## Comment

# Towards a more balanced assessment of the dynamics of North Atlantic ecosystems—a comment on Drinkwater and Kristiansen (2018)

Kenneth T. Frank [ID] [1]*, Brian Petrie[1], William C. Leggett[2], and Daniel G. Boyce [ID] [3]

[1]Ocean and Ecosystem Sciences Division, Bedford Institute of Oceanography, Dartmouth, NS B2Y 4A2, Canada
[2]Department of Biology, Queen's University, Kingston, ON K7L 3N6, Canada
[3]Ocean Frontier Institute, Steel Ocean Sciences Building, Dalhousie University, Halifax, NS B3H 4R2, Canada

*Corresponding author: tel: 1-902-426-3498; e-mail: kenneth.frank@dfo-mpo.gc.ca

Drinkwater and Kristiansen (hereafter D&K) (2018, A synthesis of the ecosystem responses to the late 20th century cold period in the northern North Atlantic, *ICES Journal of Marine Science*, 75: 2325–2341) examined multi-trophic level biological responses in relation to a 1960s–1980s "cold period" that they associated with the Atlantic Multidecadal Oscillation (AMO). They concluded that ocean temperature was a major driver of ecosystem changes throughout the North Atlantic during this interval and adversely affected the abundance, spawning stock biomass (SSB), recruitment, survival success of several species including cod in four North Atlantic ecosystems (NE Arctic, Iceland, West Greenland, and Labrador–northern Newfoundland). D&K further suggested that negative ocean temperature anomalies during this cold period occurred first in the Eastern Arctic and Barents Sea, propagated westward across the North Atlantic to the Labrador Sea and were potentially related to a sequential E–W collapse of the four cod stocks. We take issue with these conclusions and suggest that a more quantitative discussion of fisheries exploitation was in order.

**Keywords:** AMO, cod, exploitation, North Atlantic, top–down

## Issues arising from D&K

In focusing mainly on ocean temperature D&K, in our view, did not adequately evaluate or acknowledge an extensive and growing literature documenting the reality that top–down restructuring linked to exploitation of top predators can penetrate to the base of the food chain and precipitate the multi-trophic level ecosystem responses. While D&K indicate that fishing can be another important driver, they do not provide any quantitative assessment of its importance. Here, we attempt to bring a more complete and balanced view of the dynamics of the late 20th century fishery declines. Specifically we raise the following issues arising from their paper: (i) their missing assessment of the role of fisheries exploitation in the four ecosystems featured beyond indicating it may be an important factor; (ii) the veracity of the assumption that AMO characterizes the local climate of these four regions and that the ecosystem response can be interpreted on the basis of this characterization and compared to periods when the AMO was in a different state; (iii) the issue of east to west propagation of cooler ocean temperatures and its relationship with cod SSB declines raised and discussed by D&K and further addressed here.

## Fisheries exploitation in the North Atlantic

Numerous studies, not considered by Drinkwater and Kristiansen (D&K), at regional scales have addressed the impacts of fisheries exploitation and top–down, multi-trophic level restructuring of ecosystems in the North Atlantic. Examples include Worm and Myers (2003), Johannesen *et al.* (2012), and Stige *et al.* (2014) for the Barents Sea (NE Arctic); Petrie *et al.* (2009), Fauchald (2010), Llope *et al.* (2012), and Lynam *et al.* (2017) for the North Sea; Molfese *et al.* (2014) for the English Channel; Worm and Myers

