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Local, Global, Multi-Level: Market Structure and Multi-Species Fishery Dynamics

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ABSTRACT

Price and market structures in fisheries change rapidly, now 40% of seafood is traded internationally and are associated with overharvesting of marine species. We have developed a bio-economic fishery model to address the pressing need of managing the interplay of different markets. We first regard local, multi-level and global markets individually and then analyze the effect of transitioning between markets on the exploitation of species and the stability of income. We find that in gradually globalizing markets, transition management needs to account for non-linear price changes since earlier policies may not be suitable after globalization. We hypothesize that short-term policies to ban harvest in the interest of species recovery benefit a local market in which incentives prevent overharvesting. In global markets we expect that sustained initiatives are needed to prevent overharvesting. Individual fisheries using contextualized models representing local ecological and trade structures may benefit from assessing the price dynamics presented in this analysis.

1. Introduction

To meet increasing global demand, seafood operations are likely to have to intensify efforts in existing fishing locations and expand to previously unexploited species and areas. Seafood and fish are the highest globally integrated food commodity traded at 40% internationally (FAO, 2017). Additionally, over 60% of fish stocks worldwide are fully exploited and approximately 30% are overexploited (FAO, 2014). Over the past century, many global fisheries have expanded, following patterns of serial exploitation to new areas and species (Anderson et al., 2011b; Berkes et al., 2006; Crona et al., 2015). Such expansions may show sustainable exploitation or local boom and bust cycles where a population is extracted until the population collapses and fishing either halts or continues at a much smaller rate (Anderson et al., 2011a,b). Local fishers often substitute collapsed species with alternative target species (Foley et al., 2011) and traders develop new supply markets as a result (Eriksson et al., 2015; Sethi et al., 2010). The expansion to new target species and areas is facilitated by the rapidly increasing number of trade relations (Cash et al., 2006; Gephart and Pace, 2015).

Recent articles recognize the importance of price structure and market characteristics to critical changes in fisheries (Burgess et al., 2017; Fryxell et al., 2017). Globalizing market structures can directly affect prices, supply channels, and investments in processing capacities (Dreher, 2006; Fujita and Thisse, 2006; Liu et al., 2013; Rogoff, 2003). Overexploitation of fisheries is often connected to this emergence of export markets (Barnes, 2002; Berkes et al., 2006; Crona et al., 2016; Eriksson et al., 2015). Béné et al. (2010) find that fishing livelihood strategies are highly vulnerable to changes and the collapse of fish populations increases this vulnerability. Fishers access to multiple fish populations is key to a stable income and thus we will pay special attention to the changes induced in prices from local to global markets in a multi-species fishery.

Changes in market structure are associated with the emergence of export markets, increasing globalization of supply chains, and the dynamics between local supply and global market demand. We hypothesize that these may be key factors affecting fishery dynamics in the exploitation of target populations. We refer to a change in market structure as the development of new trade connections, such as when a buyer from the international market connects to a local fishery. Global, local and multi-level markets are defined by their price structures as described in Section 2.3.1. We explore the the effects of market structure on fishery dynamics in the following research questions:

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- How do the different price structures that characterize local, multi-level and global markets affect fisher income and fish populations in a multi-species fishery?
- Under which conditions does a change in market structure i.e. from local to multi-level market, lead to a serial collapse of fish populations?

The most widely used bio-economic models in fisheries research often depict the market side as a single lumped parameter, i.e. price and cost (Béné and Tewfik, 2001; Gordon, 1954; Sanchirico and Wilen, 1999). Models that assume a constant market price began with the Gordon-Schaefer model (Gordon, 1954) and spread into further work. This price structure has been employed to describe the rise and fall of multi-species fisheries (Chaudhuri, 1986), necessary bio-economic conditions for extinction (Berck, 1979), and exploitation in a trophic system (Wilen and Wilen, 2012).

The majority of current models do not take into account the complexity of price and market structures. Complexity in the social networks of fisheries commercialization systematically affects the “law of one price” (Graddy, 1995; Härdle and Kirman, 1995). The “law of one price” assumes the fisher to be a price taker. Here we assume that the fisher can choose between markets and thus seek to maximize their income. The price-taking assumption is prevalent in the theoretical literature, however differences in prices are widely empirically observed (Graddy and Hall, 2011; Kirman and Vriend, 2001). These differences have been associated with limited price information and diverse buyer-seller relationships (Jensen, 2007; Kirman and Vriend, 2001).

We aim to provide a systematic analysis of several market structures, represented by differences in price structure. First, we investigate how fishers' commercialization strategy impacts the equilibrium of the fish population and the stability of fisher income. Ultimately, we introduce a switching function allowing fishers to choose between the two species to explore simple patterns of serial exploitation between species.

