NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

Serial No. N5077 **NAFO SCR Doc. 05/3**

SCIENTIFIC COUNCIL MEETING – JUNE 2005

An Illustration of the Implications for B_{lim} and Stock Projections of Various Indices of Reproductive Potential for Divisions 3LNO American Plaice

M. J. Morgan

Dept. of Fisheries and Oceans, P.O. Box 5667, St. John's
NL, A1C 5X1, Canada

Abstract

Estimates of reproductive potential for Divisions 3LNO American plaice were produced by sequentially incorporating estimates of proportion mature-at-age, sex ratio-at-age and potential egg production. The estimates of reproductive potential produced by each method were broadly similar but there were important differences. Perceptions of current stock status ranged from 16 to 40% of B_{lim} depending on the index of reproductive potential used. The different indices of reproductive potential showed stock size at the end of a 10-year projection period to range from less than 60% to 150% of B_{lim} depending on the index.

Keywords: reproductive potential, maturity, fecundity, sex ratio, reference points

Introduction

Several factors contribute to the number of recruits produced by a fish population. Many of these factors are not incorporated into traditional estimates of spawning stock biomass. The sex ratio of the spawning stock can vary, leading to changes in egg production (Marshall *et al*., 1998; Kraus *et al*., 2002). The age structure of the spawning stock is important and may affect the spawning success of the population (Lambert, 1990; Kjesbu *et al*., 1996; Marteinsdottir and Thorarinsson, 1998; Trippel, 1998). Variation in condition of the spawners can result in changes in fecundity and/or viability of eggs and larvae, or even in failure to spawn (Marshall *et al*., 1998; Marteinsdottir and Steinarsssson, 1998; Lambert and Dutil, 2000; Rideout *et al*., 2000). In addition the proportion of fish that are mature at each age can show substantial changes over time (Jorgensen, 1990; Rijnsdorp, 1989; Hunt, 1996; Morgan and Colbourne, 1999). The combination of these factors will determine a population's reproductive potential (Trippel, 1999).

The relationship between spawning stock biomass and recruitment is an important aspect in the determination of biological reference points under the precautionary approach. Limit reference points are generally chosen as the spawning stock biomass below which recruitment is seriously impaired (Mace and Sissenwine, 1993; Shelton and Rivard, MS 2003). In addition, predictions about the potential for depleted stocks to rebuild will depend on the underlying assumptions about the stock recruit relationship. The use of spawning stock biomass assumes that it is a good estimate of stock reproductive potential. If spawning stock biomass is not a good predictor of recruitment, then our ability to set limit reference points and predict stock recovery will be seriously impaired.

The purposes of this study were to quantify the extent of the impact of changes in maturity, sex ratio and potential egg production at age in American plaice in Div. 3LNO on estimates of the reproductive potential (RP) and recruitment rate of the stock. Example limit reference points are derived from each estimate of RP and 10-year deterministic stock projections conducted.

Methods

Maturity

Female maturity data were collected during research vessel bottom trawl surveys from 1963 to 2002. Data from 1972 to 2002 were from stratified random surveys covering the entire Div. 3LNO. Data from earlier years came from surveys that were conducted mainly as line transects and the coverage of a stock area would generally not be as complete as the stratified random surveys. Spring survey information was used (mainly May-June). Females were classed as immature or adult according to the classification of Templeman *et al*. (1978) following macroscopic examination of the gonad. Observed proportion mature-at-age was calculated according to the method of Morgan and Hoenig (1997) to account for the length stratified method of sampling.

Maturities were modelled by cohort using a generalized linear model with a logit link function and binomial error (McCullagh and Nelder, 1983). Age was modelled as a continuous variable. Only cohorts with both a significant slope and a significant intercept were included in the overall model. The 1950 to 1995 cohorts were modelled. For the earliest and latest cohorts for which maturities could not be estimated, the average of the 3 closest cohorts was used.