(2003), Carscadden *et al.* (2001), Frank *et al.* (2006), Petrie *et al.* (2009), and Boudreau *et al.* (2011) for Labrador/northern Newfoundland; Worm and Myers (2003), Frank *et al.* (2007), and Hedeholm *et al.* (2017) for West Greenland; Frank *et al.* (2007), Pálsson and Björnsson (2011), Björnsson *et al.* (2017), and Jónsdóttir (2017) for Iceland. Collectively, these studies provide empirical evidence of top–down control, involving not only direct effects (predator–prey), but also indirect, cascading effects influencing the dynamics of lower trophic levels (e.g. zooplankton and phytoplankton) which are often presumed to be largely driven by climatic factors alone rather than by trophic interactions coupled with climate. There are several comprehensive reviews of this general topic including examples from a variety of marine ecosystems beyond the North Atlantic and, in some cases, involving comparisons to freshwater, terrestrial, and experimental systems: Parsons (1992), Micheli (1999), Reid *et al.* (2000), Cury *et al.* (2003), Hunt and McKinnell (2006), Crowder *et al.* (2008), Baum and Worm (2009), Essington (2010), Strong and Frank (2010), Möllmann and Diekmann (2012), and Daewel *et al.* (2014). While D&K do mention the importance of exploitation, their statements are qualitative in nature and do not acknowledge the role of trophic dynamics in any of the case studies reviewed.

## AMO forcing

D&K present the monthly detrended Atlantic Multidecadal Oscillation (AMO) index as their prime physical forcing and focus on its 10-year running average as the basis for defining the 1960s–1980s as a cold period (Figure 1a and Table 1A). To assess the validity of this approach, we investigated the relationship of the AMO to local observations of ocean temperature. Climatological time series compiled by ICES (https://ocean.ices.dk/iroc/) include depth-averaged temperatures for the four ecosystems of D&K (Figure 1b and Table 1A). The AMO features a broad period of negative anomalies with a decadal minimum in the 1970s; this feature is roughly seen in the four regional series, being strongest in the NE Arctic, with an average anomaly of $-0.04°C$ (over four regions, 1960s–1980s; Table 1A). The temperature differences of these decadal averages during the cold period relative to the 1950s and the 1990s ranges from $-0.5°C$ to $+1.4°C$ and averages $+0.2°C$. The standard deviations of the annual temperature anomalies are small, varying from 0.4 to 1.2°C (Figure 1b and Table 1C) and decrease to 0.2 to 0.6 when the series are filtered with a 10-year running mean (RMF), the same filter used by D&K. The correlations among the annual temperature anomaly series for the four regions range from 0.12 to 0.68 and average 0.43 (Table 1B). Correlations of the *in situ* temperature series with the AMO vary from 0.2 to 0.52 for the annual and 0.39 to 0.77 for the 10-y RMF series (Table 1D). The standard deviation of the temperature anomaly coherent with the AMO is $\sim0.2°C$ for the annual and 10-y RMF series. There is no clear sign of the westward progression of the local temperature anomalies as implied by D&K; the correlations are low and generally noisy (Figure 1c). We conclude that there is little support for the use of the AMO as a strong proxy for *in situ* temperature series for the four regions discussed by D&K. The temperature differences in the 1960–1980 cold period relative to earlier and later decades are small, with a maximum contrast of $\sim1.5°C$ (Iceland, 1950s vs. 1970s) but more typically $<1°C$. The physiological and population level impacts of a temperature change of this magnitude are judged to be negligible (Jobling, 1988; Myers *et al.*, 1997; Rindorf *et al.*, 2008).
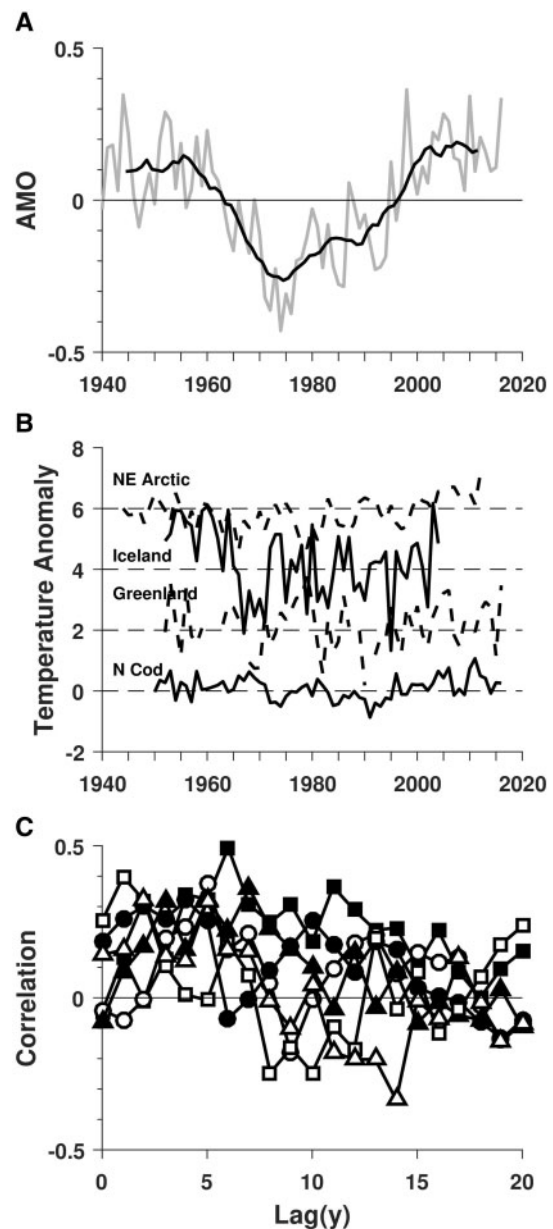


