Profitability, income inequality, and subjective well-being of mariculture households in China

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Abstract

Mariculture has a profound potential to sustainably meet the escalating demands for food and livelihoods. However, the socioeconomic impacts of small-scale aquaculture (SSA) are poorly understood, particularly for marine SSA in China, a leading global producer of aquaculture products. Using detailed household surveys, we comprehensively evaluated profitability, income inequality, and subjective well-being of marine SSA households in a representative coastal city in Southeastern China. Our results show that mariculture practices increased income but exacerbated income inequality in animal mariculture households (AMHs) and seaweed mariculture households (SMHs). Earnings from AMHs (544,549 yuan) were four times higher than those of SMHs (141,172 yuan) although AMHs were twice as likely to make a loss (27.4% versus 12.5%). Natural capital (11.37%) and the cultured variety (12.40%) were the main contributors to mariculture income inequality for AMHs, while manufactured capital (27.59%) and previous mariculture experience (8.59%) were significant for SMHs. The well-being of AMHs was better than that of SMHs. Our results suggest that secure access to sea areas, provision of financial options to mariculture smallholders, as well as diversification in mariculture type and variety could promote the socioeconomic sustainability of mariculture development.

1. Introduction

Aquaculture is probably the fastest growing one among the major food-production sectors and is increasingly considered as a promising solution to human development. The provision of food, employment and livelihood from aquaculture is expected to contribute substantially to the Sustainable Development Goals (SDGs) outlined by the Food and Agriculture Organization [1, 2]. However, it has been argued whether aquaculture could achieve all three aspects of sustainable development, in terms of economic development, social development, and environmental protection. Concerns have been raised that the pursuit of economic objectives (e.g., profit and exports) in aquaculture can lead to ecological degradation and undermine social objectives, including equality and well-being [3, 4]. Currently, the impact of aquaculture on the environment (e.g., disease transmission, water pollution, coastal wetland loss) has received the most attention [5, 6]. However, some issues have emerged in the social dimensions of aquaculture placing social sustainability at the forefront of the sector [4]. Estimating the impact of aquaculture on the local economy and social development of rural communities [3, 7], and how social and economic benefits from increased productivity contribute to the well-being of aquaculture farmers, have become key topics for the development of sustainable aquaculture [8, 9].

Household units account for 70%–80% of the producers involved in aquaculture worldwide [10]. In these small-scale aquaculture (SSA) households, where aquaculture is the primary livelihood activity,
a significant investment has been made in livelihood capitals such as natural resources, time, labor, and infrastructure [11]. Positive livelihood outcomes such as improved food security [12, 13] and increased income [14–16] have steadily been recognized; negative outcomes such as increased inequality and decreased well-being have also emerged. SSA households in coastal Bangladesh face diminished land security [17] and aggravating gender and social class inequalities [15]. Reports from Vietnam show that SSA is facing social sustainability challenges with 30% of households at or below the national rural poverty line [18]. The outcomes of inequality appear contradictory for different aquaculture types in various regions. SSA households in the Philippines reported reduced inequality [19] while those in Bangladesh and Ghana experienced the opposite [14, 20]. The emergence of commercial aquaculture was often associated with negative subjective well-being, despite the usually positive economic outcomes [15]. To date, the impact of social dimensions on the sustainability of aquaculture is not fully understood as comparatively little research has been undertaken.

The livelihood outcomes of SSA units are largely dependent on their livelihood capitals [21] and the risks posed by the local environment and globally fluctuating market [22]. Ambiguous property rights and limited access to natural resources constrain the benefits to SSA households from aquaculture [23–25]. Insufficient financial capital further impedes positive livelihood outcomes by limiting investment in manufacturing facilities, high quality fry, and advanced aquaculture technologies [26, 27]. Environmental issues can also have severe impacts on aquaculture. The disordered and intensive mariculture triggered the spread of infectious salmon anemia virus in 2008 and harmful algal blooms in 2016, both of which occurred in Chile. This further led to the collapse of the salmon aquaculture industry causing serious economic and social disruption [28, 29]. SSA households are also exposed to risks from the financial volatility of seafood and currency markets [30]. Mariculture farmers worldwide are subject to boom and bust cycles due to seafood market volatility and price fluctuations [31, 32]. To maximize the contribution of SSA and improve the development of sustainable aquaculture, it is important to clarify the contribution of livelihood capitals to negative outcomes, and to assess the relationship between risk and economic returns.

