Ecological Modelling 264 (2013) 130–142

Contents lists available at SciVerse ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Effects of hunting, fishing and climate change on the Hudson Bay marine ecosystem: I. Re-creating past changes 1970–2009

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ARTICLE INFO

Article history:
Available online 18 March 2013

Keywords:
Ecopath
Ecosystem modelling
Harvest
Climate change
Arctic ecosystems
Cumulative impacts

ABSTRACT

An ecosystem model was created for the Hudson Bay region, Canada, for 1970–2009, aiming to identify ecosystem linkages while bringing together research from diverse sources. The model presented here in detail includes 40 functional groups. Using the Ecopath with Ecosim (EwE) modelling framework we are able to provide estimates for previously unknown parameters such as the biomass of fish species. In addition to providing a comprehensive overview of the trophic dynamics within the system, temporal simulations mimic the changes known to occur in the region. The model is fitted to catch data for the Hudson Bay region, along with environmental drivers (sea surface temperature and ice cover). Declines in sea ice and increases in the spring bloom facilitate a shift from benthic to pelagic pathways in lower trophic levels of the model. Polar bears, bearded seals and eastern Hudson Bay belugas demonstrate the greatest declines due to hunting mortality. Additional model scenarios testing the model sensitivity to hunting and environmental pressures indicate higher trophic level organisms (marine mammals) are more responsive to hunting pressures, while lower trophic levels (benthos, zooplankton) are primarily influenced by climate drivers. While marine mammals are the most well studied, the region lacks comprehensive assessments on fish and other mid trophic level organisms. This model captures many patterns present in the system, while identifying gaps in existing data for future research and provides the first step for future research simulating climate change and its impacts on the Hudson Bay ecosystem.

1. Introduction

Polar regions are increasing in temperature faster than temperate areas, with Arctic temperature rising at almost twice the rate of the rest of the world (ACIA, 2004). The fourth International Polar Year (IPY) in 2007–2009 highlighted the need for research to increase our knowledge of the dynamics occurring in Polar areas. While Hudson Bay (HB) (Fig. 1) is geographically considered sub-Arctic, between 50° and 70°N, this system reflects high Arctic attributes such as climate, biogeography, and higher trophic level animals. For example, polar bears are found at their lowest latitudinal range in HB due to the cold winters and the ice available for foraging (Stirling and Parkinson, 2006). Moreover, many species present in this ecosystem have adapted to the seasonal ice cycle, from whales occupying the region during the ice free seasons to seals breeding on the ice, and the ability of smaller zooplankton to survive winter months using nutrients frozen within the sea ice (Poltermann, 2001; Stewart and Lockhart, 2005).

Research in HB has been limited in the past, compared to other Arctic ecosystems. Two surveys of phytoplankton and zooplankton have been completed in HB assessing lower trophic levels: one in 1993 sampling from James Bay (JB) along the east coast of HB into Hudson Strait (HS) (Harvey et al., 1997, 2001) and a second in 2003 running east to west through the middle of HB (Harvey et al., 2006). The most comprehensive benthic summary from numerous locations in HB from 1953 to 1956 (Atkinsor and Wacasey, 1989), while valuable, only recorded the presence of benthic species. Fish in the region are poorly understood, although there is the general belief that fish are not abundant in HB, a situation somewhat verified by unsuccessful commercial fishery ventures (Stewart and Lockhart, 2005). Marine mammals are some of the most well studied species in the region, although only a handful of surveys have been completed for each species (Ferguson et al., 2010).

Surface temperatures in HB have increased by 0.5–1.5 °C during the 1955–2005 (Hansen et al., 2006), and sea ice extent decreased by $2000 \pm 900\,km^{-2}\,y^{-1}$ between 1978 and 1996 (Parkinson et al., 1999). These changes combined with a longer ice free season (Gagnon and Gough, 2005) are likely yielding large scale changes to the sympagic marine ecosystem. Ice algae, which contributes up to 57% of primary production in some Arctic regions (Gosselin et al., 1997), and roughly 25% of total production in some areas of

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http://dx.doi.org/10.1016/j.ecolmodel.2013.02.005

