The following supplements accompany the article

Extending time series of fish biomasses using a simple surplus production-based approach

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Supplement 1. List of stocks included in the analyses, time period of data coverage and identified changes in productivity regimes

Table S1. The stocks included in the analyses, their abbreviations and scientific names. The stock definitions are from the ICES assessment Working Group reports.

Abbreviation	Stock	Scientific name
cod-2224	Western Baltic cod (SD 22-24)	*Gadus morhua*
cod-2532	Eastern Baltic cod (SD 25-32)	'
cod-7e-k	Celtic Sea Cod	'
cod-arct	Northeast Arctic cod	'
cod-coas	Cod in Norwegian coastal waters	'
cod-farp	Faroe Plateau cod	'
cod-iceg	Icelandic cod	'
cod-iris	Cod in Division VIIa	'
cod-kat	Cod in the Kattegat	'
cod-nsea	Cod in the North Sea	'
cod-scow	Cod in Division VIa	'
ple-celt	Plaice in Divisions VIIfg	*Pleuronectes platessa*
ple-eche	Plaice in East Channel	'
ple-echw	Plaice in the Western Channel	'
ple-iris	Plaice in the Irish Sea	'
ple-kask	Plaice in Division IIIa	'
ple-nsea	Plaice in the North Sea	'
sol-bisc	Sole in Bay of Biscay	*Solea solea*
sol-celt	Sole in Divisions VIIfg	'
sol-eche	Sole in east Channel (Subarea VIId)	'
sol-echw	Sole in the Western Channel (Division VIIe)	'
sol-iris	Sole in Division VIIa	'
sol-kask	Sole in Division IIIa	'
sol-nsea	Sole in the North Sea	'
her-2532	Herring in the central Baltic Sea	*Clupea harengus*
her-30	Herring in Bothnian Sea	'
her-31	Herring in Bothnian Bay	'

her-3a22	Herring in Div. IIIa and Subdiv. 22-24	'
her-cs	Herring in Celtic Sea and Division VIIj	'
her-nirs	Irish Sea Herring (Division VIIa (N))	'
her-noss	Norwegian spring-spawning herring	'
her-nsea	North Sea Herring	'
her-riga	Herring in the Gulf of Riga	'
her-vasu	Icelandic summer-spawning herring	'
her-vian	Herring West of Scotland	'
sar-soth	Sardine in Divisions VIIIc & IXa	*Sardina pilchardus*
spr-2232	Sprat in the Baltic Sea (SD 22-32)	*Sprattus sprattus*
cap-icel	Capelin in Iceland-East Greenland-Jan Mayen	*Mallotus villosus*
cap_12	Barents Sea capelin	'
ghl-arct	Greenland halibut	*Reinhardtius hippoglossoides*
had-7b-k	Haddock in the Celtic Sea and west of Ireland	*Melanogrammus aeglefinus*
had-arct	Northeast Arctic haddock	'
had-faro	Faroe haddock	'
had-iceg	Icelandic haddock	'
had-nsea	Haddock in the North Sea and Skagerrak	'
had-rock	Haddock in Division VIb	'
had-scow	Haddock in Division VIa	'
nop-nsea	Norway Pout in the North Sea and Skagerrak	*Trisopterus esmarkii*
sai-arct	Northeast Arctic saithe	*Pollachius virens*
sai-faro	Faroe saithe	'
sai-icel	Icelandic saithe	'
sai-nsea	Saithe in the North Sea and Skagerrak	'
whb-comb	Blue Whiting	*Micromesistius poutassou*
whg-7e-k	Whiting in the Celtic Sea	*Merlangius merlangus*
whg-nsea	Whiting in the North Sea	'

Table S2. The time period of data included in the analyses of regime shifts (RS) in surplus production rates (SPR); the years when significant changes in SPR were identified, and corresponding regime shift index (RSI). Positive and negative values indicate a significant increase or a decline in SPR, respectively. See Table S1 for description of stocks

