternative income projects. Heterogeneity in preferences for attributes of livelihoods that are not captured in wages may in part explain the mixed results of so many alternative income programs (e.g. Hill *et al.*, In press; Sievanen *et al.* 2005).

The limited selection bias, small number of goods, and incomplete labor and resource markets made estimating the effect of the copra price change more tractable. However, some of these attributes also limit the generality of the results. Perfect labor markets may buffer responses to alternative income projects because new labor can come in from outside. If there were well-functioning labor markets in Kiribati, households with lots of land might hire laborers, which would give land owners more free time that they could possibly use to go fishing. Perfect credit markets could strengthen the negative impact of the copra subsidy by enabling households to invest in fishing gear. With improved credit markets, fishing effort could increase with deleterious effects on the reefs. Lastly, there are a very limited number of goods to purchase or leisure activities in Kiribati. If more options were available, people may substitute other goods or activities for fishing labor as leisure, such as televisions and other mass consumption goods, lessening the negative impact of the copra subsidy. In addition, increased access to outside markets may break-down cultural institutions that support preferences for traditional livelihoods. However, the evidence of important psychological benefits from fishing in developed country contexts (e.g. Smith, 1981; Apostle et al. 1985; Pollnac and Poggie, 1988; Gatewood and McKay, 1990) runs counter to this argument.

The results of this research suggest that alternative income program design needs to consider the role of non-monetary benefits associated with livelihoods, as well as heterogeneity in preferences for these benefits, to avoid perverse outcomes. In cases where the non-monetary benefits of traditional livelihoods are high, alternative income programs may need to be coupled with direct regulation of fishing or provide similar non-monetary benefits as the traditional livelihood or both. There has been some success in transitioning fishermen in Belize into the tourism business while also creating marine protected areas (Gibson *et al.*, 1998). These fishermen report that the tourism jobs are satisfying because they allow them to have a similar lifestyle to fishing. In addition, some fishermen in Belize, and Mexico, are involved in monitoring and enforcement of marine protect areas or fishing concession, which may also provide non-monetary benefits that are similar to fishing. Although these anecdotes and case studies are intriguing, future research is needed to determine the success of these types of arrangements and their scalability.

