Aquaculture: the missing contributor in the food security agenda

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Abstract

Aquaculture's rapidly increasing contribution to global aquatic food supply is masked by rhetoric on sustainability and international trade. We examine the association of country-level aquaculture production and per capita consumption of aquatic food in 163 countries. We find a positive association between aquaculture production and aquatic food consumption at the national scale where a 1% increase in domestic aquaculture production is associated with a 0.9% increase per capita consumption. The results corroborate previous case studies showing consumption of aquatic food has increased among the poor as domestic aquaculture has expanded. The findings provide important insight to the role of aquaculture in global food security and highlight the significance of advancing aquaculture development in regions with high rates of malnutrition and food insecurity.

Highlights

- Domestic aquatic food consumption is positively associated with aquaculture.
- Aquaculture producers show comparably larger increases in per capita consumption.
- Aquaculture plays an increasing role in aquatic food security.

Keywords: fish farming, fish consumption, poverty, seafood

1. Introduction

Globally, aquaculture is the fastest growing food production system (Garlock et al. 2020). It offers an important means to meet growing food demand and address nutritional deficiencies (Golden et al. 2021; Smith et al. 2010; Filipski and Belton, 2018), and with lower environmental impact than many alternative animal source foods (Gephart et al. 2021; Hilborn et al. 2018; Froehlich et al., 2018; MacLeod et al. 2020). However, suppressed by discourse on sustainability and ocean health (Tlusty et al. 2019; Bogard et al. 2019) and stigmatized as a food destined for the wealthy (Golden et al. 2016; McCauley et al. 2018), aquatic food from aquaculture is often at the periphery of global food security planning and discussions on the future of food (Bennett et al. 2021). Here, we examine the association between country-level aquaculture production and provisioning of aquatic food.

Fish and other aquatic food from marine and freshwater environments are nutrient dense animal source food. Aquatic food is rich in bioavailable micronutrients such as zinc, calcium, and long-chain n-3 polyunsaturated fatty acids, and consumption of aquatic food is critically important for fetal neurocognitive development and adult cardiovascular health (Rimm et al. 2018; Hibbeln et al. 2019; Mohan et al. 2021). Multiple factors influence aquatic food consumption including food production and availability, international trade, wealth, culture, religion, and health consciousness, among others (Govzman et al. 2021). Globally, average per capita consumption is 20.21 kilograms (kg) per year and is increasing although consumption varies considerably by region and country, with many developing countries and small-island states consuming more than double the average per capita. In some Asian countries where wealth, international trade and aquaculture are increasing, per capita consumption is increasing. For instance, consumption of aquatic food in China has more than tripled since 1990, increasing from 11.2 kg per capita per year to 38.0 kg per capita per year in 2018. This development has paralleled growth in aquaculture, and China is currently responsible for about 57% of global aquaculture production and about 35% of global consumption of aquatic food.

Capture fisheries provide a diversity of nutrient-dense aquatic foods that are often culturally preferred and traditionally more accessible in rural and low-income communities (Golden et al. 2021; Hall et al. 2013). Stagnant or declining marine and freshwater catches and the absence of food-oriented fisheries management poses challenges for wild fish for food security in many low-income countries (Youn et al. 2014; Bene, Barange et al. 2015; Bennett et al. 2021). Changes in climate will add further challenges as many of the world's most dependent people live in the tropics where the impacts of rising temperatures will be most severe (Barange et al. 2018; Pincinato, Asche and Oglend 2020; Maire et al. 2021). New recommendations by EAT-Lancet Commission suggests a healthy diet includes 28g of fish and aquatic food per day, which, if met, would require a substantial increase in supply, and rising prices for aquatic food are already indicative of high demand (Willet et al. 2019; Tveteras et al. 2012). Improved governance of fisheries resources is not expected to substantially increase global supply of aquatic food although reductions in food waste may have a marginally larger impact (Love et al. 2015).