China has been leading global production of seafood, with mariculture animals and seaweeds accounting for 58% and 57% of the global mariculture yield in 2018, respectively [33, 34]. Currently, there are two major mariculture types existing in China’s inshore areas, namely animal mariculture (culturing finfish and invertebrates in submerged net cages or boxes) and seaweed mariculture (culturing seaweeds attached to ropes or bamboos floating on sea surface). Mariculture of different types and varieties require different inputs of livelihood capitals, having varying sensitivities to risks, and thus yield different socioeconomic outcomes. Compared with seaweed mariculture, the aquaculture of farm-fed animals requires more sophisticated technology. Consequently, animal mariculture invests more financial and manufactured capital in initial fixed (e.g. raft, net cages and manufacturing facilities) and variable costs (e.g. feeds, fry, and employed labor). Seaweed mariculture uses more natural resources than animal mariculture as the farmed product derives the required inorganic nutrients for growth from the surrounding surface water via photosynthesis and other metabolic processes. Studies have shown that animal mariculture is also more sensitive to environmental exposure and complex to operate and manage [35]. The accumulation of excess dissolved inorganic nutrients and pathogenic bacteria from finfish mariculture can also have serious consequences for the environment resulting in the spread of disease and reduced production [36]. Under the national export-oriented policy of China, the higher economic value farm-fed marine animals are often traded internationally [37]. This makes animal mariculture more vulnerable to market volatility thus affecting its productivity and profitability. The fluctuating economic returns within and between mariculture groups can also exacerbate negative social outcomes by increasing inequality and decreasing well-being.

Here, we conducted a systematic assessment of the socioeconomic outcomes of marine SSA in a representative coastal city in Southeastern China. We aim to (a) analyze the income levels and profitability for mariculture households of different types and different cultured varieties; (b) assess the household income inequalities and identify the livelihood capitals contributing to mariculture income inequality; and (c) evaluate and compare the subjective well-being conditions of the different mariculture households. Our study is one of the first to quantitatively assess the conflict between objectives associated with economic and social dimensions in the development of sustainable mariculture. Our analysis of income inequality and subjective well-being for different mariculture households will complement the existing literature at the forefront of the development of sustainable aquaculture: how socioeconomic benefits generated by increased productivity in aquaculture sector are distributed and to which extent it contributed to SSA households.

2. Materials and methods

2.1. Study area

Ningde City (118°32′–120°43′ and 110°16′–110°26′) is situated in Fujian Province, Southeastern China (figure 1). Ningde has a sea area of approximately 45000 km² and a coastline of about 1046 km, and was
selected as one of China’s national marine ranching demonstration zones for the period 2017–2025 [38]. In 2016, the gross output of mariculture in Ningde reached USD 1.21 billion; the sector provided livelihoods to approximately 50,000 people in its production sector alone, of which most were from SSA households [39].

2.2. Data collection

2.2.1. Household survey
We collected our household surveys in August 2017, and randomly selected a total of 282 mariculture households, including 186 animal mariculture participants and 96 seaweed mariculture participants (see the spatial distribution of sampled households in figure S1 (available online at stacks.iop.org/ERL/16/064084/mmedia)). Here, we defined animal mariculture households (AMHs) as households culturing animal species such as finfish (e.g. large yellow croaker (Larimichthys crocea)) and invertebrates (e.g. abalone (Haliotis spp.), sea cucumber (Apostichopus japonicus)) as their primary products (defined by cost inputs and monetary returns). We then defined seaweed mariculture households (SMHs) as households that solely culture seaweeds (e.g. porphyra (Porphyra spp., commonly referred to as nori), laminaria (Laminaria japonica, commonly referred to as kelp), gracilaria (Gracilaria spp.)) (see supplementary material for further details). Furthermore, we classified AMHs into three groups, i.e. those culturing finfish, invertebrates, and both finfish and invertebrates. We classified SMHs into two groups, i.e. those culturing porphyra and those culturing laminaria or gracilaria. Usually the head of each household or their spouse were selected as the interviewees because they were the decision makers, familiar with household affairs [40]. The information elicited included demographic factors, household livelihood activities (especially mariculture practices), social ties to local leaders and mariculture communities, household incomes and subjective well-being in 2016. Here, mariculture income was net income, i.e. the value of the total output sold minus the cost of fry, feed, maintenance, and hired labor (which was also the case for other business activities).