Abbreviation	**Years of coverage**	**Years of RS**	**RSI**
cod-2224	1970–2009	-	0
cod-2532	1946–2009	-	0
cod-7e-k	1971–2007	-	0
cod-arct	1900–2009	1964	0.19
cod-coas	1984–2009	-	0
cod-farp	1961–2009	-	0
cod-iceg	1955–2009	1965	0.32
cod-iris	1968–2009	-	0
cod-kat	1971–2009	-	0
cod-nsea	1921–2009	1960	0.28
cod-scow	1978–2009	1997	–0.66
ple-celt	1977–2009	-	0
ple-eche	1980–2009	-	0
ple-echw	1980–2009	-	0
ple-iris	1964–2009	1977/1988	0.29/–0.91
ple-kask	1978–2006	-	0
ple-nsea	1957–2009	1981	0.18
sol-bisc	1984–2009	1992	–0.07

sol-celt	1971–2009	-	0
sol-eche	1982–2009	-	0
sol-echw	1969–2009	-	0
sol-iris	1970–2009	-	0
sol-kask	1984–2009	1992	–0.17
sol-nsea	1957–2009	-	0
her-2532	1974–2009	1999	0.38
her-30	1973–2009	1982/1990	0.18/–0.24
her-31	1980–2009	-	0
her-3a22	1991–2009	-	0
her-cs	1958–2009	-	0
her-nirs	1961–2006	-	0
her-noss	1907-2008	1972/1987	0.08/–0.04
her-nsea	1947–2009	1978/1983	0.35/–0.54
her-riga	1977–2009	-	0
her-vasu	1986–2009	-	0
her-vian	1957–2009	-	0
sar-soth	1978–2007	-	0
spr-2232	1974–2009	-	0
cap-icel	1979–2009	-	0
cap_12	1972–2009	-	0
ghl-arct	1964–2009	-	0
had-7b-k	1993–2009	-	0
had-arct	1950–2009	-	0
had-faro	1957–2009	-	0
had-iceg	1979–2009	-	0
had-nsea	1963–2009	-	0
had-rock	1991–2009	-	0
had-scow	1978–2009	-	0
nop-nsea	1983–2009	-	0
sai-arct	1960–2009	2002	–0.46
sai-faro	1961–2009	1979/2002	0.18/–0.17
sai-icel	1962–2009	-	0
sai-nsea	1967–2008	-	0
whb-comb	1981–2008	-	0
whg-7e-k	1982–2009	1994	–0.51
whg-nsea	1921–2009	-	0

Historical data treatments:

The original pre-assessment biomass hindcasts for North Sea cod and whiting (Pope & Macer 1996) refer to the middle of a year, whereas the biomasses from ICES assessments are for the beginning of a year. We used the average ratio between total stock biomasses in the middle and in the beginning of a year during the period of overlap in both data series (1963–1990 for cod and 1980–1990 for whiting) to scale the pre-assessment biomasses to the beginning of a year in 1921–1962 and 1921–1979 for the 2 stocks, respectively.

For plaice in the North Sea, the original estimates of biomass start from 1929 (Rijnsdorp & Millner 1996). The estimates of fishing mortality however extend back to 1893 (Rijnsdorp & Millner 1996) and we used these to obtain the estimates of biomass for 1893–1928. Biomass in each year during this period was defined as the catch divided by the proportion of the stock removed by the fishery. In the period of ICES assessment (1957–2008), biomass derived in a similar way was strongly correlated with the analytical estimates ($r^2 = 0.90$, $p < 0.01$). The original estimates of total biomass were lacking for years 1939–1945, where the trends were extrapolated based on the values before and after this gap in the time series.