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9. Figures

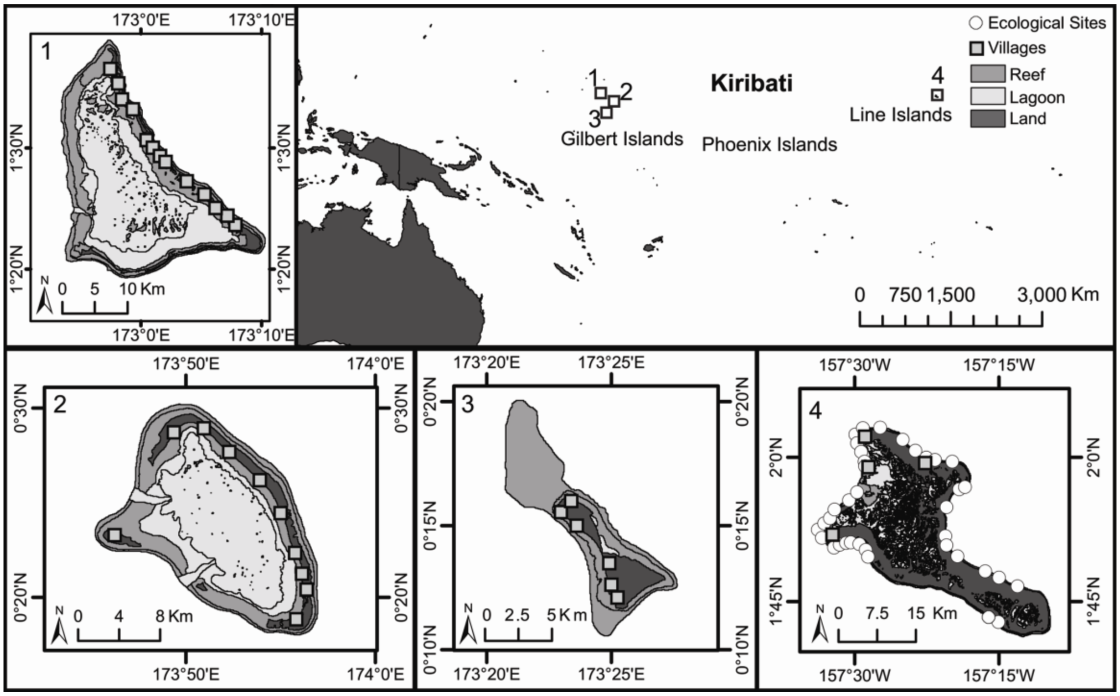

Fig. 1. Map of the Republic of Kiribati showing study islands with villages and ecological sites.

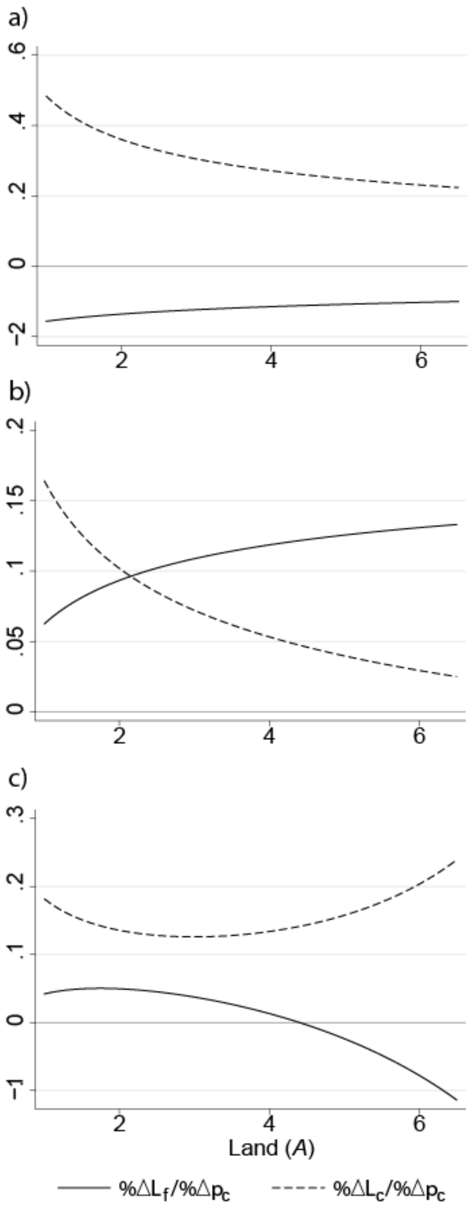

Fig. 2. Simulation results for changes in copra labor and fishing labor with respect to changes in copra price for different levels of land and preferences: a) Cobb-Douglas-like preferences: greater substitutability between fishing labor and other consumer goods, b) greater complementarity between fishing labor and other consumer goods, and c) heterogeneous preferences with households with little land having preferences that make fishing labor more complementary with other consumer goods.