Aquaculture is a promising path to meeting the demand gap for aquatic food (Costello et al. 2020). Aquaculture has more than doubled the availability of aquatic food in the past three decades, growing from 13.1 million mt in 1990 to 82.1 million mt in 2018[1], and continued growth is almost certain (Kobayashi et al. 2015). Growth in aquaculture production has been unevenly distributed, and developing countries dominate global production as they have participated in the blue revolution to a much greater extent than the developed world (Garlock et

[1] Excludes aquatic plants.

al. 2020). The largest aquaculture producing countries are in Asia, and countries in this region have shown the largest increases in per capita consumption of aquatic food since 1990 (Figure 1).

The contribution of aquaculture to the diets of the Global South have been intensely debated (Beveridge et al. 2013; Bene et al. 2016; Belton et al. 2018; Golden et al. 2016; Golden et al. 2017; Belton et al. 2020). Trade of aquatic food has increased rapidly in parallel to the expansion of aquaculture (Anderson et al. 2018; Gephart and Pace 2015), and this has led to aquaculture being portrayed by some as a capital-intensive production practice oriented towards high-value or luxury species that are exported, reducing local access to fish among the world's poorest populations (Golden et al. 2016; Smith et al. 2010). Belton, Bush and Little (2018) challenge the narrative that aquaculture supports wealthy consumers and provide evidence that aquaculture facilitates access to aquatic food among low and middle classes in the ten largest developing country producers and show that aquaculture has a lower export share and is priced lower than capture fisheries. Toufique and Belton (2014) show farming of inexpensive freshwater fish facilitates greater accessibility and affordability of aquatic food to poorer segments of societies in Bangladesh. Garlock et al. (2020) show that the three largest aquaculture producing countries are among the world's four most populated countries, with the U.S. as the exception, which also supports the notion that aquaculture provides food domestically. In this paper, we contribute to this literature by examining the association of country-level aquaculture production and aquatic food consumption in 163 countries.

2. Methods

2.1 Analysis

We examine temporal trends in average per capita consumption of aquatic food by two types of production level: absolute production and production per capita. We also examine per capita consumption, per capita fisheries production, and per capita aquaculture production by region and period. We employ regression analyses to examine the association of within country aquaculture production and apparent per capita consumption of aquatic food in 163 countries. We estimate two models, and the dependent variable in both is defined as national apparent per capita consumption of aquatic food. In the first model, aquaculture production is defined by a continuous variable *Aqua*, which is aquaculture production in metric tons in a given country in a given year when an aquaculture industry exists (i.e., production is greater than 10,000 mt). We specified the regression model as:

$$\ln(y_{ct}) = \beta_0 + \beta_1(\ln(Aqua_{ct} + 1)) + \alpha_c + \theta_t + X_{ct} \quad (1)$$

where *y* is per capita consumption of aquatic food, θ is the year fixed effects, α is the country fixed effects, and *X* is the covariates for country *c* at time *t*.

In the second model, a time trend dummy *T* is interacted with a treatment dummy *Treat* and coefficients are estimated for each period relative to the treatment onset similar to Sun and Abraham (2021). This model is specified as:

$$\log(y_{ct}) = \beta_0 + \beta(T * Treat_c) + \theta_t + X_{ct} \quad (2)$$

where *Treat* is a dummy variable that is equal to 1 if the country *c* is in the treatment group and 0 if in the control group, and *T* is a time trend dummy that is zero in the year the treatment begins, +1, +2, +3, and so forth in years following the treatment onset and -1,-2,-3, and so forth in years preceding the treatment onset. The treated group was defined as a given country in a given year with aquaculture production above a threshold of 10,000 metric tons. Countries having production less than 10,000 metric tons (where most have zero production during the whole time series available) served as the control group.