2.2.2. The index system to measure human well-being (HWB)
Life satisfaction can be regarded as a global cognitive judgement of a person’s life and is often used...
to measure their subjective well-being [41, 42]. We used the framework proposed in the Millennium Ecosystem Assessment to measure households’ satisfaction of their lives in five interrelated dimensions: material, security, health, relation, and freedom [40, 43], and constructed the index system for HWB (see table S1 for details). Where, material referred to basic goods and services for life, including food, clothes, living conditions and transportation; security referred to the safety of a person and their possessions including secure access to property and other resources; health referred to the physical and mental health conditions of household members; relation referred to social relations including social cohesion and mutual respect; freedom referred to the choices and actions including control over outcome and attainment of personal values. Together, these five dimensions provided the conditions for physical, social, psychological, and spiritual fulfillment to comprehensively describe the life satisfaction and subjective well-being of SSA households.

2.3. Data analysis
2.3.1. Statistical analysis of household incomes
We divided household incomes into six categories: earnings from mariculture, wages from employment, earnings from business, income from property (i.e. renting houses, woodlands, cultivated land and sea areas, and investment activities), income from social gifts, insurance and subsidies, and income from agriculture. We then calculated the differences of incomes among household groups by one-way ANOVA using Stata Statistical Software, version 14.1 (StataCorp LP, TX, USA).

2.3.2. Income generation and decomposition of inequality using the Shapley value
Our basic concept for analyzing inequality will be the cumulative distribution function of income \( I \). First, we ranked households from the lowest to the highest income; second, we drew the Lorenz curve that constituted as the cumulative proportion of income on \( y \)-axis against the cumulative proportion of households on \( x \)-axis. We observed that a substantial proportion of the population had a negative income (but the mean was positive), which indicated the lower bound of the Gini coefficient \( G \) was still zero, but the upper bound value was greater than one. Some scholars have proposed rescaled versions of \( G \) to ensure it is bounded between zero and one [44–46]; however, the rationale for imposing an upper bound for the inequality index is debatable. Notionally, if all but one household entered debt without restrictions on the transfer of income to one household accumulating all the positive income, there was no reason to consider that a ‘maximum’ level of inequality existed [47]. This situation was evident for our study, as mariculture practice in Ningde is a commercial operation and a substantial portion of mariculture households had a negative income in 2016. Thus, with no maximum limit, \( G \) could be estimated as follows:

\[
G = 1 - \sum_{i=1}^{n} (X_i - X_{i-1}) (Y_i + Y_{i-1})
\]

(1)

where \( n \) is number of households; \( X_i \) is the cumulative proportion of households up to the \( i \)th household; \( Y_i \) is the cumulative proportion of income for the same household \( i \) \( (i = 1, 2, \ldots, n, X_0 = 0, X_n = 1, Y_0 = 0 \) and \( Y_n = 1 \)).

The regression-based decomposition of inequality has the advantage of enabling identification as well as quantification of root causes or determinants, which can be arbitrary [48]. In this study, we followed the method developed by Wan and Zhou [49] to generate our decomposition outcomes using the Shapley value. First, we built two income generation functions for the total net income and mariculture income using the income sources and income determinants according to equation (2):

\[
Y_i = f(X_{i1}, \ldots, X_{ik}, \ldots, X_{ik})
\]

(2)

where \( Y_i \) is the total net income or mariculture income of the household \( i \); \( X_k \) is the value of income source \( k \) or determinant \( k \) of the household \( i \) \( (k = 1, \ldots, K) \).