Sex ratio

Observed sex ratio was calculated as the proportion female-at-age calculated from estimates of population numbers-at-age by sex from stratified analysis programs applied to stratified random research vessel data from 1972 to 2002 (Smith and Somerton, 1981). These proportions were examined for significant cohort and age effects using generalized linear models with a logit link function and binomial error. Cohort and age were modelled as class variables. The fitted models were used to produce estimates of sex ratio-at-age for each cohort.

Fecundity

A time invariant fecundity-length relationship was used to estimate the number of eggs produced at each age. This relationship was applied to mean length-at-age on January 1, as derived from sampling of the commercial fishery. The relationship was taken from Pitt (1964). The relationship was:

$$\text{Log fecundity} = 3.17 * \log \text{length} - 2.68$$

Indices of reproductive potential

To examine the possible impact of changes in maturity, sex ratio and fecundity (through changes in length and age composition of the spawners) several different indices of reproductive potential (RP) were calculated. The basis for all of the calculations was the number-at-age from sequential population analysis and the mean weight-at-age, both from the beginning of the year (Morgan *et al*., MS 2003).

The first estimate of RP (knife-edge maturity) assumed that there has been no change in the maturity schedule of the fish and that the spawning stock was simply the sum of the biomass above a certain age. Biomass was calculated by multiplying the weights-at-age described above by half of the estimate of the population number-at-age. This biomass was summed over the ages that were historically used in the calculation of RP for this stock, age 9+. This method of calculating RP also assumes that the sex ratio is 50:50 for all ages and all cohorts.

$$RP_{knife-edge} = 0.5 \sum_{a=i}^{j} N_{ay} W_{ay}$$

where: N_{ay} = population number at age a in year y
W_{ay} = weight at age a in year y
a = age from *9* to *15+*

The second estimate of RP (variable maturity) incorporates the estimated proportion mature-at-age for each cohort by multiplying one half of the population number-at-age by the weight-at-age and estimated proportion mature-at-age. This estimate will show the impact of any changes in maturation over time.

$$RP_{maturities} = 0.5\sum_{a=i}^{j} N_{ay} W_{ay} M_{ay}$$

where: M_{ay} = proportion mature at age a in year y
a = age *5* to *15+*
and the other symbols are as defined above.

The third (sex ratio), applied the variable sex ratios that were estimated along with the estimates of proportion mature-at-age.

$$RP_{sex\,ratio} = \sum_{a=i}^{j} N_{ay} W_{ay} M_{ay} SR_{ay}$$

where: SR_{ay} = the proportion female at age a in year y
and the other symbols are defined above.

The final index of RP incorporated estimates of fecundity (egg production). The fecundity-at-age series derived from the fecundity at length relationships and mean length-at-age as describe above was multiplied by the population number-at-age times the proportion mature-at-age times the sex ratio-at-age.

$$RP_{egg\,production} = \sum_{a=i}^{j} N_{ay} M_{ay} SR_{ay} E_{ay}$$

where: E_{ay} = the number of eggs produced at age a in year y
and the other symbols are defined above

Recruitment rate

Number of recruits was taken as number of 5 year olds from SPA. The recruitment rate (RPS: recruits/RP) was determined from each index of reproductive potential. The RPS from each index was standardized to the mean rate for the index to facilitate comparison.

B_{lim} and projections

As an example of setting B_{lim} the index of reproductive potential predicted to result in 50% of the maximum recruitment was chosen. For each reproductive potential/recruit scatter a smoother was fit to determine the level of maximum recruitment. Smoothers were lowess with the smoothing window determined by minimizing Akaike information criterion.