2.2 Data

We use apparent per capita consumption of aquatic food in kg/capita/year from 1975 to 2018 from the United Nation's Food and Agriculture Organization (FAO) as the dependent variable in our models. Data are accessible at fao.org/faostat/en/#home. National annual aquaculture production from FAO (accessible at http://www.fao.org/fishery/statistics/software/fishstatj/en) was used as an explanatory variable. Gross domestic product (in 2010 USD) and population estimates were obtained from the World Bank (World Bank, Accessed 10/28/19) and FAO (FAO STAT Accessed, 10/28/19), respectively, and included in the model as covariates. Sensitivity of the models to China's aquaculture production were explored. The statistical inference did not change when Chinese production was excluded from the analysis, and there were only minor quantitative differences in the coefficients. All analyses were conducted using R software.

3. Results

Aquaculture's contribution to maintaining aquatic food in the diets of developing countries may be more prominent than previously understood. We find a positive association between aquaculture production and aquatic food consumption at the national scale. Countries that have developed aquaculture industries (i.e., production >10,000 mt) show higher per capita consumption of aquatic food, and countries with higher aquaculture production per capita show comparably larger increases in per capita consumption between 1975 and 2018 (Figure 2). On average, countries with per capita aquaculture production below 0.09 mt/1000 persons have no clear trend in per capita consumption between 1975 and 2018, and countries with per capita aquaculture production between 0.09 and 2.9 mt/1000 persons show a comparably larger increase in per capita consumption over the period despite having lower per capita consumption throughout. This is indicative of the fact that in some countries demand for aquatic food can be supplied by provisioning of capture fisheries and/or imports of aquatic food and thus making aquaculture unnecessary.

Per capita consumption of aquatic food varies by region with wealthier regions showing higher per capita consumption (Figure 3). Asia has the largest increase in per capita consumption between 1990 and 2018 and also has the largest increase in aquaculture production per capita. All regions apart from Northern America and the Caribbean show increases in per capita consumption, and notably Northern America and the Caribbean are also the only regions that do not have increases in aquaculture production per capita. Fisheries production per capita is steady or decreasing for all regions with the largest decline occurring in South America. The decline in fisheries production per capita in South America is, to a large extent, driven by the declining production of reduction fisheries, and this combined with increasing aquaculture production per capita has yielded a slight increase in per capita consumption.

Our model estimates that a 1% increase in domestic aquaculture production is associated with a 0.9% increase per capita consumption (Table 1). The positive association of aquaculture production and aquatic food consumption shows that the results of studies in individual countries, such as Toufique and Belton (2014), Belton et al. (2018b), and Dey et al. (2005) which find that consumption of inexpensive farmed fish has increased among the poor as local aquaculture has rapidly expanded, are generalizable. The model results also indicate that per capita fish consumption is larger in less populated countries and wealthy countries. While this is seemingly intuitive, it is also interesting to point out that there are several exceptions such as in the case of China, the world's most populous country, which has high per capita consumption of about 30 kg per capita, and Indonesia, the fourth most populous country, which has also high per capita consumption at 44 kg per capita (2018).

We examine the association of aquaculture and domestic aquatic food consumption through time and find that the association is positive and increases through time (Figure 4). This is consistent with studies showing production of many farmed species, once produced in sufficiently large quantities, will stabilize or drive down fish prices (Tveterås et al. 2012; Belton, Bush and Little 2018), both of which contribute to increased accessibility of aquatic food among the poor.

4. Discussion

Discourses on aquaculture is often critical of its potential to improve local access to fish and food security among the poor (Golden et al. 2017), and capture fisheries are perceived to better serve the poor segments of society given the natural provisioning of capture fisheries has traditionally provided a relatively inexpensive and easily accessible source of aquatic food (Belton and Thilsted 2014). This paper contributes to an emerging literature that indicates this narrative in general is not true (Belton, Bush and Little 2018; Gephart et al. 2020). We show that aquaculture production is positively associated to aquatic food consumption at the national scale, and the association is strongest in the long-term as production increases and enables greater access to aquatic food at lower costs (Asche et al. 2009; Tveteras et al. 2012; Belton and Thilsted 2014).

