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Research paper

Disentangling economic, social, and environmental drivers of coral-reef fish trade in Micronesia

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ABSTRACT

Fisheries represent a fundamental resource linking social and ecological systems. Yet, unsustainable fishing regimes prevail across many tropical regions as a result of growing consumer demand and market expansion. Using the extensive reef-fish trade between Chuuk and Guam (Micronesia) as a case study, we examined 12 years of commercial reef-fish export data to capture both inter-annual and intra-annual trends. Reef-fish exports from Chuuk increased steadily between 2003 and 2010 fueled by increasing demand on Guam, but declined sharply from 2010 to 2014 as export costs grew and profit margins were reduced. Intra-annual examinations furthered that low winds and new moon periods were the strongest drivers of daily exports during the initial years of the study, but the governmental disbursement of food-stamp allowances on Guam became the strongest driver in later years when profit margins were lower. Seasonal cycles were also influential, as exports within each year peaked during the Catholic lent season. In sum, the Chuuk-Guam reef-fish trade industry became increasingly dependent on opportunistic demand from Guam, while environmental regimes evolved to become secondary drivers of export volume. The ability to meet foreign demand may suggest a sustainable fishery in Chuuk, however, mounting evidence suggests that consistent supply to international markets masks growing, unsustainable harvesting regimes. Dwindling profits may lead to instability in Guam's fresh reef-fish trade industry, and also suggested uncertain futures for Chuuk fishers, Guam retailers, and a society dependent on healthy protein. We last compared the sequential expansion of Guam's reef-fish acquisition footprint across the Indo-Pacific with expansions reported for the Hong Kong live reef food fish trade industry, highlighting the growing impacts of population centers on small-scale coral-reef fisheries as markets globalize.

1. Introduction

Coral-reef-fisheries are estimated to provide nearly $6 billion USD in net benefits to the world annually, while supporting the livelihood of over 6 million fishers (Cesar et al., 2003; Teh et al., 2013). However, the socioeconomic reliance on coral reefs is not distributed equally (Donner and Potere 2007), as many developing nations have limited opportunities for alternative livelihoods beyond reef-related tourism and fishing. While subsistence fishing by early settlers may have had limited ecosystem impacts on coral reefs, recent socioeconomic and technological advances now facilitate unsustainable fishing regimes across most tropical regions, with ensuing impacts to coral-reef and socioeconomic resilience (Newton et al., 2007; McClanahan et al., 2011). The status of fisheries has generally been linked with human population density (Mora 2008; Williams et al., 2011), but growing evidence points towards exogenous market drivers as well (Maire et al., 2016; Cinner et al., 2016). Yet, exogenous forces represent a suite of social, biological, and environmental factors, and disentangling these factors remains a priority for understanding and managing coastal fisheries (Berkes et al., 2006; Cinner et al., 2009).

Worldwide demand for fresh fish coupled with improvements to refrigeration and transportation have resulted in the expansion of fishing footprints to remote areas, previously non-targeted for commercial purposes (Birkeland 2004; Swartz et al., 2010). For coral reefs, evidence generally supports the concept that increased urbanization coincides with unsustainable fishing pressure on nearby reefs initially, followed by expansions to remote areas that remain within the range of commercial markets (Sadovy et al., 2003; Aswani and Sabetian 2010). The impacts of fisheries expansions are now evident, with distance from commercial markets predicting significant amounts of variation in fish biomass at local and global scales, yet consistent supply to markets may dilute or mask some of these impacts (Brewer et al., 2009; Cinner et al., 2012; Maire et al., 2016; Crona, 2016). One major concern is that expansions lead to reduced profitability as transportation costs increase. Fishers must increase their catches to maintain a steady income because the market value of fish usually does not keep up with the harvesting

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costs (Sumaila et al., 2007; Hicks et al., 2014), and transportation costs are subject to the steady rise in oil costs. Thus, a negative, self-reinforcing system emerges, whereby less fish are available to provide food and key ecosystem functions, and more expenses are required to maintain consistent fisher profits (Birkeland 2004). Other potential socioeconomic impacts of expanding reef-fisheries include the demise of customary systems, compromised food security, increased conflicts among fisheries stakeholders, and rising levels of debt among fishers (McClanahan et al., 2008; Cinner, 2014; Crona, 2016). In the end, a better appreciation of how economics, local demand, and environment factors interactively drive fisheries is required to address the negative impacts of fisheries expansions. However, standardized monitoring programs that capture fisheries statistics remain lacking or limited in quality for most tropical regions (Pauly and Zeller 2014), creating a situation where novel approaches are often required to uncover datasets that can help describe fishery dynamics (Van Houtan et al., 2013; Cuetos-Bueno and Houk, 2014; Pauly and Zeller 2016).

Exogenous drivers of small-scale fisheries are often complex and contextualized with local settings. Examples include fishing bans during Sabbath days in Fiji and Solomon Islands (Cooke et al., 2000; Molea and Vuki 2008), seasonal peaks of demand/landings during Lent and Christmas in Hawaii and Saipan (Pooley 1987; Cuetos-Bueno and Houk, 2014), and Ramadan in Tanzania and Bangladesh (Davies and Jaddawi 2006; Aktar et al., 2013), and the fall of fish prices following relaxation of Catholic fasting rules in USA (Bell 1968). Other cases that reflect the complexity of fisheries include consumer preferences that shifted size-selective fishing in Mexico (Reddy et al., 2013), mobile phone connectivity in India that sparked seafood market chains (Abraham 2006), and road development in Nicaragua that stabilized fish prices (Schmitt and Kramer 2010). Regardless of the inherent complexity of small-scale fisheries, catch-based data provide an opportunity to distill trends with respect to exogenous drivers, and provide guidance to better maintain socioeconomic and ecological resilience.