2. Model

2.1. Fish Populations

We employ a logistic population model and harvest function which allows us to focus on the effect of market structure. In order to isolate the influence of market structure we do not include specific ecological details such as direct or indirect competition between the species, environmental fluctuations, or size- and age-structure of the fish populations. In the second part of the analysis involving switching functions, we use the analogous discrete time model instead of the continuous one. This implies a single annual reproductive rhythm that guides the time steps of all other processes.

The continuous time equations for fish populations are

$$\frac{dN_i}{dt} = r_i N_i\left(\frac{K_i - N_i}{K_i}\right) - C_i;\ N_i \geq 0 \quad (1)$$

and the analogous discrete time system is

$$N_i(t+1) = N_i(t) + r_i N_i(t)\left(\frac{K_i - N_i(t)}{K_i}\right) - C_i(t);\ N_i \geq 0 \quad (2)$$

N_i denotes the biomass of i fish populations, r_i is the per capita growth rate, and K_i the carrying capacity of the ecosystem for fish species i. The harvest of the two species of fish, C_i, depends on a catchability factor representing gear efficiency. This factor is linear in total effort and population biomass following common bio-economic models. We consider two archetypical species types, r- and K-strategist, because the interaction of life history characteristics has a strong effect on the response of a species to fishing pressure (Adams, 1980). A K-strategist typically has high carrying capacity and low growth rate and a r-strategist has low carrying capacity and high growth rates. These different life-history strategies are associated with the resilience of species to harvesting pressure; r-strategist species generally show higher resilience. In the individual steps of analysis we specify access and decision making.

$$C_K(t) = N_K(t) E q_K L \quad (3)$$

$$C_r(t) = N_r(t) E q_r (1 - L) \quad (4)$$

The parameter E determines effort, which is a measure of the amount of input in the fishing activity. Overall effort is fixed $E\epsilon[0,1]$. Catchability, $q_i \in [0,1]$, is the fraction of fish that are caught encountered by a fisher. The parameter $L \in [0,1]$ is the fraction of effort allocated to species K. Thus, $1 - L$ is the remaining effort allocated to species r. We assume that the fisher catches only two species that are both available year round.

2.2. Market Prices

Fishers' commercialization strategy is driven by the prices from two alternative markets. As in many real fisheries, species are demanded from different markets as a result of price, consumer preferences, and logistics costs (Estrin et al., 2008). The fisher sells to the two markets in a profit-maximizing manner. We do not take into account supply chain and social dynamics, which are themselves a worthy topic of investigation. The fisher is directly linked to the respective markets. Elasticity of demand, defined as $\varepsilon = \frac{dC_i}{dP_i}\frac{P_i}{C_i}$, underlies the price functions and thus the difference in markets (Estrin et al., 2008). Andreyeva et al. (2010) have gathered literature values for the price elasticity of fish, with a mean of $\epsilon = 0.5$ and a confidence interval of $\epsilon = 0.3 - 0.69$. We assume the global market price to be constant.

$$P_{ig} = p \quad (5)$$

The elasticity of this function is $\epsilon = 0$. Since demand is perfectly inelastic, price does not change when catch quantity changes. As a result, revenue increases linearly (see Fig. 1b). Highly inelastic, linear demand functions have been found for salmon, tuna, northern lobster, and lake trout in the U.S. fishery market (Nash and Bell, 1969).

The local market is characterized by decreasing returns to scale. Demand is saturated as more fish is sold to the local market and as a result the price decreases. This behavior replicates small volume markets, such as local markets or limited demand international markets. The latter is usually associated with high value species (Eriksson and Byrne, 2015). For species i, the price (P_{il}) is described by an exponential function. For analytical tractability, we use an exponential function that is inverse to the empirically observed log behavior for a number of marine traded species, such as haddock, cod, flounder, whiting, bluefish, mackerel and scallops (Nash and Bell, 1969).

$$P_{il} = d_i e^{-\beta_i C_i} \quad (6)$$

d_i is the price for the first fish sold on the local market. As more of the catch C_i is sold, the parameter β_i determines the lowest price per unit of fish. We assume that there is no species interaction and that both species are not substitutable. Thus prices are independent. The local market P_{il} has an elasticity of $\varepsilon = \frac{1}{\ln\left(\frac{p}{d}\right)}$. This is an elastic demand curve when $d_i < P_{il} < d_i e$ and inelastic when either $0 < P_{il} < d_i$ or $P_{il} > d_i e$. The multi-level market structure has two sales channels to the local and the global market in which we assume perfect price discrimination (see Fig. 1a for the corresponding price volume relationship). If price declines with catch and the global price is less than d_i, the inequality $0 < P_{il} < d_i$ always holds and the curve of the multi-level market is always inelastic.