The increase in international trade of aquatic food is generally believed to weaken the importance on where aquatic food is produced. For instance, many wealthy countries, such as the US and UK, import substantial quantities of farmed aquatic food, which may compensate for the lack of domestic aquaculture production (Shamshak et al. 2019). However, our results suggest that where aquaculture production occurs is important for increasing aquatic food availability at the national level. This is perhaps because non-producing developing countries lack the logistics and transportation infrastructure to import aquatic food and/or are unable to pay higher international prices. The latter is consistent with Anderson et al. (2018) who show that most highly traded aquatic food are also high-value commodities such as shrimp and salmon.

Research on factors driving adoption of aquaculture has generally focused on country-level, regional or local case studies (Ruff et al. 2020). In some countries, aquaculture development may be driven by export-oriented demand such as in the case of US markets for Chilean salmon (Salazar and Dresdner 2021). In other countries, aquaculture growth is driven by domestic demand for aquatic food (Belton and Little 2011; Belton et al. 2018b). Demand for aquatic food is influenced by population, culture, religion, and wealth, among other factors, and the abundance of capture fisheries and trade of aquatic food can satisfy varying degrees of aquatic food demand (Naylor et al. 2021). Technical and governance considerations also influence aquaculture development such as biophysical factors, infrastructure, capital, and policy (Bostock et al. 2010; Engle and Stone 2013). Increasing urban domestic demand and infrastructure development have been important factors for aquaculture growth in Asia (Belton and Little 2011), whereas in developed countries it is often suggested that regulatory policies have constrained development of aquaculture (Abate et al. 2016; Engle and Stone 2013).

Aquaculture will be pivotal in global efforts to shift to more environmentally sustainable diets and simultaneously achieving food security goals. Fished aquatic food production is stagnant and distributional shifts in fish stocks resulting from climate change will reduce capacity for fisheries to contribute to future aquatic food security in tropical, low-income nations (Lotze et al. 2019). Advancing aquaculture in regions with high rates of malnutrition and food insecurity, such as sub-Saharan Africa where aquaculture is limited, is important for maintaining and improving access to aquatic food (Chan et al. 2019; Golden et al. 2016; Koehn et al. 2021).

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Figure captions

Figure 1. Difference in per capita aquatic food consumption (kg/year) between 1990 and 2018.

Figure 2. Mean annual per capita consumption of aquatic food (kg) by (a) aquaculture production (MT in 2018) and (b) aquaculture production per capita (MT/1,000 persons in 2018).

Figure 3. Per capita aquatic food consumption (kg/year), per capita fisheries production (mt/1000 persons), and per capita aquaculture production (mt/1000 persons) by region and period.