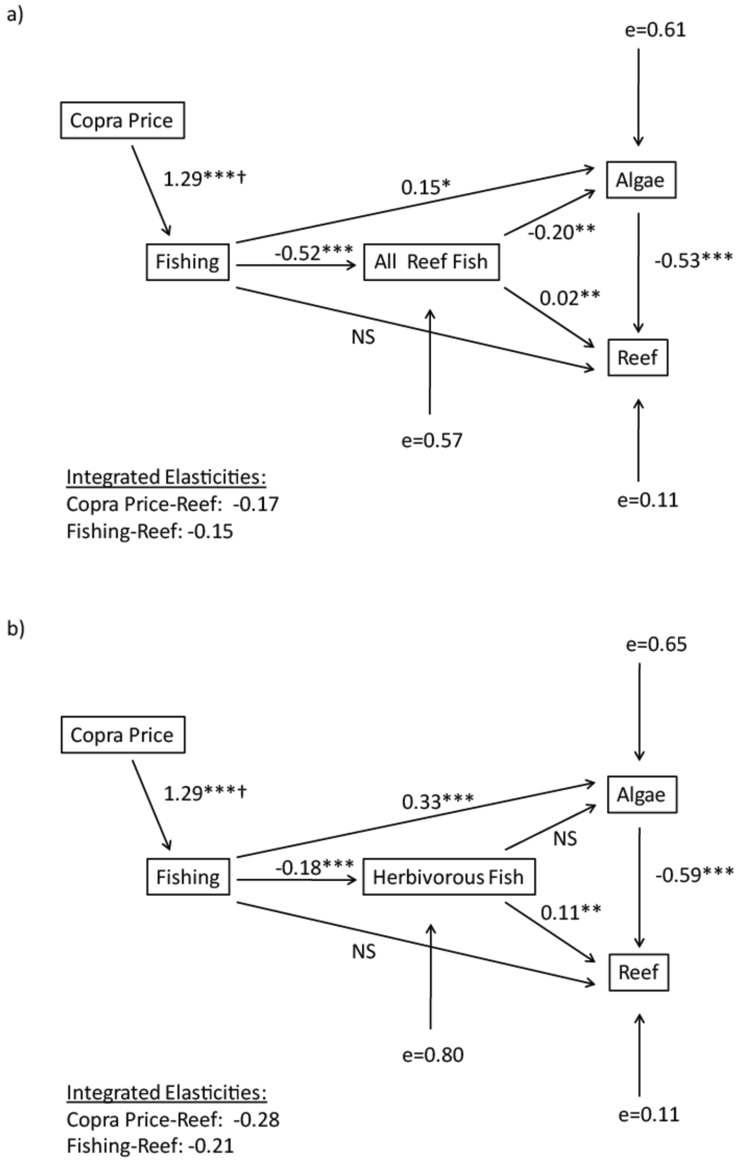

Fig. 3. Ecosystem models and estimates of elasticities from a path analysis of the effect of fishing on the coral reef ecosystem, occurring primarily through changes in (a) total fish biomass and (b) biomass of herbivorous fish only. * $p<0.1$, **$p<0.05$, ***$p<0.01$ + Based on econometric results.

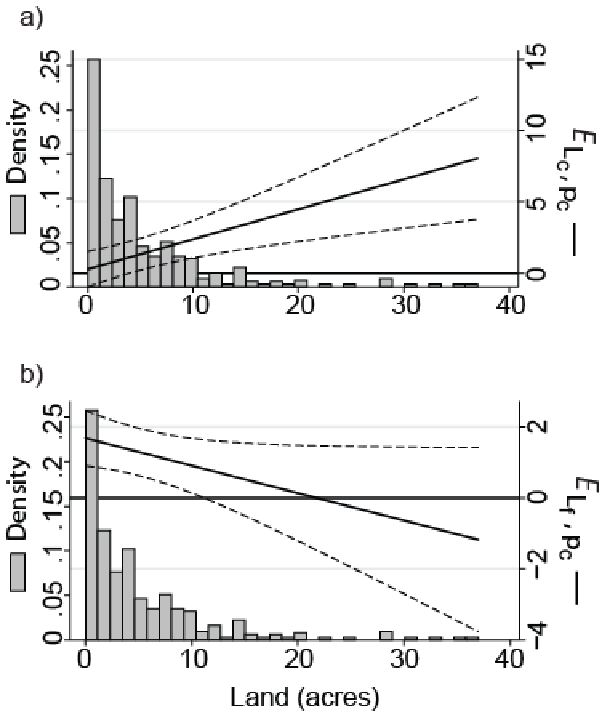

Fig 4. Empirical estimates of the elasticity of copra labor (a) and fishing labor (b) with respect to the copra price for different levels of land.

Table I. Government controlled copra buying price and market fish price (2001 AUD/kg).

Year	Gilbert Islands				Lines Islands			
	p_c	% Δ	p_f	% Δ	p_c	% Δ	p_f	% Δ
2001	0.45	NA	0.77	NA	0.42	NA	0.66	NA
2002	0.43	-5	0.74	-4	0.40	-5	0.62	-6
2003	0.47	9	0.75	1	0.47	17	0.61	-2
2004	0.57	21	0.78	4	0.57	21	0.56	-8
2005	0.57	0	0.82	5	0.57	0	0.58	4
2006	0.58	2	0.86	5	0.58	2	0.61	5

Table II. Descriptive statistics of household survey data.