LITERATURE CITED:

Pope JG, Macer CT (1996) An evaluation of the stock structure of North Sea cod, haddock, and whiting since 1920, together with a consideration of the impacts of fisheries and predation effects on their biomass and recruitment. ICES J Mar Sci 53:1157–1169

Rijnsdorp AD, Millner RS (1996) Trends in population dynamics and exploitation of North Sea plaice (*Pleuronectes platessa* L.) since the late 1800s. ICES J Mar Sci 53:1170–1184

Supplement 2. Incorporating the effects of density dependence and climate forcing

Northeast Arctic cod:

The rate of increase in an unexploited population at its carrying capacity is considered to be close to zero (e.g. Haddon 2001). The biomass of Northeast Arctic cod in the beginning of the time series from ICES assessment (1946) was at the highest level observed since then, corresponding to a relatively low fishing mortality (ICES 2009). The information on relatively low catches and non-intensive fishery before the 1940s (Hylen et al. 2008) suggest that fishing pressure on this stock was likely relatively low during the entire first half of the 20th century. Relatively low surplus production rate values observed in the late 1940s (1946–1949, Fig. S1) might thus be related to density dependence and were considered more likely to apply for the preceding decades than the higher production rates observed during most of the subsequent period of intensive exploitation.

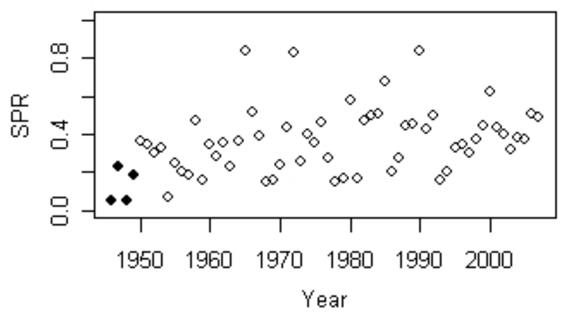


Fig. S1. Surplus production per biomass (SPR) of Northeast Arctic cod in 1946–2007. Filled data points distinguish the values for 1946–1949

Norwegian spring-spawning herring:

Several studies have found positive effects of temperature on Norwegian spring-spawning herring (e.g. Toresen & Østvedt 2000, Sætre et al. 2002). In this study, it was assumed that the main impacts of temperature can be represented by changes in the North Atlantic Oscillation (NAO) (Jones et al. 1997) during winter when the NAO has its greatest influence on sea temperatures and hydrographic variability in the North Atlantic (Marshall et al. 2001, Ottersen et al. 2001). NAO index data was provided by the Climate Analysis Section, NCAR, Boulder, USA, Hurrell (1995) (www.cgd.ucar.edu/cas/jhurrell/indices.html. Accessed 10.12.2010). A general additive model (GAM) was used to visualise long-term changes in the NAO index. The model was fitted to NAO time series using locally weighted least squares regression (LOESS), with degrees of freedom selected objectively using a generalized cross-validation (GCV) procedure (SAS Inc. 2000).

Average surplus production rate (SPR) of Norwegian spring-spawning herring in 1950–1969 (before the stock collapse) was significantly lower ($t = –4.068$; $p < 0.001$) than in 1988–2006 (after the recovery); concurrent to a higher NAO index in the later period (Fig. S2). The GAM-fitted NAO index in 1930–1949 was generally negative, similar to the situation in 1950–1969; the average production rate observed in 1950–1969 was therefore used to calculate the biomass from 1950 back to 1930. The average SPR observed in 1988–2006 was applied for 1907–1929, as both of these periods were characterised by a similar positive NAO index (Fig. S2).