Second, we derived the contribution of independent variables \( X_k \) to the overall Gini coefficients using the regression-based approach (see supplementary material for full details). The extensive computing was executed using the Distributive Analysis Stata Package [50], which was primarily designed to assist researchers and policy analysts interested in conducting distributive analysis using Stata software.

In addition to income sources, we constructed an index system of livelihood capitals using confirmatory factor analysis to decompose the income inequality. Each of five livelihood capitals (i.e. human, social, natural, manufactured, and financial) consisted of four indicators representing a household’s possession of assets (see table S2 for the indicator description).

3. Results
3.1. Household income levels and mariculture profitability
Compared with SMHs, the total net income (figure 2(a)), per capita total net income, net mariculture income and per capita net mariculture income for AMHs were all higher (tables S3 and S4). The total average annual net income for AMHs (606 544 yuan) was three times more than that of SMHs (189 508 yuan).
Figure 2. Income sources and their contributions to inequality for animal and seaweed mariculture: (a) mean (±SE) incomes for each livelihood activity and a breakdown by mariculture type and variety (different letters indicate significant differences (* P < 0.05, ** P < 0.001) between income sources); (b) the contributions of each income from different livelihood activities to the total income inequality and a breakdown by mariculture type and variety.

Income from mariculture accounted for 90.36% and 74.68% of the total income of AMHs and SMHs, respectively (tables S5 and S6). With a total net mariculture income of 544,549 yuan, the average earning from AMHs were nearly four times greater than those of SMHs. Despite the overwhelming advantage in revenue generation, AMHs were more than twice as likely to make a negative profit than SMHs. Tables S3 and S4 show that 27.4% (51 out of 186) of AMHs and 12.5% (12 out of 96) of SMHs were unable to recover their mariculture operating costs from the sale of their products.

Within AMHs, the culturing of both finfish and invertebrates achieved the highest income (1826,733 yuan), which was approximately six times and three times higher than households culturing only finfish and invertebrates, respectively. Invertebrate mariculture had the lowest risk (21.4%) of profitability failure. It is interesting to note that finfish farming was the least profitable animal mariculture practice at
305 252 yuan and had the highest probability of profitability failure (32.7%). The differences in profitability between the SMH groups were negligible compared with those of the AMHs.

### 3.2. Income inequality

#### 3.2.1. Income source inequality

The overall income inequality for the Ningde mariculture community was captured by a $G$ of 1.470 (table S7). Figure 2(b) shows that income from mariculture caused most of inequality for both AMHs and SMHs, with contributions of 98.42% and 78.10%, respectively. Interestingly, household groups with higher average incomes also faced greater income inequalities. Overall, the $G$ of total net income for AMHs (1.521) in Ningde was much higher than that of SMHs (0.557). Figure 3 shows that AMHs had greater inequalities for both mariculture and non-mariculture incomes than SMHs. The magnitude of mariculture income inequality between AMHs

![Figure 3. Lorenz curves for mariculture household income inequality showing breakdown by type and variety: (a) mariculture; (b) non-mariculture.](image)
The overall satisfaction of AMHs (77.31) was not significantly different from that of SMHs (73.59). However, the individual dimensions of material (76.02) and security (82.58) for AMHs were significantly different from those of SMHs which were 70.89 and 78.33 for material and security respectively, indicating an increased HWB for animal mariculture practices. Inspection of the sub-dimensions also revealed that AMHs had significantly better conditions of basic goods and services for life, and the safety of people and possessions, compared with SMHs.

Within AMHs, the culturing of both finfish and invertebrates showed the optimum conditions of subjective well-being in all dimensions (figure 4(b)). For the SMHs, the culturing of porphyra, laminaria or gracilaria showed no significant differences in HWB indices for all dimensions (figure 4(c)).