Variables	[units]	Mean	N	SD	Max	Min
L_f	[persons*hrs/yr]	0.50	1574	0.63	7.88	0
L_c	[persons*hrs/yr]	0.57	1627	1.15	10.00	0
L_{other}	[persons*hrs/yr]	0.19	1620	0.56	4.50	0
p_c	[2001 AUD/kg]	0.51	1627	0.07	0.58	0.40
p_f	[2001 AUD/kg]	0.73	1627	0.13	0.95	0.51
Land	[acres]	5.15	1627	6.35	37.00	0.01
HH Size	[count]	6.61	1627	3.15	19.00	1.00
Males	[count (15-60yr)]	2.00	1627	1.34	8.00	0
Education	[yrs >primary]	1.96	1627	1.81	10.00	0
Rain	[mm/yr]	1733.98	1627	688.69	2998.81	547.26
Rain$_{(t-1+t-2)}$	[mm/yr]	3146.29	1627	1451.69	5499.55	616.14
Reef Area	[km^2]	372.29	1627	152.54	560.60	52.12
House	[1=concrete]	0.14	1595	0.35	1.00	0.00
Boats	[count]	0.47	1627	0.85	6.00	0

Note: hours of labor are normalized so that 40 hrs/wk for 50 weeks/yr=1.

Table III. Descriptive statistics of fishing and ecological survey data.

Variable	[units]	Mean	N	SD	Max	Min
Std. Fishing Effort	[hrs/km/wk]	275	37	294	947	0
Total Fish	[mT/ha]	2.43	37	2.07	8.28	0.17
Herbivorous Fish	[mT/ha]	0.51	37	0.22	1.11	0.00
Algae	[cover]	0.35	37	0.19	0.80	0.08
Reef	[cover]	0.61	37	0.19	0.91	0.17

Table IV. Estimates of labor

	$\ln(L_f)$				$\ln(L_c)$			
VARIABLES	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
$\ln(p_c)$	1.731	1.683***	1.682***	1.559***	0.372	0.277	0.272	0.148
	[1.081]	[0.397]	[0.397]	[0.338]	[3.176]	[0.639]	[0.638]	[0.731]
$\ln(p_f)$	0.063	0.034	0.030	-0.310	0.260	0.057	0.041	-0.419
	[1.816]	[0.778]	[0.776]	[0.725]	[4.263]	[0.843]	[0.841]	[0.869]
Land (A)	-0.029	-0.071		-0.028	0.190	0.009		0.041
	[0.060]	[0.051]		[0.045]	[0.122]	[0.116]		[0.116]
$\ln(p_c)*A$	-0.078	-0.077*		-0.013	0.159	0.210***		0.251***
	[0.089]	[0.040]		[0.034]	[0.185]	[0.065]		[0.069]
$\ln(p_c)*A_{t=0}$			-0.077*				0.211***	
			[0.040]				[0.065]	
HH Size	0.104***	0.118***	0.119***	0.115***	0.089*	-0.061	-0.060	-0.054
	[0.040]	[0.040]	[0.040]	[0.036]	[0.050]	[0.076]	[0.076]	[0.076]
Males	0.425***	0.389***	0.389***	0.364***	0.101	0.045	0.046	0.037
	[0.069]	[0.114]	[0.114]	[0.111]	[0.129]	[0.176]	[0.176]	[0.176]
Education	-0.221***	-0.135	-0.136	-0.128	0.029	0.284	0.280	0.283
	[0.051]	[0.086]	[0.085]	[0.080]	[0.071]	[0.184]	[0.182]	[0.183]
Rain$_{(t-1+t-2)}$	-0.000	-0.000*	-0.000*	-0.000*	0.000	-0.000	-0.000	-0.000
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Rain				0.000				-0.000
				[0.000]				[0.000]
Reef Area				0.006***				-0.040**
				[0.002]				[0.003]