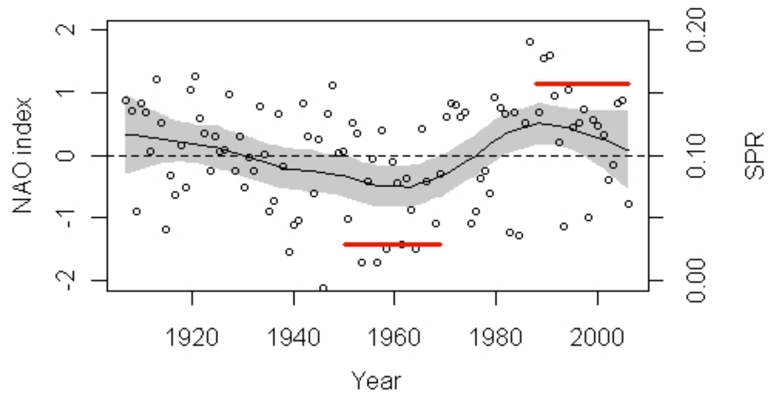


Fig. S2. North Atlantic Oscillation (NAO) index (dots) in 1907–2006 with the trend fitted by general additive modelling (GAM) including 95% confidence intervals (shaded grey). Straight bold lines indicate average surplus production per biomass (SPR) of Norwegian spring-spawning herring in 1950–1969 and in 1988–2006

LITERATURE CITED:

Haddon M (2001) Modelling and quantitative methods in fisheries. Chapman&Hall/CRC, Boca Raton, FL

Hylen A, Nakken O, Nedreaas K (2008) Northeast Arctic cod: fisheries, life history, stock fluctuations and management. In: Nakken O (ed) Norwegian spring-spawning herring & Northeast Arctic cod: 100 years of research and management. Tapir Academic Press, p 83–119

ICES (2009) Report of the Arctic Fisheries Working Group (AFWG). ICES CM Document 2009/ACOM: 02, London

Jones PD, Jonsson T, Wheeler D (1997) Extension to the North Atlantic oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland. Int J Climatol 17:1433–1450

Marshall J, Kushnir Y, Battisti D, Chang P and others (2001) North Atlantic climate variability: phenomena, impacts and mechanisms. Int J Climatol 21:1863–1898

Ottersen G, Planque B, Belgrano A, Post E, Reid PC, Stenseth NC (2001) Ecological effects of the North Atlantic Oscillation. Oecologia 128:1–14

SAS Inc (2000) The SAS system for data analysis (Proc GAM). SAS Corporation, Cary, NC

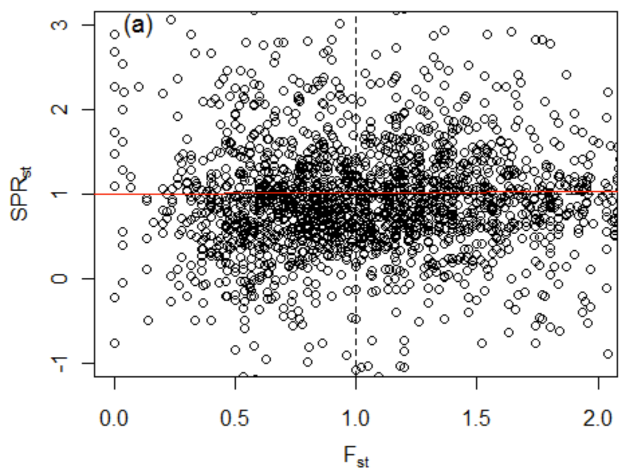
Sætre R, Toresen R, Anker-Nilssen T (2002) Factors affecting the recruitment variability of the Norwegian spring-spawning herring (*Clupea harengus* L.). ICES J Mar Sci 59:725–736

Toresen R, Østvedt OJ (2000) Variation in abundance of Norwegian spring-spawning herring (*Clupea harengus*, Clupeidae) throughout the 20th century and the influence of climatic fluctuations. Fish Fish 1:231–256

Supplement 3. Potential links between surplus production rate and fishing mortality

Surplus production rates of exploited populations could be expected to be influenced by concurrent levels of fishing mortality. We investigated this hypothesis by looking at patterns in the observed SPR values and corresponding fishing mortalities using a combined dataset for all 55 stock included in the analyses. To do so, the time series of SPR for each stock was standardised relative to the mean value observed in the time series for a particular stock. The time series of fishing mortalities were standardized relative to reference values, which were defined by species groups and the values roughly represented the average fishing mortalities recorded for these species during the available time series. The reference values applied were: 0.6 for cod; 0.5 for other gadids and flatfish and 0.3 for small pelagics. The standardized annual fishing mortalities plotted against corresponding standardized SPR values did not show any association between the 2 parameters (Fig. S3a).

