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ScienceDirect
Estuarine, Coastal and Shelf Science 73 (2007) 711−724
ESTUARINE COASTAL AND SHELF SCIENCE
www.elsevier.com/locate/ecss

# Changes in the northern Gulf of St. Lawrence ecosystem estimated by inverse modelling: Evidence of a fishery-induced regime shift?

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Received 15 June 2006; accepted 13 March 2007
Available online 2 May 2007

**Abstract**

Mass-balance models have been constructed using inverse methodology for the northern Gulf of St. Lawrence for the mid-1980s, the mid-1990s, and the early 2000s to describe ecosystem structure, trophic group interactions, and the effects of fishing and predation on the ecosystem for each time period. Our analyses indicate that the ecosystem structure shifted dramatically from one previously dominated by demersal (cod, redfish) and small-bodied forage (e.g., capelin, mackerel, herring, shrimp) species to one now dominated by small-bodied forage species. Overfishing removed a functional group in the late 1980s, large piscivorous fish (primarily cod and redfish), which has not recovered 14 years after the cessation of heavy fishing. This has left only marine mammals as top predators during the mid-1990s, and marine mammals and small Greenland halibut during the early 2000s. Predation by marine mammals on fish increased from the mid-1980s to the early 2000s while predation by large fish on fish decreased. Capelin and shrimp, the main prey in each period, showed an increase in biomass over the three periods. A switch in the main predators of capelin from cod to marine mammals occurred, while Greenland halibut progressively replaced cod as shrimp predators. Overfishing influenced community structure directly through preferential removal of larger-bodied fishes and indirectly through predation release because larger-bodied fishes exerted top-down control upon other community species or competed with other species for the same prey. Our modelling estimates showed that a change in predation structure or flows at the top of the trophic system led to changes in predation at all lower trophic levels in the northern Gulf of St. Lawrence. These changes represent a case of fishery-induced regime shift.


*Keywords:* food webs; inverse methods; mass-balance models; cod collapse; regime shift; Gulf of St. Lawrence (Canada)

## 1. Introduction

Abundance of many Atlantic cod (*Gadus morhua*) and groundfish stocks in the Northwest Atlantic declined to low levels in the early 1990s, resulting in cessation of directed fishing for these stocks (CAFSAC, 1994; Swain and Castonguay, 2000; Gascon, 2003). In the northern Gulf of St. Lawrence (Fig. 1), biomasses of Atlantic cod, redfish (*Sebastes* spp.), and large demersals (including white hake [*Urophycis tenuis*], black dogfish [*Centroscyllium fabricii*], and Atlantic halibut [*Hippoglossus hippoglossus*]), decreased 15, eight-, and fourfold, respectively (Morissette et al., 2003; Savenkoff et al., 2004a). These changes have had profound effects on the fishery and the livelihood of harvesters, but the impact on the ecosystem as a whole is less clear. Shifts from ecosystems dominated by demersal fish to ecosystems dominated by pelagic fish have been documented in the Atlantic and the Baltic (Worm and Myers, 2003; Bundy, 2005; Frank et al., 2005) and other coastal ecosystems (Jackson et al., 2001).

The synthesis of ecosystem information into a model is designed to enable a whole-system view using parameters that are basic to understand populations and the ecosystem

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doi:10.1016/j.ecss.2007.03.011