**Figure 1.** (a) Time series of the annual (light line) and 10-year average (dark line) AMO (see Figure 1, D&K). (b) Temperature anomaly time series for: Northern cod (Labrador–northern Newfoundland), annual 0–176 m (Colbourne *et al.*, 2017); Greenland, Fyllas Banke, June/July 50 m Station 4 (Mortensen, 2018); northern Iceland Siglunes hydrographic section, five stations from 4 to 85 km offshore, late spring 0–200 m (Astthorsson *et al.*, 2007); NE Arctic, Kola hydrographic section, stations 4–7, annual 0–200 m (Hollowed and Sundby (2014). The Greenland, Iceland, and NE Arctic series are offset for clarity by 2, 4, and 6°C, respectively. (c) Lagged correlations among the four time series: NE Arctic–Iceland (filled circle); NE Arctic–Greenland (open circle); NE Arctic–Northern cod (filled square); Iceland–Greenland (open square); Iceland–Northern cod (filled triangle); and Greenland–Northern cod (open triangle).

## Quantifying the impact of fishing

D&K preface their section headed **Fish and shellfish** by stating— "Fish and shellfish have long been known to respond to climate forcing (Hjort, 1914; Helland-Hansen and Nansen, 1920;

**Table 1.** Statistics of ocean temperature times series and the AMO (1940–2016).

**(A) Decadal averages of temperature and AMO anomalies**

| Decade | L−nN | Greenland | Iceland | NE Arctic | AMO |
|---|---|---|---|---|---|
| 50s | 0.17 | 0.22 | 1.40 | −0.05 | 0.12 |
| 60s | 0.26 | 0.29 | 0.23 | −0.46 | −0.02 |
| 70s | −0.07 | 0.42 | −0.13 | −0.42 | −0.26 |
| 80s | −0.11 | −0.05 | −0.06 | −0.42 | −0.12 |
| 90s | −0.20 | −0.26 | −0.15 | −0.13 | −0.02 |
| 00s | 0.23 | 0.36 | 0.54 | 0.42 | 0.15 |

**(B) Correlation matrix for the temperature time series**

| | L−nN | Greenland | Iceland | NE Arctic |
|---|---|---|---|---|
| N cod | 1 | – | – | – |
| W Greenland | 0.68 | 1 | – | – |
| Iceland | 0.65 | 0.32 | 1 | – |
| NE Arctic | 0.36 | 0.12 | 0.47 | 1 |

**(C) Standard deviations of temperature anomalies**

| | | | | |
|---|---|---|---|---|
| Annual | 0.36 | 0.84 | 1.2 | 0.5 |
| 10-y RMF | 0.21 | 0.31 | 0.56 | 0.29 |

**(D) Correlations of temperature series with the AMO**

| | | | | |
|---|---|---|---|---|
| Annual | 0.52 | 0.20 | 0.24 | 0.33 |
| 10-y RMF | 0.65 | 0.39 | 0.69 | 0.77 |

L−nN, Labrador–northern Newfoundland.

