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Stability of cooperative management of the Pacific sardine fishery under climate variability

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ABSTRACT

Asymmetry in transboundary fish stock distribution caused by climate variability can make the stability of cooperative management challenging. Pacific sardine (*Sardinops sagax*), which exhibits extreme decadal variability in abundance and geographic distribution corresponding to water temperature regime shifts within the California Current Ecosystem, is expected to face such issues. Pacific sardine is a transboundary resource targeted by Mexican, U.S. and Canadian fisheries. Our study applies a three-agent game theoretic model that incorporates environmental effects on Pacific sardine abundance and biomass distribution. Simulations are conducted to evaluate the stability of full and partial cooperative management of the Pacific sardine fishery, under seven different climate variability scenarios. Our results show that ocean climate variability could motivate the formation of stable cooperative management outcomes for the Pacific sardine fisheries operated by Canada, the U.S. and Mexico.

1. Introduction

The Pacific sardine stock (*Sardinops sagax*) inhabiting the California Current Ecosystem (CCE) is a transboundary stock, currently inhabiting the exclusive economic zones (EEZ) of Mexico, the U.S. and Canada. The stock is fished and managed independently by each country; an arrangement that has worked reasonably well under recent conditions where sardines have been relatively abundant in the CCE. The robustness of the sardine stock in the CCE is considered strongly influenced by climate variability which effects both its abundance and its geographic range [1–3]. These effects are primarily associated with water temperature where above average water temperature in the CCE increases the abundance of Pacific sardine and causes a distributional shift in biomass that spans the Pacific coasts of Mexico, the U.S. and Canada. Conversely, cold water decreases the abundance of the Pacific sardine stock and reduces its distribution to almost exclusively off southern California, the U.S. and Baja California, Mexico. Accordingly, the current, above average water temperature in the CCE is at least partly the reason for increased sardine abundance in Canada's EEZ and reduced abundance in Mexico's EEZ. Of particular concern in this regard is a long term, decadal scale water temperature regime shift in the CCE where a seemingly permanent zonal redistribution of the sardine stock has significant implications in terms of transboundary sharing arrangements of the stock.

Because the availability of the sardine stock in each country's EEZ is related to climate change, the relevant questions to ask are: (i) will cooperative management of sardine stocks result in economic and biological gains to all three countries, and (ii) will cooperative management solutions be stable in the face of climate change? The literature on shared stocks has shown rather convincingly that non-cooperative fisheries conservation and management (from here on simply management) of shared stocks leads to outcomes that are biologically and economically undesirable, due to negative dynamic externalities [4]. Ishimura et al. [5] developed a game theoretical model to investigate the first question as to whether or not cooperative management would lead to an overall improvement in biological and economic benefits. In this contribution, this study addresses the second question of whether and under what conditions cooperative management outcomes may be stable.

2. Background

Ocean climate variability often induces significant changes in the physical and ecological dynamics of the marine environment [6]. This can affect availability and the critical habitat of

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fish stocks leading to changes in their spatial distribution [7]. For example, the North Atlantic Oscillation, one of the major drivers of climate variability on earth, and greatly influences the abundance and the migration patterns of Norwegian spring-spawning herring in the Norwegian Sea [8]. Perry et al. [9] showed that the centers of distributions in eight fish species, and the range limits for four species, experienced warming-related northward shifts from 1977 to 2001 in the North Sea.

Climate change has also been implicated in the decadal scale boom and bust cycle observed for Pacific sardine before the advent of its fishery [10], and also in the demise of the California historic fishery of the 1930s and 1940s. From the 1920s through the 1940s, a warm regime period in the CCE, the Pacific sardine resource fueled the largest fishery in North America, with annual landings averaging about 500,000 t, and a peak of 700,000 t. Between the late 1940s and 1970s, a shift to a cold water regime in the CCE, combined with extreme fishing, resulted in the collapse of the stock. During this period, Pacific sardine disappeared completely from Canadian waters contracting southward until harvestable amounts were only found in waters off Baja California [11]. This collapse caused California to institute a moratorium on its directed sardine fishery, beginning in 1967 [12]. In the mid-1980s, a warm water regime shift in the CCE, along with fisheries closures, allowed the stock to recover rapidly. From 1983 to 2000, the estimated biomass of Pacific sardine increased nearly ten-fold (Fig. 1a). California landings started increasing in the early 1990s, and as the resource rebounded it expanded northward rejuvenating fisheries in northern California, Oregon (OR), Washington (WA) and British Columbia (BC), Canada. By 2007, coastwide landings had reached 173,120 t (Fig. 1b) the highest recorded since the stock recovery [13].