In Micronesia, growing human populations, Westernization, and the emergence of monetary economies have led to compromised coral-reef-fisheries, especially in the most populated islands of Saipan (Houk et al., 2012; Cuetos-Bueno and Houk, 2014; Houk et al., 2014; Smith and Marx, 2016) and Guam (Houk et al., 2012; Lindfield, 2015; Martin et al., 2015). These jurisdictions rely upon imports from nearby islands to meet commercial reef-fish demand (Zeller et al., 2007; Smith and Marx, 2016), similar to other places in the tropical Pacific (Craig et al., 1993; Brewer et al., 2009). Using the extensive trade between Chuuk and Guam as a case study, we examined multi-year trends, seasonal dynamics, and social and ecological impacts of the commercial reef-fish trade. We first uncovered novel export records to highlight the economic value and temporal trends in reef-fish trade over 13 years. We then show how environmental and socioeconomic factors combined, and evolved, to drive export patterns across. Finally, we place the rapid expansion and decline of reef-fish exports from Chuuk to Guam within the context of consumer demand and economic profitability. The findings serve to assess and forecast ecological and socioeconomic consequences for both Chuuk and Guam, offering an improved appreciation for the complexity of local coral-reef-fisheries alongside increasingly globalized markets.

2. Materials and methods

2.1. Study area

This study explored coral-reef-fish trade between Chuuk, Federated States of Micronesia, and the United States Territory of Guam (Fig. 1). Guam is the main population center in Micronesia with over 159,000 residents and over 1.3 million visitors every year (US Census 2010; Guam Visitors Bureau 2014). Coral-reef fisheries have historically played a key nutritional and cultural role in Guam while balancing sustainable harvesting with subsistence needs (Amesbury and Hunter-Anderson, 2003). Diminished fishing success and the current overfished state of reef-fish assemblages in Guam are generally attributed to the relatively small reef area of Guam coupled with a large growth in human population and technological advances (Taylor et al., 2014; Lindfield et al., 2015). Evidence suggests that Guam's reef-fisheries production has been insufficient to fulfill growing demand, resulting in a growing reliance upon imports since the 1960s (Johannes 1981; Myers et al., 1983). Currently, nearly 1/3 of Guam's population participates on the US Department of Agriculture Supplemental Nutrition Program (hereafter SNAP), which provides nutritional assistance to low-income individuals and families through monthly disbursements that can be used at local retail stores for food or other essential commodities. SNAP recipients are believed to account for an important proportion of reef-fish demand in Guam, but no data are available to quantify their contribution.

In contrast with Guam, Chuuk, Federated States of Micronesia, is comprised of an extensive lagoon system with over 2000 km^2 of reef habitat. Chuuk reef-fish assemblages are some of the healthiest in Micronesia (Houk et al., 2016). Yet, striking gradients in fish biomass exist, as reefs near population centers have among the lowest fish biomass reported in Micronesia, while sites near the barrier reef have some of the highest (Houk et al., 2015). Fisheries expansion in Chuuk has been fueled by low employment rates (< 9%; FSM SD, 2014), highly unregulated fisheries, and a governmental distribution of fiberglass motorized boats in the 1980–90s that were provided to increase fishing capacity and commercialization. Chuuk has provided reef-fish to Guam through regular flights four times per week for the past decades. In addition to commercial exports to Guam, limited non-commercial exports to Guam, Hawaii, and mainland USA also exist, along with reported but unquantified commercial exports to Asia by live reef food fish trade operations.

2.2. Data collection and processing

2.2.1. Export data

Hard-copies of bills-of-shipping associated with commercial flights between Chuuk and Guam were collected and stored by Chuuk Office of Food Safety. Records from 2003 to 2014 were available at the time of this study, yielding 1554 reports of overall daily reef-fish exports over the twelve-year period that were digitized into an electronic database. Limited data from 2015 (January-July) were available at the time of this study, but used for preliminary estimates of 2015 exports. For analysis other than estimation of overall exports, and prior to analyses, data were cleaned and standardized using the following criteria.

1) Only export data from Tuesday, Thursday, and Saturday flights were used because commercial fishing rarely occurred on other days.
2) Extreme values of total daily exports were considered outliers, potentially due to errors in reporting (> 3 SD above the mean, 0.8% of the data).
3) To focus on understanding how lunar periods, windspeeds, and Guam's monthly SNAP program may have driven export trends, daily records were standardized within each individual month as the percentage difference between daily exports and the monthly mean. To minimize potential issues associated with months of limited daily exports values when standardizing daily exports, months with less than six records of daily exports were excluded from further analysis (6% of months; and 2.5% of the data).
4) In order to assess inter-annual seasonal trends, mean daily exports for each month were standardized within each individual year as the percentage difference between each monthly mean and the corresponding yearly mean.

2.2.2. Environmental data

Daily windspeeds were collected from readings taken at Weno Airport, Chuuk (http://www.ncdc.noaa.gov/cdo-web/; *last visited*

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