Shepherd *et al.*, 1984), thus it is not surprising that with the downturn in temperatures during the 1960s to the 1980s strong responses resulted." Within this context, they discuss the declining trends of spawning stock biomass (SSB) among the NE Arctic, Iceland, West Greenland, and Labrador–northern Newfoundland (Northern cod) cod stocks which they attribute to the cold period. However, the 1960s–1980s period was also a time when exploitation was high, with an average instantaneous fishing mortality of 0.59, corresponding to 45% removal of the SSB annually (Figure 2). This direct, massive removal of biomass is completely independent of links to lower trophic levels through food availability as D&K hypothesize but did not quantify. In the Labrador–northern Newfoundland region, an extraordinary 11.3 Mt of cod was harvested between 1960 and 1989 (Lilly *et al.*, 2006). During the same period, 4.1 Mt of cod was harvested from the Greenland fishery (ICES, 2016a, 2017). In the NE Arctic and Iceland, 18.9 and 11.4 Mt of cod were landed during the cold period (ICES, 2016b, 2018). These harvest levels are considered to be minimal estimates given their omission of discarded fish in either directed or non-directed (by-catch) fisheries (Crowder *et al.*, 2008).

## The spatial and temporal structure of SSB declines

D&K noted that during the cold period the four cod stocks seemed to decline at a similar rate and do so progressively from the northeast to the southwest (see D&K, Figure 6). In addition, they indicated that there was some evidence of a parallel progression of air temperature declines (Johannessen *et al.*, 2004) and of the intensity of the sea surface temperature cold pool from the Barents to the Labrador Sea (see D&K, Figure 3).

To evaluate these assertions, we quantified the decadal-scale rates of decline in cod SSB for the four areas referenced by D&K. We found that they differed by as much as a factor of ∼2, from a low of 58 000 t/y (1959–1968) for the Icelandic cod stock to a high of 102 000 t/y (1962–1976) for Northern cod. NE Arctic cod declined at a rate of 68 000 t/y (1946–1958) and the cod stock at Greenland 77 000 t/y (1959–1974). This suggests that the cod SSB
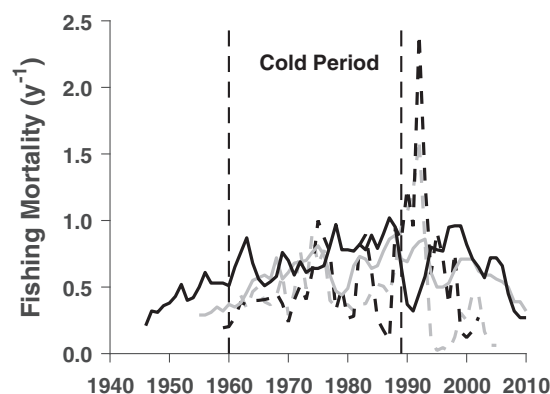