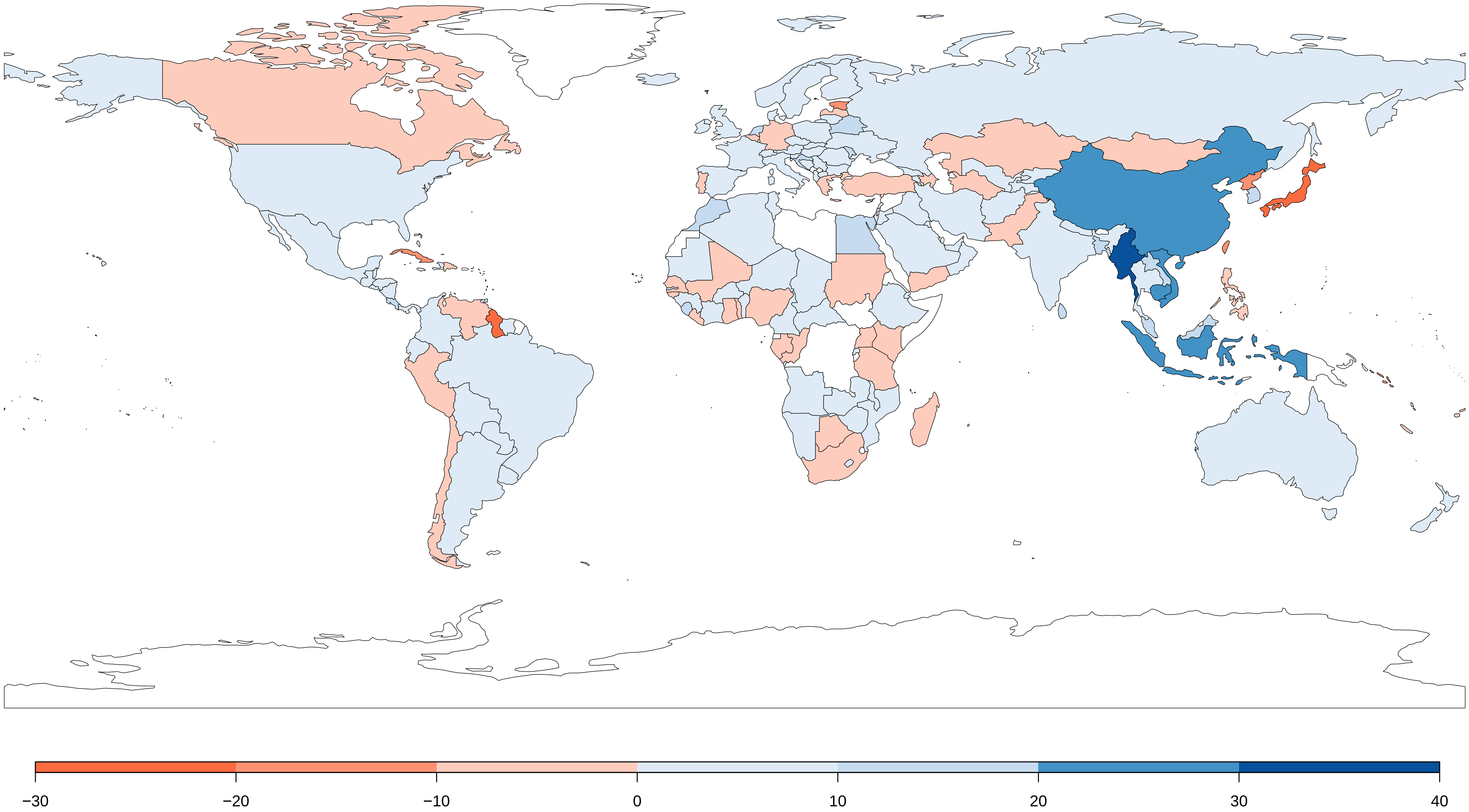
Figure 4. Estimated relationship per capita aquatic food consumption and aquaculture production. Black points indicate no significance, orange points indicate significance at 0.05, and red points indicate significance at 0.001. A time of zero indicates the year in which the treatment begins (i.e., aquaculture production exceeds 10,000 metric tons).