Once B_{lim} was established, 10 year deterministic projections were carried out for each stock using each index of RP. The projections used the following process and assumptions:

population numbers were projected assuming F = 0 and M = 0.2
recruitment = average RPS from last 3 years before projection period calculated for each index of RP * index of RP in year cohort born
weights - average last 3 years before projection period
maturities - cohort model or average last 3 years before projection period if no estimates of maturity for a cohort
sex ratio - cohort model or average last 3 years before projection period if no estimates of maturity for a cohort
egg production-at-age – fecundity length relationship applied to average length-at-age over last 3 years before projection period

Results and Discussion

Changes in maturity and sex ratio

There have been substantial changes in the maturation of Div. 3LNO American plaice with fish from more recent cohorts maturing at a much younger age. Age at 50% maturity for the earliest cohorts modelled was around 11 years while the cohorts of the 1990's had A_{50} of around 8 years (Morgan *et al*., MS 2003). There have also been significant changes in sex ratio over time ($\chi^2 = 603$, df = 25, $P < 0.0001$) and there is a significant difference in sex ratio across age ($\chi^2 = 5180$, df = 11, $P < 0.0001$). Sex ratio increases from less than 50% female at the youngest ages modelled to 1 at about age 13 (Fig. 1). The proportion female showed some decline from the cohorts of the mid-1970s to about 1982. Then it increased steeply until the 1987 cohort, after which it showed some decline but has remained above the level seen prior to the 1980s.

Indices of reproductive potential

The overall trends in RP are similar regardless of the method of estimation (Fig. 2). However, there are some important differences. RP knife-edge started to increase in the 1970s 2 years before the other indices, but reached its next peak at the same time as the other indices. Knife-edge RP then started to decline ahead of the other indices in the 1980s.

The absolute level of difference between the indices can be compared for knife-edge maturity, variable maturity and sex ratio. The difference in the estimates of RP was sometimes substantial. The maximum difference between knife-edge maturity and the other two indices was 160 000 tons. The maximum difference between the index using variable maturity and the one incorporating sex ratio was smaller at 45 000 tons. There is a major impact of the changes in maturity-at-age on the estimated size of the spawning stock, as well as an additional impact of estimated changes in sex ratio.

Recruitment rate

Trends in the standardized recruitment rate for each index also show the same overall patterns (Fig. 3). However there are some major differences. If all indices showed the same pattern the lines would all indicate the same level relative to the mean, in each year. This is not the case. There is a large divergence of more than 50% in the mid-1970s and the indices diverge again in the most recent period.

B_{lim} and projections

An example of the stock recruit scatters and setting of B_{lim} using the various measures of RP is given in Fig. 4. Although any index of RP can be used in the setting of reference points, the current status of a stock relative to the reference point will vary depending on which index of RP is used. In this example, the current index of RP using knife-edge maturities is about one-half the percentage of B_{lim} that the other indices of RP are currently estimated to be. If the knife-edge index of RP is used the stock would need to increase by more than 6 times its current size before reaching B_{lim}, while the other indices of RP show that less than a 3 fold increase is needed. The ranking of stock status derived from the various indices will depend on the current characteristics of the spawning stock, relative to that observed during the period used to construct B_{lim}.

The results of short term deterministic projections again show that different measures of RP will result in different perceptions of stock status relative to B_{lim} (Fig. 5). In this example, the largest projected increase in stock size is for the index of RP incorporating sex ratio and the stock is projected to be the highest relative to B_{lim} using this index as well. The projections using the maturity and sex ratio indices of RP are at or slightly above B_{lim} by the end of the projection period while the projection using the knife-edge index of RP is less than 60% of B_{lim}. The variation in the level of the stock relative to B_{lim} at the end of the projection period is the result of the evolution of age structure during the projection period, the perceived productivity using each index of RP and differences in the initial estimated status of the stock relative to B_{lim}.

References

HUNT, J. J. 1996. Rates of sexual maturation of Atlantic cod in NAFO Division 5Ze and commercial fishery implications. *J. Northw. Atl. Fish. Sci*., **18**: 61-75.

JORGENSEN, T. 1990. Long-term changes in age at sexual maturity of northeast Arctic cod (*Gadus morhua* L.). *Journal du Conseil Permanent international pour l'Exploration de la Mer*, **46** : 235-248.

KJESBU, O. S., P. SOLEMDAL, P. BRATLAND, and M. FONN. 1996. Variation in annual egg production in individual captive Atlantic cod (*Gadus morhua*). *Can. J. Fish. Aquat. Sci*., **53**: 610-620.