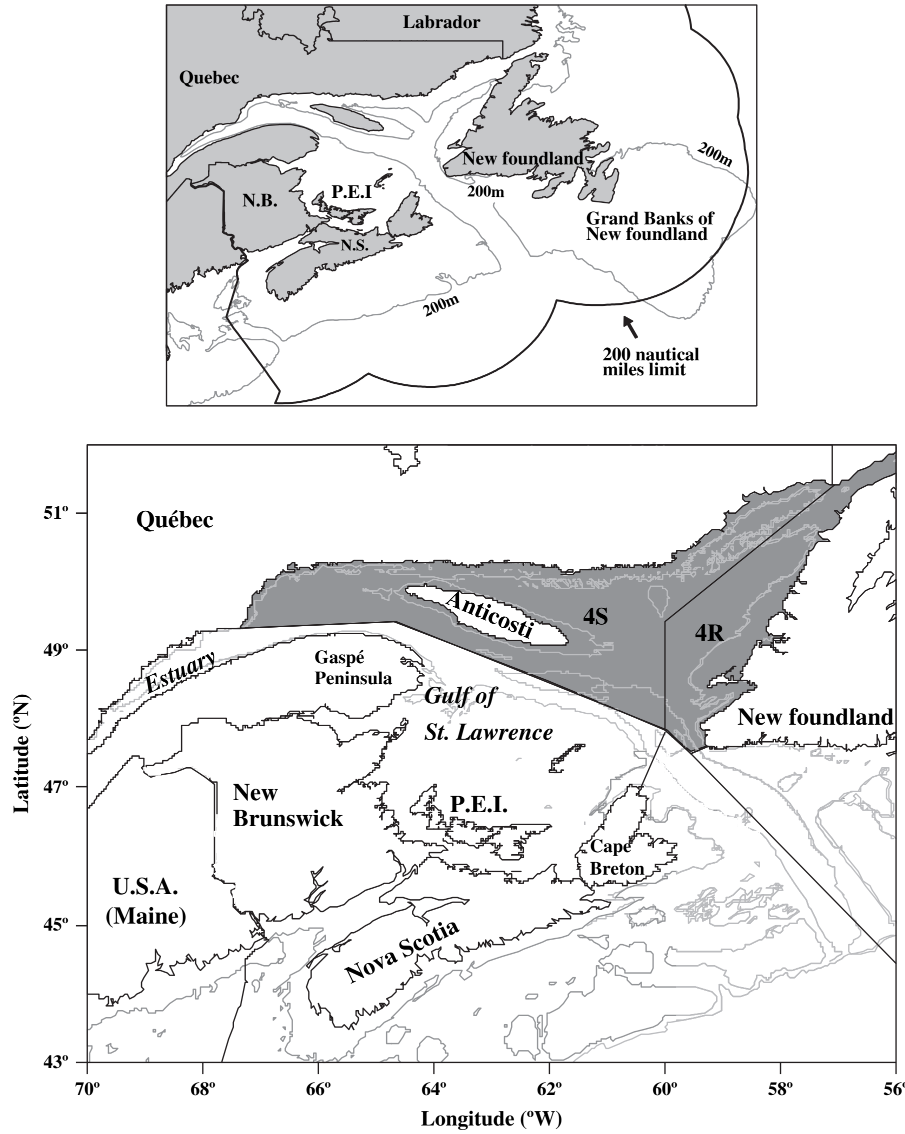


Fig. 1. The northern Gulf of St. Lawrence (NAFO divisions 4RS).

(Christensen et al., 2000). A common approach uses a family of models known as mass-balance models that are normally used to integrate biomass and rate estimates, and to identify major energy pathways and gaps in the knowledge of an ecosystem. Ecopath is one example of mass-balance modelling approach that has been widely used to explore ecosystem structure and function (Christensen and Pauly, 1992; Christensen et al., 2000). However, this approach lacks clear objective criteria to determine which one among the infinite number of potential solutions to the underdetermined mass-balance problem can be considered optimal (Savenkoff et al., 2001; Bundy, 2005). This limits the power of comparative analyses using mass-balance models because it is not always clear how much of the differences among flow networks depends on subjective choices. Another approach for developing mass-balance models is inverse methodology (Vézina and Platt, 1988; Savenkoff et al., 2004b). Inverse models also use mass-balance principles, but, in contrast to the Ecopath approach, trophic flows are estimated using an objective least-squares criterion. Thus, inverse methods directly compute a balanced network, if it is possible with the available data, subject to constraints posed by the data and eco-physiological knowledge of the system. Another difference with Ecopath is the use of upper and lower limits to constrain the majority of input values (production, consumption, export, and diet composition) and the choice of weights for each mass-balance equation and for each unknown flow make inverse modelling a flexible tool to quantify mass-balanced flow diagrams and trophic transfer efficiencies that are internally consistent. Inverse analysis is increasingly used in ecosystem modelling to compensate for insufficiency of data on the ecosystem, to objectively reconstruct a large number of unknown flows or interactions from a small number of observations, and to generate a “snapshot” of the system at one moment in time (Leguerrier et al., 2003; Vézina et al., 2004; Savenkoff et al., 2004b).

In a previous study, Savenkoff et al. (2004b) compared several scenarios in the northern Gulf of St. Lawrence for the mid-1980s, before the collapse of groundfish stocks: (1)