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Compilation and discussion of driver, pressure, and state indicators for the Grand Bank ecosystem, Northwest Atlantic

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ABSTRACT

There are global calls for new ecosystem-based fisheries management (EBFM) approaches. Scientific support for EBFM includes assessing ecosystem indicators of biological communities, environmental conditions, and human activities. As part of a broader research project we have synthesized a suite of traditional and new indicators for the Grand Bank in Atlantic Canada, which we share here. This is an ideal ecosystem for indicator analysis because it experienced dramatic changes over the past three decades, including a collapse in fish biomass that had profound socio-economic consequences. We exploit the wealth of data for this ecosystem to investigate how individual indicators reflect observed changes in the ecosystem, and then illustrate two applications of this indicator suite. Correlations were used to show that relationships among the fish functional groups changed after the collapse, and that a subset of indicators is sufficient to characterize each ecosystem category. Lagged correlations highlighted how changes in the drivers and pressures are often not immediately manifest in the fish community structure. We also organized indicators into the DPSIR (driver-pressure-state-impact-response) management framework. This exercise illustrated that indicator categorization is contextual and not straightforward, and we advocate for use of simpler categories that clearly show what is actionable. Additional future analyses that can be performed with our newly published suite of indicators are recommended.

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1. Introduction

There are global calls to supplement traditional single species fisheries management with ecosystem based approaches that account for interactions among multiple factors and commercial and non-target species (e.g. Fisheries and Oceans Canada, 2007; Misund and Skjoldal, 2005). To support this holistic type of management, decision makers need quantitative information on the state of the marine ecosystem, which can be provided by data-based indicators that describe biological communities, environmental conditions, and human activities (Jennings, 2005). Criteria for useful indicators have been defined, including measurability, sensitivity to change, ecological meaning, and public awareness (Cury and Christensen, 2005; Rice and Rochet, 2005). Many indicators have been developed that meet these criteria, and sets of indicators are typically used to capture ecosystem complexity (e.g. Jennings, 2005; Rice, 2003). Interpreting these sets can be challenging and subjective, requiring rigorous analysis and historical context (Shin et al., 2010).

We are engaged in a long term project focused on quantitative analysis that can identify optimal sets of indicators for ecosystem-based fisheries management (EBFM). As part of that research, we compiled data and calculated a suite of indictors for the Grand Bank, Canada (Fig. 1). We subsequently invested thought into how to identify first-order relationships between indicators, and how to categorize them using a management framework. We recognize the value of these efforts for others working in this region, as well as those using indictors for EBFM elsewhere. Here we make our preliminary work accessible to this broader community, and have included the indicator suite in the supplementary material.

The Grand Bank is one of the major ecosystem units within the Newfoundland Shelves bioregion (Pepin et al., 2014; NAFO, 2014), and is ideal for indicator analysis because it is a tightly coupled human-ecological system. For centuries it was one of the most productive fishing grounds in the world (Rose, 2007), but prolonged heavy fishing pressure combined with an environmental regime shift led to complex ecological changes, best characterized by the

