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A bio-economic analysis of harvest control rules for the Northeast Arctic cod fishery

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ABSTRACT

Harvest control rules (HCRs) have been implemented for many fisheries worldwide. However, in most instances, those HCRs are not based on the explicit feedbacks between stock properties and economic considerations. This paper develops a bio-economic model that evaluates the HCR adopted in 2004 by the Joint Norwegian–Russian Fishery Commission to manage the world's largest cod stock, Northeast Arctic cod (NEA). The model considered here is biologically and economically detailed, and is the first to compare the performance of the stock's current HCR with that of alternative HCRs derived with optimality criteria. In particular, HCRs are optimized for economic objectives including fleet profits, economic welfare, and total yield and the emerging properties are analyzed. The performance of these optimal HCRs was compared with the currently used HCR. This paper show that the current HCR does in fact comes very close to maximizing profits. Furthermore, the results reveal that the HCR that maximizes profits is the most precautionary one among the considered HCRs. Finally, the HCR that maximizes yield leads to un-precautionary low levels of biomass. In these ways, the implementation of the HCR for NEA cod can be viewed as a success story that may provide valuable lessons for other fisheries.

1. Introduction

1.1. Northeast Arctic cod and its current management plan

Northeast Arctic (NEA) cod (*Gadus morhua*) is currently the world's largest cod stock, distributed from its feeding grounds in the Barents Sea to its spawning grounds off the Lofoten islands in the Norwegian Sea [1]. The fishery consists of two parts that are geographically separate: the feeding-ground fishery in the north and the spawning-ground fishery further south (Fig. 1). Humans have been fishing on the spawning grounds for more than a thousand years, beginning with the export of cod during the Viking Age [2]. Until the 1930s, the spawning-ground fishery dominated catches, due to its proximity to coastal villages and ports. However, during the 1930s the advent of industrial fishing technology facilitated the expansion of the NEA cod fishery into the Barents Sea. This expansion led to a shift of catches toward the stock's feeding grounds, as well as to an increase in the total fishing mortality (Fig. 2a). In 2010, ICES (the International Council for Exploration of the Sea) estimated the spawning-stock biomass (SSB) of NEA cod to reach 1,145,000 t, the highest amount that has been observed since 1947 [3]. The stock's total biomass has also increased, even though not concomitantly with the SSB (Fig. 2b). In addition to possible climate effects, this recent increase in SSB could have at least two explanations: First, illegal fishing has been reduced from the maximum of 166,000 t in 2005 to approximately zero in 2009 [4]. This decline is most likely due to the introduction of port control in 2007, requiring all vessels to document that their landings are legally caught. Second, a joint Norwegian–Russian harvest control rule (HCR) that determines the total allowable catch (TAC) has been implemented since 2004, to ensure that the stock is not at "risk of being harvested unsustainably" or "suffering reduced reproductive capacity" [5,6].

NEA cod is an economically very important fish resource [7,8] mostly situated in the exclusive economic zones of Norway and Russia (Fig. 1). For years, NEA cod has been managed jointly by

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those two countries, though not without scientific and political disagreements [9]. To enable more farsighted management and to simplify the annual negotiations on harvest levels, an HCR was agreed upon by the two countries in 2004 (Fig. 2c). In general, an HCR is an algorithm and a tactical management tool that translates biological information, such as a stock's current SSB, into management information such as a TAC for that stock during the next fishing season. An HCR is often designed with the help of reference points for target biomass and fishing mortality. In particular, the precautionary reference points for biomass and fishing mortality, B_{pa} and F_{pa}, respectively, act as buffers to account for natural variability and uncertainty in the stock assessment: B_{pa} implements a "safety margin" to reduce the risk that the true SSB falls below a limit reference point B_{lim} below which the stock is expected to suffer from reduced reproductive capacity. Likewise, F_{pa} is meant to avoid a true fishing mortality that exceeds the limit reference point F_{lim} above which SSB is expected to drop below B_{lim} [5]. The range of these buffers depends on the level of uncertainty and on the level of risk fisheries managers are willing to accept on behalf of society.