4. Discussion

4.1. Economic returns and profitability of mariculture

Economic returns from mariculture were considerable and contributed substantially to household incomes. First, annual average earnings of mariculture households in Ningde (191 200 yuan for animal mariculture and 45800 yuan for seaweed mariculture) were higher than the mean per capita disposable income for Chinese residents (23821 yuan) in 2016 [51]. This was also consistent with studies of mariculture in other countries such as Bangladesh [17], Vietnam [52] and Ghana [53]. Second, the economic outcome was dependent on the type of mariculture with AMHs earning four times more than SMHs, which was like the income differences between

Table 1. Factors determining mariculture income generation and the contribution of each to mariculture income inequalitya.

| Variable | Net animal mariculture income | Net seaweed mariculture income |
|----------|-------------------------------|-------------------------------|
|          | Standardized coefficient (Robust S.E.) | Gb | G%c | Standardized coefficient (Robust S.E.) | G | G% |
| Experienced | −0.08 (50.58) | 0.05 | 2.94 | 0.18 (6.43) | 0.05 | 8.59 |
| Varietyf | 0.18 (31.61) | 0.21 | 12.40 | 0.00 (5.63) | 0.00 | 12.0 |
| Human capitalf | 0.02 (34.50) | 0.01 | 0.78 | 0.01 (3.57) | 0.00 | 0.64 |
| Social capitalf | −0.17 (131.18) | 0.06 | 3.60 | −0.12 (6.58) | 0.03 | 4.79 |
| Natural capitalf | 0.24 (256.21) | 0.19 | 11.37 | −0.15 (11.21) | 0.03 | 5.42 |
| Manufactured capitalf | 0.01 (137.17) | 0.01 | 0.54 | 0.43 (25.48) | 0.18 | 27.59 |
| Financial capitalf | 0.16 (117.07) | 0.16 | 9.51 | −0.17 (26.95) | −0.01 | −1.82 |

a Unit of analysis is the mariculture household.
b Absolute contribution to the total G.
c Proportionate contribution to the total G.
d 1—household previously engaged in mariculture (animal or seaweed), 0—households engaged solely in animal or seaweed mariculture from the outset.
e AMHs, 1-household only cultured finfish, 2—households only cultured invertebrates, 3—households cultured both finfish and invertebrates; SMHs, 1—household only cultured porphyra, 2—households cultured laminaria and gracilaria.
f Detailed indicators for the five forms of capital are given in table S4.

*P < 0.05.
**P < 0.01.
Figure 4. Overall and individual satisfaction of mariculture households based on the HWB indices (normalized, 0–100; different letters indicate significant differences, $^*P < 0.05$): (a) differences between animal and seaweed mariculture; (b) differences between animal mariculture groups (finfish, invertebrates, and finfish and invertebrates); (c) differences between seaweed mariculture groups (porphyra, and luminaria/gracilaria).

freshwater and brackish-water aquaculture in Malaysia [54]. Third, high returns are often accompanied by increased risks and AMHs were twice as likely to make a loss compared with SMHs. This finding illustrated the balance between strategies to achieve high profit or a secure livelihood.

4.2. Social impacts of mariculture

4.2.1. Aggravated income inequality

Among all income sources (i.e. mariculture, wages, business, property, transfer and agriculture), mariculture had the highest contribution to income inequality for both AMHs and SMHs in Ningde. However, a study from the Philippines showed that income from aquaculture reduced inequality, accounting for one third of the total household income but 3% of the total G [19]. This finding may be due to differences in mariculture scale at the household level, the magnitude of which was considerably larger for Ningde than the Philippines. Expansion of scale was shown to have the opposite effect on inequality for aquaculture farms of different sizes, reducing inequality for smallholders and increasing inequality effect for large units [55].