In a next step, we investigated whether the annual deviations between the original biomasses from the assessments and those obtained applying mean stock-specific SPR values for all years were associated to concurrent levels of fishing mortality (Fig. S3b). We hypothesised that at lower fishing mortalities, the biomasses are relatively more driven by variable biological production and larger deviations from original biomasses could in these situations be expected when applying constant production rates for all years. This pattern was however not apparent within the range of observed fishing mortalities, which extended from being twice as high or only about one third of the average level recorded for a particular species group (Fig. S3b). The back-calculated biomasses deviated from the original estimates by a similar magnitude, regardless of the level of fishing mortality. However, at lower fishing mortalities, biomasses were slightly more often under than over-estimated.



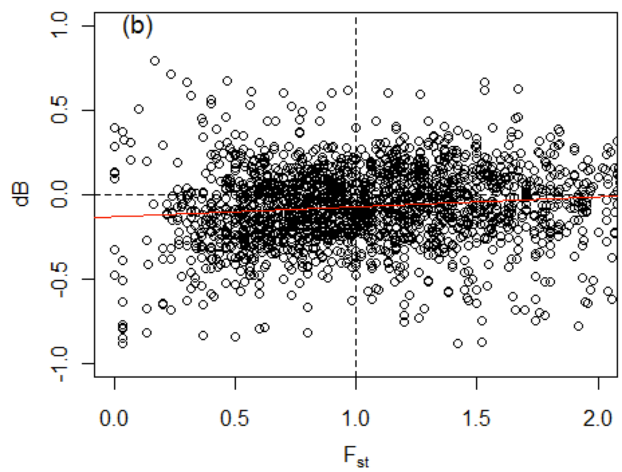


Fig. S3. Annual standardized fishing mortalities (F_{st}) plotted against corresponding (a) surplus production rate values (SPR_{st}) and (b) the differences between the observed and back-calculated biomasses (dB), obtained applying mean SPR for all years. The data are shown combined for all stocks included in the analyses for the time-period covered by ICES assessments. The SPR_{st} and F_{st} corresponding to 1 represent the mean observed SPR for a particular stock, and roughly the average F observed for a particular species group, respectively.

Supplement 4. Robustness of the SPR-based approach to inter-annual variability in surplus production rates

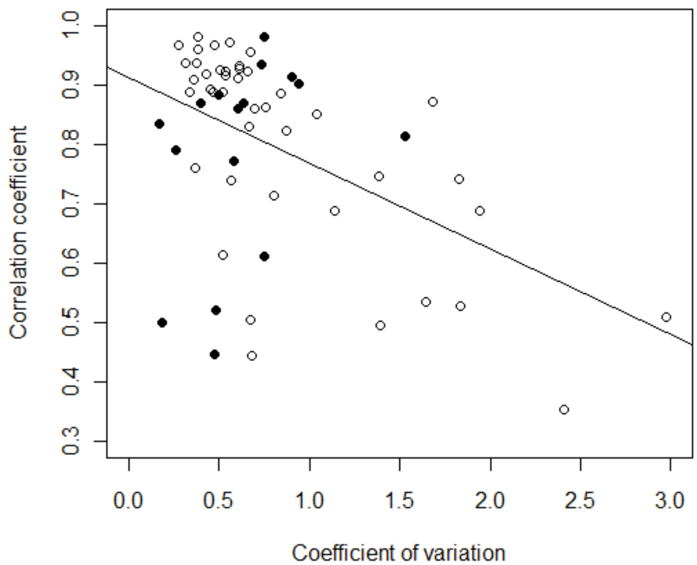


Fig. S4. Coefficient of variation (CV) of annual surplus production rates of different stocks plotted against correlation coefficients (rho) between the original and back-calculated biomasses applying mean surplus production rate (SPR) values for all years. Each data points refer to one stock. The plot distinguishes between the stocks for which significant changes in SPR over time were identified (filled dots) and the stocks with no significant change in SPR (open circles).