Cost of selectivity: inducing of density-dependent growth in Eastern Baltic cod (*Gadus morhua*)

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Summary
Over the last decades, views on fisheries have oscillated between mistrust and confidence in management progress. The predominating policy remedy to world fish crisis, promoted by the Johannesburg declaration, aims at Maximum Sustainable Yield (*MSY*) by adjusting gear selectivity and fishing effort. Here we show a strong case study on how the strive for higher yields from the Eastern Baltic cod stock by increasing selectivity has become exceedingly detrimental for its productivity. As fish number in non-fishable sizes successively increase, growth potential is severely reduced, whereas fishing mortality increases on fishable sizes. Our findings suggest that policies focusing on maximum yield and targeting greater sizes are risky and should instead be redirected towards more risk-averting combinations of selectivity and effort, giving less yield but higher catch-per-unit-effort. Disregard of dynamic interactions will have dire consequences for the cod stock functioning, profitability of the fishing industry and overall ecosystem structure and function.

Introduction
After several decades of excess fishing mortality, the Eastern Baltic cod stock (*Gadus morhua*) has improved considerably (Eero *et al*. 2012, ICES 2013). Due to these promising signals of population recovery from stock assessment, the management framework has been regarded as sustainable since 2009.

However, shortly after the management objectives were reached in 2009 (Eero *et al*. 2012a), growth (measured as weight-at-age) was observed having declined in recent years and the growth potential (measured as the mean maximum length of a cohort, L_∞) has declined steeply over the last 15 years (Svedäng and Hornborg 2014). This decline in growth is linked to a significantly increased gear selectivity over the past 15 years (Feekings *et al*. 2013). Higher selectivity has led to reduced juvenile mortality, resulting in density-dependent growth as the number of small sized fish have increased since the beginning of the 2000s, whereas abundance of fish >45 cm has declined since 2010.

Changes in selectivity are often less rewarding than adjustments in effort, of which the latter usually is set too high, in particular, in relation to the Maximum Economic Yield, MEY (e.g. Quinn II and Deriso 1999). The present fishery is unprofitable at fleet level due to low growth but also due to the fact that *F* is too high. In order to increase yield from the stock, it is of paramount interest to increase growth potential. There is an obvious risk that growth potential will be substantially lowered when management is aiming at the seemingly highest yields. For the development of a more integrated and transparent management strategy for Eastern Baltic cod, priorities and trade-offs between management objectives need to be clarified.

Material and methods
In order to model economic performance under different selectivity and effort regulations, the Swedish Agency for Marine and Water Management (SwAM) was asked to provide information concerning a subset of the Swedish demersal trawling fleet in the Baltic Sea, whose landings of cod caught in ICES SD

25-29 exceeded 50% of the value of their annual landings during 2008-2011. This subset of fishing vessels is in our study used as a template for the entire Baltic cod fishery.

Size structure of the Eastern Baltic cod stock is retrieved from ICES DATRAS (1991-2013). For modelling reasons, a knife-edge selectivity is assumed, meaning that all members of a cohort reach fishable size at length at first catch, L_c (Quinn II and Deriso 1999).

Results

The total yield of Eastern Baltic cod in 2011 is estimated as *c.* 50 000 tonnes, according survey based fishing mortality, *F*, estimates at about 0.8-0.9 (Svedäng and Hornborg 2014) and L_c nominally at 44 cm (Feekings *et al*. 2013); this is rather similar to reported catches (ICES 2013). It can be noted that the predicted yield at L_c = 30 cm and *F* = 0.3 would be very similar though the economic performance would be widely improved.

Further, we assumed that a lowered L_c to about 30 cm would act to restore growth potential in the stock by counter-acting density-dependence. It is found that at a moderately restored growth potential of L_∞=90 would result in total yields at about 91 000 tonnes at *F*=0.5. However, the highest economic returns at expected at *F* = 0.3, equalling 118 million US $. Profitability declines steeply at higher and lower *F* at this level of L_c. The MEY approach would only marginally inflict on the amount of landed cod (85000 v. 91 000 tonnes). It is also observed that the population size structure is more dependent on L_∞ than on *F*, measured as Large Fish Indicator (LFI).

Discussion

If sustainable development of fisheries is to be achieved, management policies need to be evaluated in perspective of several objectives (Larkin 1977). Policies aiming at achieving maximum sustainable yield have been a step forward as to avoid impaired recruitment and to combat growth overfishing (Lassen *et al*. 2014). Although local MSYs at specific selectivity are achievable, this harvest strategy remains to be evidenced as desirable, especially when risking inducing density dependent growth. A lower effort level than is required for MSY contributes to a more ecologically robust situation. As it involves higher fishable biomass in the ecosystem than is required, this will in turn bring higher economic profit for individual fishers. The costs of lost growth potential and associated skewed size structure include, besides economic aspects, important ecological aspects (Garcia *et al*. 2012).

References

Eero, M., Köster, F.W. and Vinther M. 2012. Why is the Eastern Baltic cod recovering? Marine Policy 36: 235-240.

Feekings, J., Lewy, P. and Madsen, N. 2013. The effect of regulation changes and influential factors on Atlantic cod discards in the Baltic Sea demersal trawl fishery. Canadian Journal of Fisheries and Aquatic Sciences 70: 534-542.

Garcia, S.M., Kolding, J., Rice, J., Rochet, M.-J., Zhou, S., et al. 2012. Reconsidering the consequences of selective fisheries. Science 335: 1045-1047.

ICES 2013. Report of the ICES advisory committee. ICES Advice. Books 1–11, International Council for the Exploration of the Sea, Copenhagen.

Larkin, P.A. 1977. An epitaph for the concept of maximum sustained yield. Transactions of the American Fisheries Society 106: 1-11.

Lassen, H., Kelly, C. and Sissenwine, M. 2014. ICES advisory framework 1977–2012: from F_{max} to precautionary approach and beyond. ICES Journal of Marine Science 71: 166-172.

Quinn II, T.J. and Deriso, R.B. 1999. *Quantitative Fish Dynamics*. Oxford University Press, pp. 542.

Svedäng, H. & Hornborg, S. 2014. Selective fishing induces density-dependent growth. Nature Communications 5: 4152 doi: 10.1038/ncomms5152.