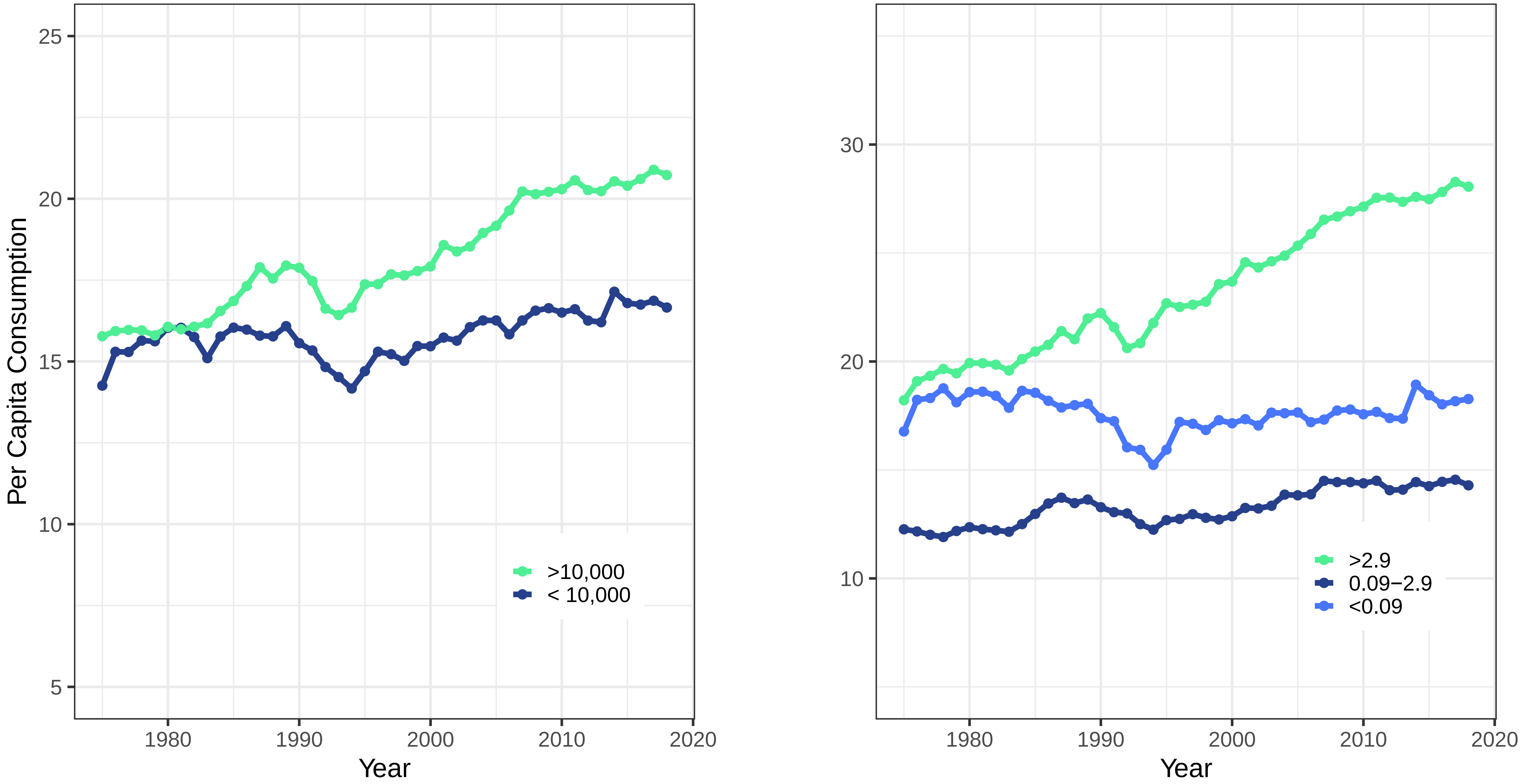
Tables

Table 1. Difference-in-differences estimation.