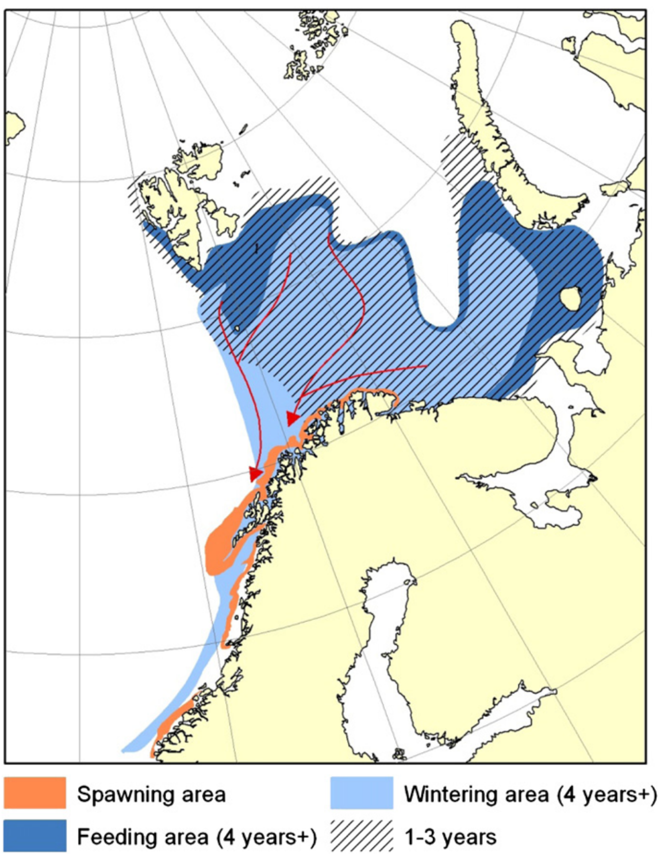

Fig. 1. Distribution of NEA cod, with feeding grounds in the Barents Sea and spawning grounds along the Norwegian coast. The figure has been developed by the Norwegian Institute of Marine Research.

In autumn 2004, the 33rd session of the Joint Norwegian–Russian Fishery Commission adopted a HCR stipulating that the fishing mortality is allowed to be at F_{pa} as long as SSB exceeds B_{pa}, but is required linearly to decrease from F_{pa} to 0 as SSB decreases from B_{pa} to 0 (Fig. 2c). Therefore, fishing can take place at all SSB levels [10]. The HCR contains additional elements that aim to restrict how much the TAC can change from one year to the next. However, the TAC advised by the adopted HCR is not always followed. For example in 2009, due to the high SSB, the TAC was decided by the Joint Norwegian–Russian Fishery Commission to be 525,000 tonnes, while the adopted HCR advised 473,000 tonnes [11]. Today, the NEA stock is classified as having "full reproductive capacity" and being "harvested sustainably" [6,12].

1.2. Need for adaptive management and clear objectives

Despite considerable attention to the management of marine ecosystems, most fisheries have yet to be optimized to reach management goals [13–16]. Political obstacles and roadblocks play an important role in failures of fisheries management [17]. Also, some scientific models for optimal management are not easily applicable to real-world situations, and may be based on hidden and/or overly simple assumptions [18].

Another obstacle for successful fisheries management is the fact that it is often not explicit, or evident *a priori*, which particular objectives should be pursued [16,19,20]. At a very basic level, a specific fish stock can provide income to society, but also serves as an important food source. Therefore, one may favour a harvesting rate that provides the highest perpetual yield, known as the maximum sustainable yield (MSY), and this objective has been endorsed in various international agreements [19]. Economic science has added an important refinement to the purely biological consideration of MSY by accounting for the costs and benefits associated with resource extraction [21,22]. This allows deriving an exploitation path that maximizes profits from harvesting, but is based on the simplifying assumption that the government, at least theoretically, is the "sole owner" of the resource. The contrast between these two basic approaches already shows that a crucial prerequisite for achieving optimal exploitation is the clear specification of management goals.

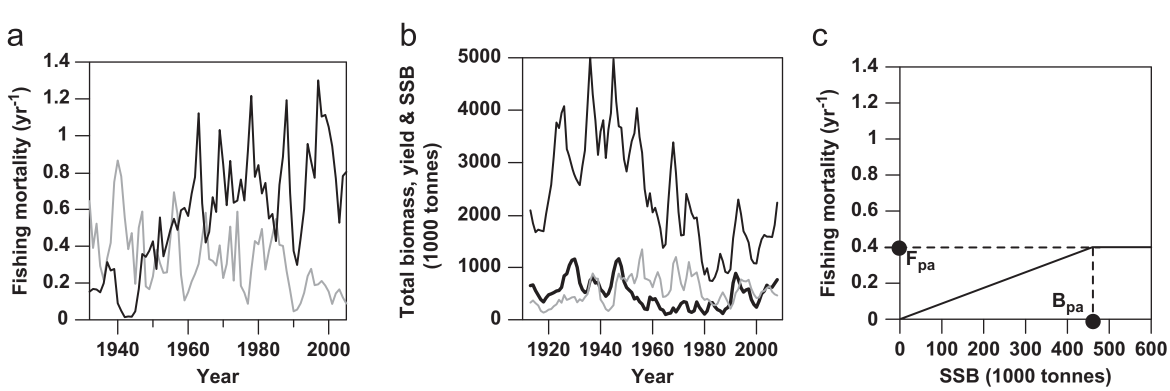

Fig. 2. (a) Historic fishing mortality rates in the feeding grounds (black line) and spawning grounds (grey line) for 1932–2005. (b) Time series of total biomass for individuals aged 3 years or older (black line), reported yield (grey line), and spawning-stock biomass (SSB, thick black line), as reported by ICES AFWG 2009. (c) Current HCR (continuous line), as determined by the two parameters B_{pa} and F_{pa} (dashed lines).