In view of the combined impact of fishing and ocean climate variability on the sardine stock an important emerging issue is the need for stable transboundary management given expected changes in the stock's availability within the effected countries' EEZs. Cooperative management requires agreement on how the benefits from cooperation will be shared by the participating countries [14]. Stability can be defined as participants (or participating countries) not having incentives to deviate from the established cooperative agreement [15,16]. While ocean climate variability causes dynamic changes in fish stock distribution, traditional sharing rules (i.e., Nash bargaining solution, Shapley value, the core and the nucleolus) are usually based on static spatial distributions of the stock available in the participating countries' waters (e.g., the zonal attachment principle for the European Union and Norway during the late 1970s [14]). Uncertainties in fish distribution arising from ocean climate variability, therefore, can create incentives to deviate from cooperative management for those countries who witness increased availability of the target stock in their waters. In countries where the availability of fish may decrease with ocean climate variability, the possibility exists that the motivation for the conservation of the stock and any sustainable fishery operation may be lost due to the disappearance of fish within their waters.

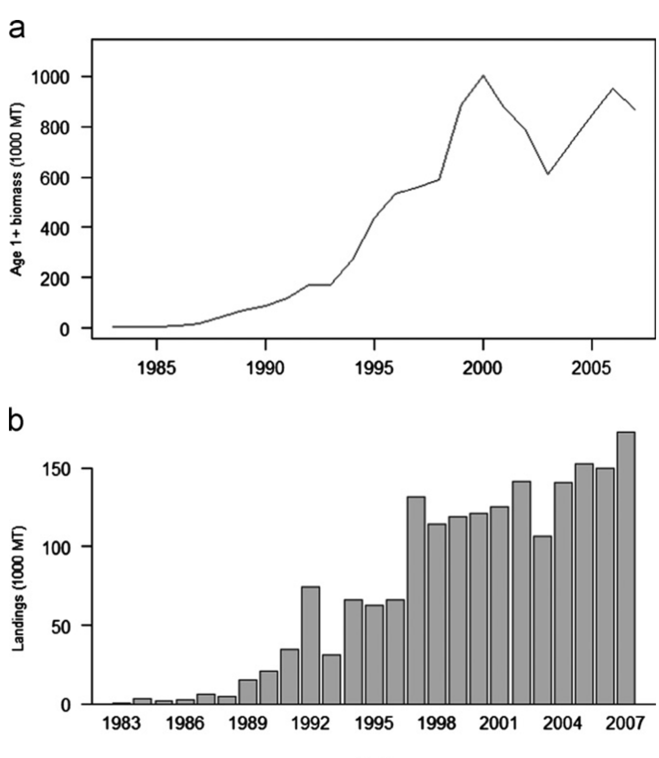

Fig. 1. (a) Costal-wide age 1+ biomass change of the Pacific sardine resource between 1983 and 2007. (b) Coast-wide landings of the Pacific sardine resource between 1983 and 2007 (data from Hill et al. [13]).

Only a limited number of studies have looked at ocean climate variability with respect to transboundary fisheries [5,17,18]. One of the most recent papers, authored by Brandt and Kronbak [19], undertook an analysis on the stability of full and partial cooperative management of three country groups participating in Baltic cod fisheries under climate changes. They concluded that climate change may reduce the benefits from Baltic cod, and lessen the feasibility of stable cooperative conservation and management of the resource.

Game theory has been widely applied to the analysis of biological and economic outcomes of non-cooperative and cooperative management of transboundary fisheries resources [16,20,21] since the first study by Munro [4]. In non-cooperative management, each country acts to maximize its own benefits from that part of a transboundary fish resource that is within its waters, taking the actions of other countries as given. The benefits from the cooperative management of a transboundary fisheries resource would have to be at least equivalent to the sum of benefits under non-cooperation. In this way, each country can be paid its threat point under cooperative management.

A coalition framework allows for cooperation among a group that is smaller than the total number of players in the game [15,16,22]. Only in a situation where all countries behave rationally and in so doing realize desirable biological and economic outcomes, is cooperative management stable [23,24]. In a coalition game, participants deviate from cooperation if they stand to benefit more from deviation than from cooperation, hence satisfying the individual rationality constraint. Stability in each possible coalition is analyzed by examining outcomes and payoff shares among participants within a coalition by using the characteristic function approach, which associates benefits from each coalition with various sharing rules (e.g., core, Shapely value) within a coalition. There are only a limited number of studies where characteristic function games are applied to shared fishing resources [15,16].

3. The model

3.1. The biophysical component of the model

Pacific sardine fisheries model is based on changes from stochastic models of ocean climate variability (i.e., sea surface temperature, SST) and a population dynamics model incorporating environmental effects on the biomass distribution developed by Ishimura et al. [5]. The model incorporates objective functions