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Mechanisms affecting recovery in an upwelling food web: The case of the southern Humboldt

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ABSTRACT

Although bottom-up forcing and overfishing are known to induce shifts in ecosystem states, system changes and their reversibility under each factor are still poorly understood. In this paper, dynamic food web simulations are conducted to evaluate when and why ecological thresholds may be exceeded, and whether bottom-up forcing or fishing is more likely to induce irreversible ecosystem states. Simulations are conducted using a calibrated food web model of the upwelling system off central Chile (33–39°S) and the Ecopath with Ecosim software version 5.1. The effects of fishing scenarios are explored by changing fishing mortality according to trophic level. The effects of bottom-up forcing scenarios are explored by changing phytoplankton biomass, as a function of sea temperature, at El Niño Southern Oscillation (ENSO) and decadal scales. Simulations are carried out for 150 years and impacts, system recovery and regime shifts from each scenario are evaluated using trophodynamic indicators and limit reference points for biomass of functional groups as proxies of food web state and ecological thresholds, respectively. Proportionally distributed fishing along trophic levels is the least harmful fishing scenario, resulting in biomass limit reference points rarely being exceeded and high system recovery. Concentrating fishing at higher and lower trophic levels more likely causes reference points to be exceeded and induces ecosystem changes with low-to-medium recovery potential. No limit reference points are exceeded (or regime shift induced) under ENSO-scale bottom-up forcing. Decadal scale bottom-up forcing has different effects on the system depending on the sequence in which the high and low phytoplankton biomass periods are simulated. A shift from low phytoplankton biomass towards high phytoplankton biomass does not result in biomass limit reference points being exceeded, whereas the opposite sequence results in a large number of limit reference points being exceeded with medium recovery. The interplay between fishing and decadal scale bottom-up forcing indicates that bottom-up forcing can dampen the effects of fishing, whereas fishing increases the number of limit reference points exceeded and decreases the recovery observed under decadal scale bottom-up forcing. Results suggest that fishing (especially unsustainable strategies) is more likely to cause ecological thresholds to be exceeded and to induce regime shifts of low recovery than decadal scale bottom-up forcing. We consider these results of relevance for the management of fisheries in their ecosystem context.

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1. Introduction

It is widely recognised that fishing, by impacting living and non-living components, results in deleterious changes in ecosystem structure and function (Goñi, 1998; Jennings and Kaiser, 1998; Hall, 1999). For this reason, fishing is considered the main threat to marine ecosystems (Jackson et al., 2001; Pauly et al., 2002; Worm et al., 2006). Ecosystem components, however, are also affected by environmental changes that can result in system-level alterations. Interannual El Niño Southern Oscillation events (ENSO), decadal shifts, and the rapid rate of global warming are among the most important environmental forcing factors affecting marine ecosystems (Timmermann et al., 1999; Easterling et al., 2000; Chavez et al., 2003; Steele, 2004). Observed patterns indicate that a significant ecosystem change in structure and function is triggered when either fishing (Cury and Shannon, 2004; Frank et al., 2005; Daskalov et al., 2007) or some environmental factor (Steele, 2004) exceeds certain critical levels, i.e., there is an ecological threshold.

Ecosystem shifts induced by climate and fishing differ. For example, the effects of environmental change on stocks seem to

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