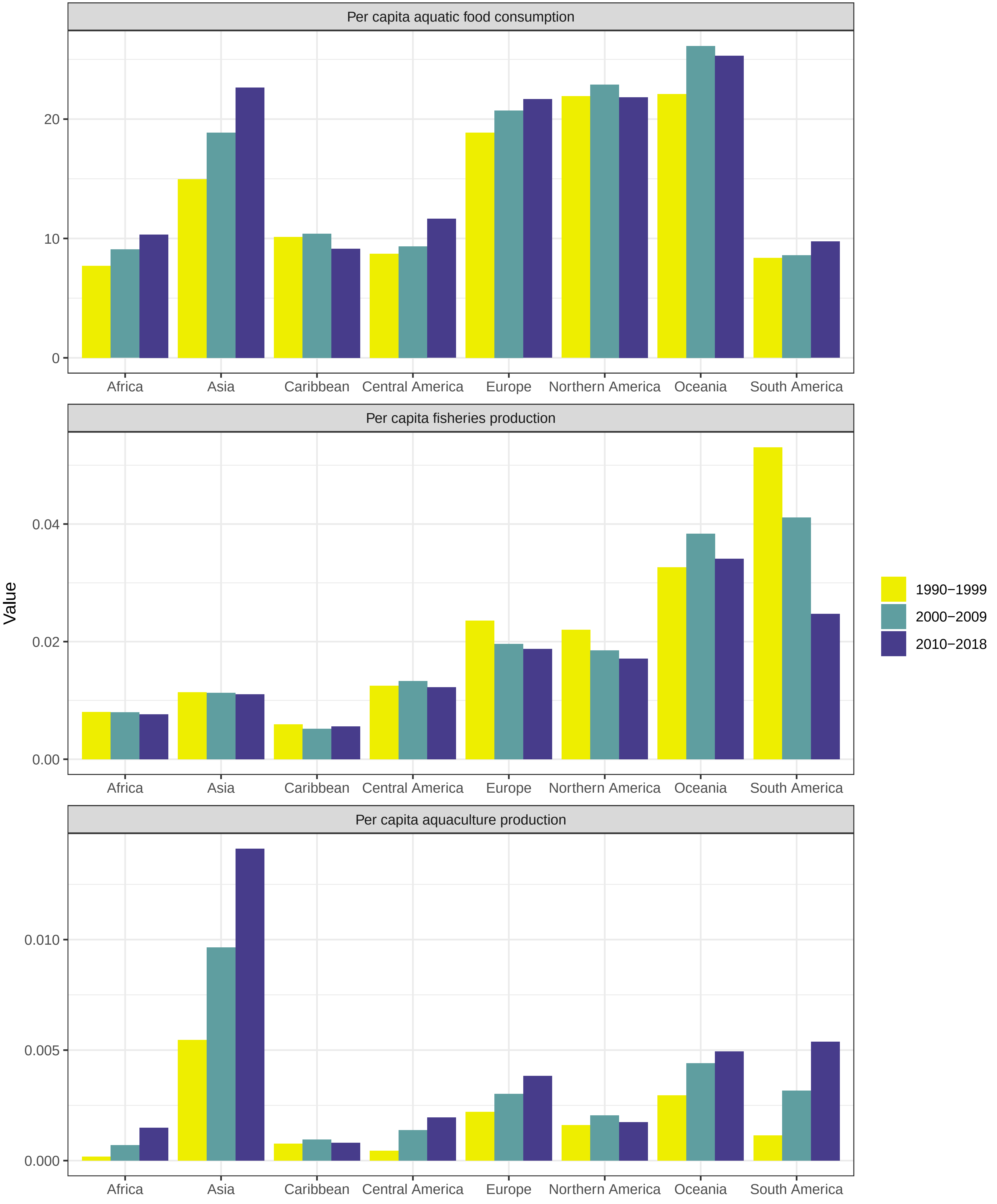
	Estimation
Intercept	-12.890 (<0.001)***
ln Population	-0.281 (<0.001) ***
ln GDP	0.573 (<0.001)***
β_1	0.009 (<0.001)***
R^2	0.905
N	6005