**Figure 2.** Time series of instantaneous fishing mortality (F) for the four areas of D&K; NE Arctic, solid black line; Iceland, solid grey; Greenland, dashed black; Northern cod, dashed grey line. During the cold period of the 1960s–1980s, the average value of F was 0.59 with a standard deviation of 0.21.
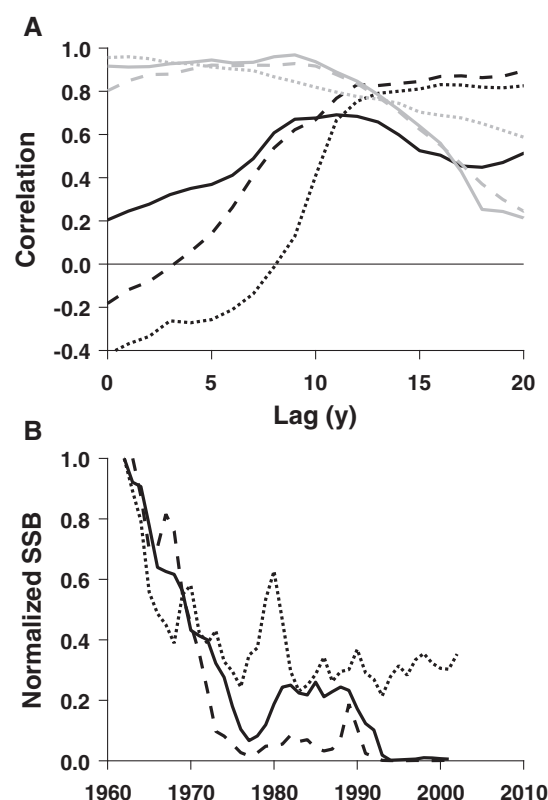


**Figure 3.** (a) Lagged correlation between SSB for the four regions (NE Arctic–Iceland, solid black; Greenland, dashed black; Northern cod, dotted black; Iceland–Greenland, solid grey; Northern cod, dashed grey; Greenland–Northern cod, dotted grey). The lags are for the second region relative to the first. When the start of the second series was <15 years after the reference series, the number of pairs in the correlation calculation was reduced. All pairs were affected except NE Arctic–Northern cod. The reduction in the number of pairs began at ten y lag for NE Arctic with Iceland and Greenland, year 1 for Iceland–Greenland, and year 8 for Iceland and Greenland with Northern cod. (b) Normalized SSB = SSB(y)/SSB(1962), where y indicates the year from 1962 to the end of the series (Northern cod, solid line; Greenland, dashed line; Iceland, dotted line).

**Table 2.** Correlation and per cent variance of SSB accounted for by F, the NAO, and the AMO in the multiple regression analysis.

| Variable | Correlation | | % Variance | |
|---|---|---|---|---|
| | **NEA** | **NWA** | **NEA** | **NWA** |
| F | −0.77 | −0.85 | 58.5 | 73.8 |
| NAO | −0.05 | −0.02 | <1 | 8.4 |
| AMO | 0.16 | 0.22 | <1 | <1 |

The Northeast Atlantic series (NEA) were from 1966 to 2012; the Northwest Atlantic series (NWA) were from 1970 to 1993; note that fishing moratoria on NWA cod were first initiated for several stocks in 1993 from Frank *et al.* (2016).

response to the AMO, if indeed it occurred, varied greatly over the North Atlantic. However, given the broad spatial scale of the AMO, it is not possible to determine whether the relationship between these rates of decline in cod SSB and the magnitude of the local climate variability is constant or variable from region to region.

We next addressed the east to west progression of the rate of decline of cod stocks implied by D&K using a lagged correlation analysis for all combinations of the four SSB time series. The analysis indicates that, based on the times when the correlations begin to asymptote, that the decline in SSB occurred first in the NE Arctic 7–11 years in advance of the decline in the three western regions (Figure 3a). Moreover, the correlations among the rates of decline in the three westernmost stocks were high at zero lag and remained relatively flat as the lag increased. This was also evident when these three SSB series were normalized by dividing by their 1962 SSB, the earliest common initial date for all three

series (Figure 3b). Thus, with the exception of a modest ∼2 years lag of Northern cod behind Iceland (Figure 3a), the timing of the dynamics of these three western stocks was essentially synchronous. We conclude that the evidence supports a bimodal response, the NE Arctic stock constituting one node and the three western stocks a second that lagged the NE Arctic by about a decade. Therefore, the evidence supporting the propagation of the decline in cod SSB from east to west is weak. D&K further explored the link between the assumed propagation of the cod declines and the progression of sea surface temperatures but were unsuccessful. Based on this result they concluded it was unclear what role temperature played in the decline of the four cod stocks and in the temporal delay. However, we find little evidence of the progressive cooling and instead attribute the cod declines to shifts in exploitation.