Concrete House				-0.813				-1.744
				[0.586]				[1.282]
Boat				1.022***				0.656**
				[0.214]				[0.259]
Constant	-0.891	0.614	-2.018**	-1.866***	-2.775	5.767	-1.152	1.296
	[1.049]	[1.678]	[0.938]	[0.677]	[2.286]	[4.021]	[1.552]	[1.199]
Observations	1,574	1,574	1,574	1,542	1,627	1,627	1,627	1,595
R-squared	0.102				0.270			
Island FE	YES	YES	YES	NO	YES	YES	YES	NO
HH FE	NO	YES	YES	YES	NO	YES	YES	YES

Robust standard errors in brackets. * p<0.1, **p<0.05, ***p<0.01

1 Appendix

Here, we provide details on the solution of the household model presented in the main text. To begin, note that for $\sigma < 0$, the value of the utility function approaches zero as any of the choices entering utility approach zero. Since indirect utility is positive at any interior solution for all choices, it is clear that the optimal values of these choices must be non-zero. Therefore, the only corner solution to worry about is where $L_c = 0$. We first discuss the interior solution and then discuss this corner solution. In both cases, we use a simplification allowed by the parameters given in the text. Given the choices of β_1, β_2, and p_f above, c_r and c_f enter the household maximization problem symmetrically. Therefore, in both the interior solution and the corner solution, $c_f = c_r = (1/2) * [f(L_f) + g(A, L_c)]$.

For an interior solution for all choices, these simplifications imply that the problem is equivalent to:

$$max_{L_f,L_c} \quad \left[\alpha_1 L_f^\sigma + (1-\alpha_1)(\frac{1}{2})^{(2/3)\sigma}[L_f^\gamma + p_c A^{1-\delta} L_c^\delta]^{(2/3)\sigma}(T - L_f - L_c)^{(1/3)\sigma}\right]^{1/\sigma}$$

One can set the first-order conditions for the labor choices equal to zero. Manipulating these first-order conditions yields the non-linear system:

$$\begin{array}{rcl} 0 & = & 2\delta p_c A^{1-\delta} L_c^{\delta-1}(T - L_f - L_c) - (L_f^\gamma + p_c A^{1-\delta} L_c^\delta) \\ 0 & = & \alpha_1 \sigma L_f^{\sigma-1} \\ & + & (1-\alpha_1)\sigma(\frac{1}{2})^{(2/3)\sigma}(T - L_f - L_c)^{(1/3)\sigma-1}(L_f^\gamma + p_c A^{1-\delta} L_c^\delta)^{(2/3)\sigma-1} \\ & * & \left[\frac{2}{3}(T - L_f - L_c)\gamma L_f^{\gamma-1} - \frac{1}{3}(L_f^\gamma + p_c A^{1-\delta} L_c^\delta)\right] \end{array}$$

These equations can be solved computationally to obtain the interior solution at each parameter value set.

Next, we consider the case where $L_c = 0$. Note that for an interior solution for consumption, we now have $c_f = c_r = (1/2) * [f(L_f)]$. Also, $\ell = T - L_f$. Therefore, the optimization problem is equivalent to:

$$max_{L_f} \quad \left[\alpha_1 L_f^\sigma + (1-\alpha_1)(\frac{1}{2})^{(2/3)\sigma}[L_f^\gamma]^{(2/3)\sigma}(T - L_f)^{(1/3)\sigma}\right]^{1/\sigma}$$

After dropping a non-zero multiplicative term, the first-order condition implies:

$$0 = \alpha_1 \sigma L_f^{\sigma-1} + (1-\alpha_1)\sigma(\frac{1}{2})^{(2/3)\sigma}(T - L_f)^{(1/3)\sigma-1}(L_f^\gamma)^{(2/3)\sigma-1}\left[\frac{2}{3}(T - L_f)\gamma L_f^{\gamma-1} - \frac{1}{3}L_f^\gamma\right]$$

We can solve this non-linear equation for L_f computationally, and then calculate the indirect utility function.

For the parameter values we have chosen, the interior solution always yields a higher optimal value than the corner solution with $L_c = 0$. Therefore, for the figures above we compute elasticities using the interior solutions.