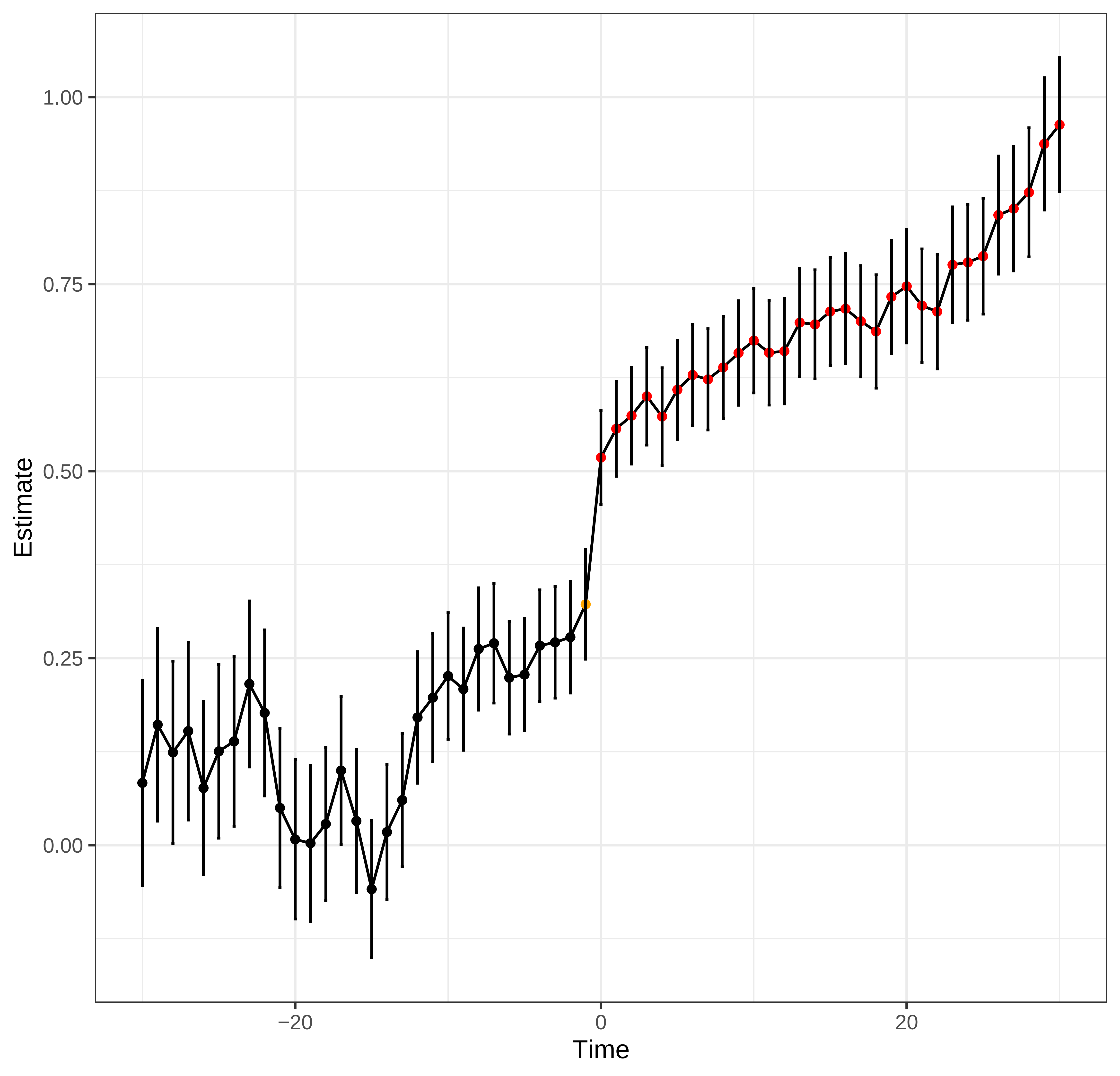
Standard errors are in parentheses.
***Statistically significant at the 0.001 level, ** 0.01 level and *0.05 level.


−30
−20
−10
0
10
20
30
40



Per Capita Consumption
25
20
15
10
5
1980
1990
2000
2010
2020
Year
>10,000
< 10,000
30
20
10
1980
1990
2000
2010
2020
Year
>2.9
0.09−2.9
<0.09


Per capita aquatic food consumption
Per capita fisheries production
Per capita aquaculture production
Value
0
10
20
0.00
0.02
0.04
0.000
0.005
0.010
Africa
Asia
Caribbean
Central America
Europe
Northern America
Oceania
South America
1990−1999
2000−2009
2010−2018



1.00
0.75
0.50
0.25
0.00
Estimate
−20
0
20
Time