The results of inequality decomposition suggested that animal mariculture had a significant unequal distribution of natural capital. More than three quarters (78.5%) of AMHs purchased or leased the sea area for a specific period (the number for SMHs was 17.7%), while the remainder acquired it via inheritance. Leasing can result in the concentration of sea areas among a small number of large operators and an unequitable distribution of resources [15]. The relatively poor AMHs have less access to sea areas and rely on the use of resources where ownership is either ambiguous or undefined and which are regarded as marginal or high-risk. The limited access of the poor AMHs to land and water resources was identified as a key constraint, preventing those sections of rural communities in benefiting from aquaculture as a livelihood option [56, 57]. Meanwhile, private ownership was generally viewed as a prerequisite for the development of an aquaculture industry as exclusive access to tenures provided the necessary incentive for producers to invest in infrastructure [58]. For SMHs, the unequal distribution of manufacturing facilities had a considerable impact on seaweed mariculture income distribution. A substantial portion of manufactured capital consisted of fixed assets (table S8). Aquaculture is often capital intensive, and the ability of farms to provide the capital required for investment in new technologies varies greatly [59]. Previous studies showed that a lack of available capital can impede the adoption of newer, more profitable technologies, especially for the poorer fish farmers who wish to finance the initial capital cost of aquaculture facilities [60, 61].

4.2.2. Disparities in subjective well-being

Our results showed that, compared with SMHs, the higher income AMHs also had higher levels of life satisfaction across all dimensions. Income is
an important measure of individual subjective well-being as the higher levels of consumption enabled by higher income are positively associated with personal utility. Previous studies have indicated that rich people have a substantially higher level of subjective well-being than poor people [62–64]. In addition to absolute income, relative income, i.e., that compared to a reference income, also has a bearing on subjective well-being, as people feel concerned if they are performing less well than their relevant others [65, 66]. Knight et al [67] found that incomes below average significantly decreased rural household happiness in China.

Except for material and security, differences in the well-being indices between AMHs and SMHs were statistically insignificant. On the one hand, this finding highlighted the positive interactions in the multidimensional formulation of HWB. As AMHs generated more income, their ability to purchase basic goods and services for life increased. This increased material well-being could in turn enhance a household’s perception of life and property security. On the other hand, the result was also consistent with the assumption that income inequality had become a significant factor in depressing people’s subjective well-being. Based on the relative deprivation theory, a high inequality generated a relative sense of deprivation and thus reduced subjective well-being [68, 69]. Empirical evidence has also shown that local income inequality has a negative effect on life satisfaction in rural China [70, 71].

4.3. Sustainable development of mariculture at the household level
Revenue from mariculture has made significant contributions to the economy of the local communities. However, the risks associated with limited access to resources and insufficient financial capital have led to increased uncertainty in household profitability [18]. This has resulted in wealth inequality between the different mariculture types and varieties, and individual households. Inequality increases the vulnerability of poor households by constraining their livelihood options when facing external challenges [72]. The well-being gap between AMHs and SMHs revealed the unequal distribution of life satisfaction in the mariculture community, which could lead to further social discontent and should be of note to policy makers.

The rapid development of mariculture in China faces urgent sustainability challenges at the household level. First, secure access and tenure rights should be considered as key elements to promote sustainable development of animal mariculture. While for seaweed mariculture, financial options, such as access to credit from formal intermediaries would enable smallholders to invest in aquaculture activities [73–75]. Second, type and variety diversification is a key strategy that mariculture households could employ to reduce their vulnerability to environmental risks and market volatility [76]. For example, the mariculture of invertebrates and seaweed may be socioeconomically sustainable. Third, studies on different periods and countries have shown that the relationship between income, income inequality, and subjective well-being is complex and differ under socioeconomic conditions [77]. Further research into the effects of changes in these income variables on the subjective well-being of SSA households will assist policy making. Such policies will be key to achieving SDGs, especially those addressing the eradication of poverty, promotion of well-being, reduction in inequality, and sustainable use of marine resources.

5. Conclusion
We used data from a detailed household survey to comprehensively analyzed the profitability, inequality, and subjective well-being conditions of households practicing different types of mariculture in the Ningde marine area of Southeastern China. Overall, animal mariculture was more profitable than seaweed mariculture. AMHs had better subjective well-being condition but also greater income disparities compared with SMHs. In this context, policy interventions implementing equitable access to common resources and providing reliable financial support will assist the development of mariculture by guiding households towards sustainable practices.

Data availability statement
The data that support the findings of this study are available upon reasonable request from the authors.

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Declarations of interest
The authors declare no competing interest.

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