A more plausible explanation for the differences in the timing of the declines of SSB between the eastern and western Atlantic is that it resulted from a shift in fishing effort, the cod stocks being first depleted in the eastern Atlantic which, in turn, led to a westward shift of effort by the European fishing fleet. Österblom and Folke (2015) provide a detailed description of the dominant impact of the Soviet fishing fleet on North Atlantic cod stocks during its westward transition during the 1960s. In support of this hypothesis, Garrod and Schumacher (1994) identified a peak in annual Northeast Atlantic cod landings of 2.2 Mt in 1956 which was followed by a steady decline. In the Northwest Atlantic, peak cod landings (1.3 Mt) occurred in 1968, again followed by a steady decline. This 12-year offset between peak landings in the eastern and western Atlantic is consistent with the results of our lagged correlation analysis (Figure 3a).
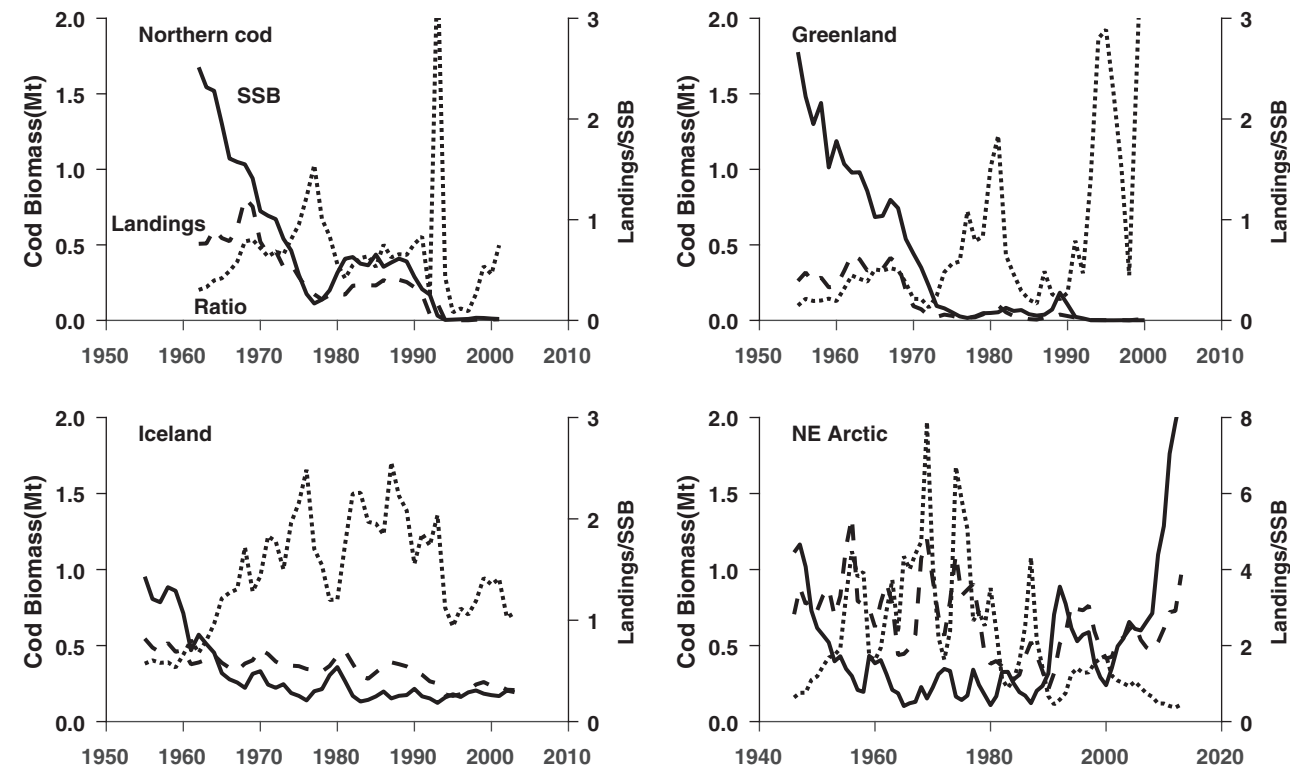