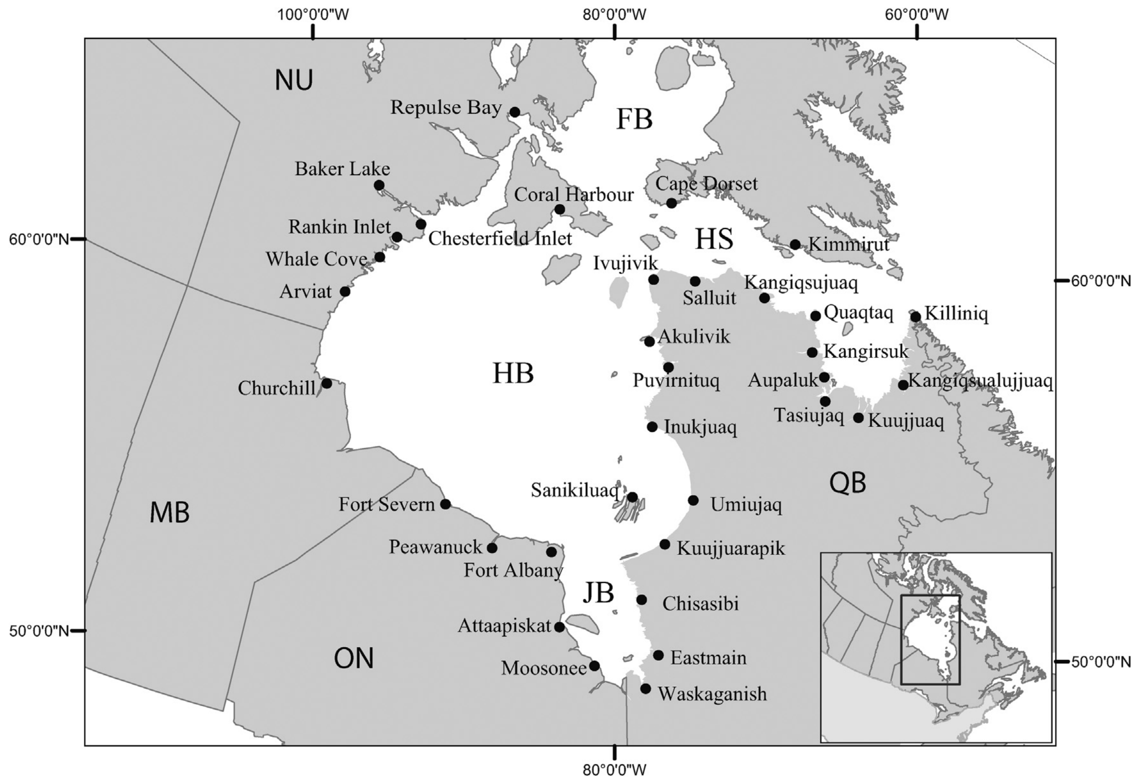

Fig. 1. Hudson Bay region including Hudson Bay (HB), James Bay (JB), Hudson Strait (HS), and Foxe Basin (FB). Communities in Nunavut (NU), Manitoba (MB), Ontario (ON), and Quebec (QB) are shown.

Hudson Bay (Legendre et al., 1996), can be stored through the winter within the sea ice. Therefore the loss of sea ice will alter the availability of algae stored within the sea ice, which will lead to shifts in the ecosystem by altering energy transfer to higher trophic levels. Such shifts have already been observed in bird diets as indicated by declines in ice associated and benthic fish species such as Arctic cod *(Boreogadus saida)*, sculpins (Family: Cottidae), and Zoarcids (Family: Zoarcidae) with increases in pelagic fish such as capelin (*Mallotus villosus*) and sandlance (*Ammodytes* spp.). Polar bear populations are at their southern limit in HB, and already experience longer summers than their northern counterparts. Lengthening of the ice free summer is believed to increase nutritional stress as there is less ice to forage on decreasing their hunting platform, making them vulnerable to sea ice declines (Stirling and Derocher, 1993; Stirling et al., 1999).

Along with environmental changes, human use of the ecosystem also has the potential to alter the abundance of species. Currently all marine mammal species are hunted annually (with the exception of bowhead where harvest only occurs in specific years), with quotas imposed only on certain cetaceans. Seabirds and fish are also harvested, however these are generally unregulated. Since the 1970s, human populations have nearly tripled (Bell, 2002; Statistics Canada, 2006; Nunavut Bureau of Statistics, 2008; Sutherland et al., 2010) with increases in harvest levels for many species also being recorded. Understanding whether these stocks can withstand the continuous pressure of harvest is important alone, and even more so in conjunction with the impacts of climate change. In order to test the importance of multiple stressors on the ecosystem, we have constructed an ecosystem model to re-create the dynamics from 1970 to 2009.

The ecosystem model was created using the Ecopath with Ecosim software (Christensen et al., 2007; Buszowski et al., 2009), to assess the HB ecosystem with a mass-balance model. Through the construction of an Ecopath mass balance model, gaps in existing ecosystem knowledge can be identified. For example, biomass of fish populations is obtained by assessing the demands of predators and the amount of fish which can be supported by lower trophic levels, based on food web structure. Ecosim temporal simulations (Walters et al., 1997; Christensen and Walters, 2004) are used to re-create observed changes since 1970, helping to identify causes to changes in ecosystem structure. The model aims to focus on the impact of climate change and hunting on marine mammal species as part of the Global Warming and Arctic Marine Mammal International Polar Year research project, therefore giving marine mammals a greater presence in the model structure. While high and low trophic level organisms are relatively well studied in this region, serious gaps regarding mid trophic level organisms (primarily benthos and fish) exist. Despite these gaps, there is an urgency to understand a system that is subjected to multiple stressors. This modelling approach allows us to infer changes likely occurring to mid-trophic level organisms through existing knowledge of predators and producers.

2. Methods

2.1. Study area

The Hudson Bay region often includes Hudson Bay (HB), James Bay (JB), Foxe Basin (FB) and Hudson Strait (HS) (Fig. 1). This system is one of the largest bodies of water in the world to freeze over every winter and open up every summer. HB and JB are both categorized by shallow, less productive waters, with large inputs of freshwater from rivers in the spring. Conversely, FB and HS have more mixing with the Labrador Sea (Straneo and Saucier, 2008), and are thought to be an important sea ice choke-point for HB, ultimately determining which marine species have access to the region (Higdon and Ferguson, 2009).