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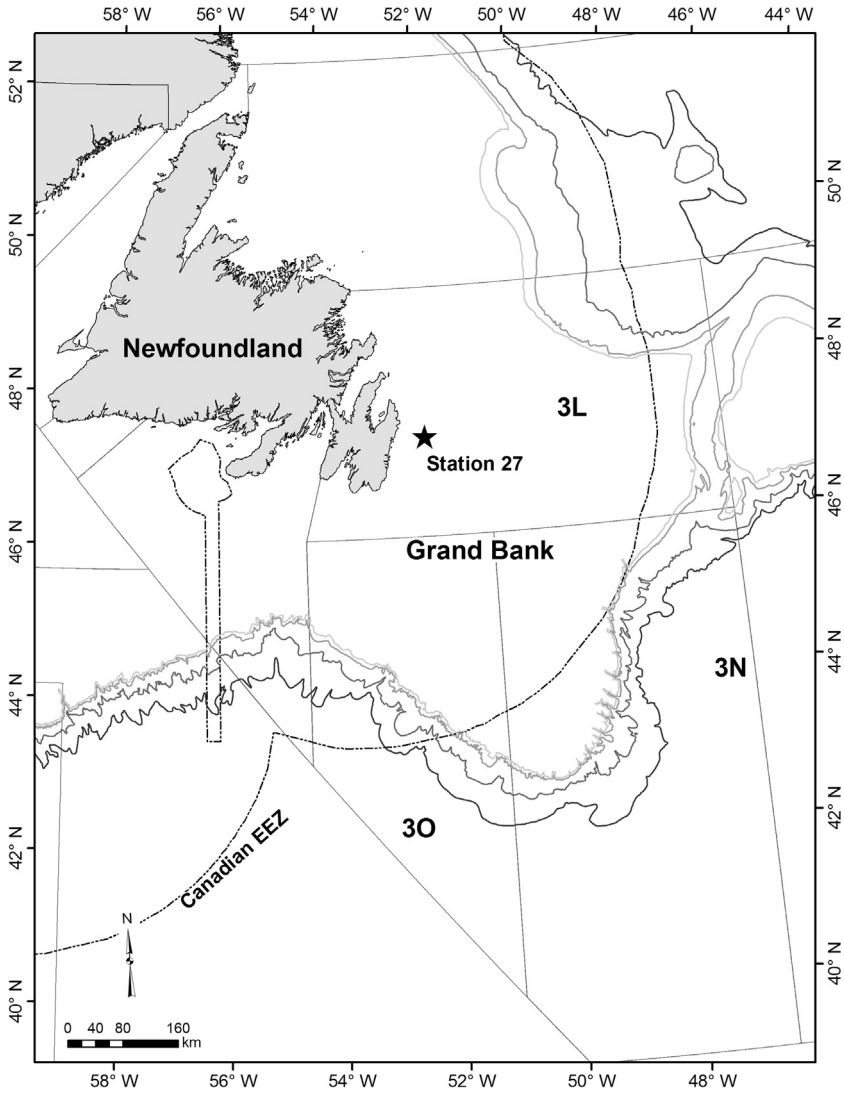

Fig. 1. Map of the Grand Bank of Newfoundland, Canada, showing Northwest Atlantic Fisheries Organization (NAFO) areas 3L, 3N, and 3O, the Canadian exclusive economic zone (dashed line), and the location of oceanographic monitoring Station 27.

collapse of fish biomass in the early 1990s (Atkinson, 1994; Buren et al., 2014; NAFO, 2010a). The collapses of major stocks in the bioregion prompted the establishment of fishing moratoria, including several Grand Bank stocks (e.g. Atlantic cod in 1994). Many moratoria remain in place today (Rose, 2007), although there are signs of recovery in some stocks (NAFO, 2014). These fisheries closures also had socio-economic impacts on Canada's province of Newfoundland and Labrador, where local fishers adapted by targeting different species (e.g. shrimp and other shellfish), retiring from the fishing industry, or leaving the province to find employment elsewhere (e.g. Hamilton and Butler, 2001; Schrank, 2005).

The bank extends from inside the Canadian exclusive economic zone (EEZ) into international waters. Fisheries management is the responsibility of Fisheries and Oceans Canada (DFO) within the EEZ, and the Northwest Atlantic Fisheries Organization (NAFO; statistical division 3LNO) in international waters (including straddling stocks). Both organizations are currently working towards implementing ecosystem approaches to management (NAFO, 2010a, 2010b; Oceans Act, 1996; Fisheries and Oceans Canada, 2009). While there have been some studies of indicators in the region, most are only available in the grey literature, and have not made their indicators available for other analyses.

We first present our compiled time series of fish community, human, and environmental indicators for the Grand Bank over the past three decades, and relate these trends to *a priori* knowledge of the ecosystem. We then discuss useful applications of these indicators, including correlation analysis to highlight potential redundant and causal relationships, and classification into the common DPSIR (driver-pressure-state-impact-response) management framework.

2. Methods

A suite of indicators was carefully chosen to describe the complex ecosystem changes that have taken place on the Grand Bank over the past three decades. Choices were constrained by data availability, as well as criteria identified by previous work (e.g. Rice and Rochet, 2005), and were derived from a variety of sources (Table S.1). The fish community indicators are annual mean values from 1985 to 2013, while fishing, socio-economic and environmental indicators extend back to 1975 to provide a broader context. Below we summarize the indicators used and our rationale for their selection.

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