**Figure 4.** Time series of the estimates of SSB (solid line), recorded landings (dashed line), and the ratio of landings/SSB (dotted line) for Northern cod, Greenland, Iceland, and the NE Arctic cod stocks.

## The response of cod to AMO, NAO and exploitation

Frank *et al.* (2016) examined the dynamics of 22 North Atlantic cod stocks, including the four stocks featured in D&K [There are at least 22 cod stocks (independently assessed and managed) across the North Atlantic discussed by Frank *et al.* (2016). In addition to the four considered by D&K, there are annual time series of cod SSB available for thirteen stocks overlapping the "cold period" that could have been part of the overall analysis conducted by D&K. They include: Flemish Cap (1972), southern Grand Banks (1959), St. Pierre Bank (1959), southern Gulf of St. Lawrence (1950), eastern Scotian Shelf (1958), western Scotian Shelf (1950), northern Gulf of St. Lawrence (1974), Faroes (1961); Celtic Sea (1971), North Sea (1963), Kattegat (1971), western Baltic (1970), and central Baltic (1966) (starting year in parenthesis; see Kelly *et al.*, 2009; Frank *et al.*, 2016; ICES website, https://www.ices.dk/ Pages/default.aspx).]. This analysis revealed that synchronous, coherent SSB variability occurred in 13 western Atlantic stocks that was distinct from a second pattern of synchronous variability in 9 eastern Atlantic stocks that included Iceland. They then investigated the relative contribution of AMO, NAO (North Atlantic Oscillation), and F (fishing mortality) to changes in these SSB patterns. Their results (reproduced here from their Supplementary Table S2) indicated that fishing mortality (F) was the major contributor to the observed variance in SSB (Table 2). In a related analysis, Vasilakopoulos *et al.* (2012) concluded that when ICES stocks are considered in aggregate, exploitation rate was the main driver of stock status trends through time.

These findings are consistent with the annual SSB and landings for the four regions assessed by D&K where the periods of strong decline of the cod fisheries align with high levels of harvesting of the stocks (Figure 4). Indeed, the ratio of landings to SSB varies from 0.39 (Greenland) to 2.8 (NE Arctic) indicating an extraordinary, high rate of removal from the stocks (Figure 4 and Table 3).

## Closing remarks

We agree with the hypothesis advanced by D&K that climate variability can play a role in shaping the dynamics of marine ecosystems. However, in our view they have not adequately acknowledged the growing body of literature that points to the large-scale influence of exploitation in shaping these dynamics. This omission has become increasingly common in the literature examining the role of ocean climate in structuring the dynamics of exploited marine systems (Frank *et al.*, 2016, 2018). Our purpose in commenting here has been to illustrate the limitations inherent in such climate-centred approaches and to encourage a greater balance in future analyses of the important question of the factors that contribute to the shaping and stability of large marine ecosystems.

**Table 3.** Total landings, average SSB and average harvest rate (≡Landings/SSB) for the 1960–1989 period.

| Cod stock | Landings (Mt) | SSB (average, kt) | Harvest rate |
|---|---|---|---|
| Labrador–northern Newfoundland | 11.3 | 643 | 0.58 |
| Greenland | 4.1 | 351 | 0.39 |
| Iceland | 11.4 | 275 | 1.38 |
| NE Arctic | 18.9 | 226 | 2.78 |

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