KRAUS, G., J. TOMKIEWICZ, and F. W. KOSTER. 2002. Egg production of Baltic cod (*Gadus morhua*) in relation to variable sex ratio, maturity, and fecundity. *Can. J. Fish. Aquat. Sci*., **59**: 1908-1920.

LAMBERT, T. C. 1990. The effect of population structure on recruitment in herring. *J. Cons. int. Explor. Mer*., **47**: 249-255.

LAMBERT, Y., and J-D. DUTIL. 2000. Energetic consequences of reproduction in Atlantic cod (*Gadus morhua*) in relation to spawning level of somatic energy reserves. *Can. J. Fish. Aquat. Sci*., **57**: 815-825.

MACE, P. M., and M. P. SISSENWINE. 1993. How much spawning per recruit is enough? *In*: Risk Evaluation and Biological Reference Points for Fisheries Management. Ed. S. J. Smith, J. J. Hunt and D. Rivard (eds). *Can. Spec. Pub. Fish. Aquat. Sci*., **120**: 101-118.

MARSHALL, C. T., O. S. KJESBU, N. A. YARAGINA, P. SOLEMDAL, and O. ULLTANG. 1998. Is spawner biomass a sensitive measure of the reproductive and recruitment potential of northeast Arctic cod? *Can. J. Fish. Aquat. Sci*., **55**: 1766-1783.

MARTEINSDOTTIR, G., and K. THORARINSSON. 1998. Improving the stock-recruitment relationship in Icelandic cod (*Gadus morhua*) by including age diversity of spawners. *Can. J. Fish. Aquat. Sci*., **55**: 1372-1377.

MARTEINSDOTTIR, G., and A. STEINARSSON. 1998. Maternal influence on the size and viability of Iceland cod *Gadus morhua* eggs and larvae. *J. Fish Biol*., **52**: 1241-1258.

MCCULLAGH, P., and J.A. NELDER. 1983. Generalized linear models. Chapman and Hall, London.

MORGAN, M. J., and E. B. COLBOURNE. 1999. Variation in maturity-at-age and size in three populations of American plaice. *ICES J. Mar. Sci*., **56**: 673-688.

MORGAN, M.J., and J.M. HOENIG. 1997. Estimating maturity-at-age from length stratified sampling. *J. Northw. Atl. Fish. Sci*., **21**: 51-63.

MORGAN, M. J., W. B. BRODIE, D. MADDOCK PARSONS and B. P. HEALEY. MS 2003. An assessment of American plaice in NAFO Divisions 3LNO. NAFO SCR Doc. 03/56.

PITT, T. K. 1964. Fecundity of the American plaice, *Hippoglossoides platessoides* (Fabr.) from Grand Bank and Newfoundland areas. *J. Fish. Res. Bd. Canada*, **21**: 597-612

RIJNSDORP, A. D. 1989. Maturation of male and female North Sea plaice (*Pleuronectes platessa* L.). *J. Conseil int. Explor. Mer*., **46**: 35-51.

RIDEOUT, R. M., M. P. M. BURTON, and G. A. ROSE. 2000. Observations on mass atresia and skipped spawning in northern Atlantic cod, from Smith Sound, Newfoundland. *J. Fish Biol*., **57**: 1429-1440.

SHELTON, P. A., and D. RIVARD. 2003. Developing a precautionary approach to fisheries management in Canada – the decade following the cod collapses. NAFO SCR Doc. 03/1.

SMITH, S. J., and G. D. SOMERTON. 1981. STRAP: A user oriented computer analysis system for groundfish research trawl survey data. *Can. Tech. Rep. Fish. Aquat. Sci*., **1030**, iv + 66p.

TEMPLEMAN, W., V. M. HODDER, and R. WELLS. 1978. Sexual maturity and spawning in haddock, *Melanogrammus aeglefinus*, of the southern Grand Bank. *ICNAF Res. Bull*., **13**: 53-65.

TRIPPEL, E. A., 1998. Egg size and viability and seasonal offspring production of young Atlantic cod. *Trans. Amer. Fish. Soc*., **127**: 339-359.

TRIPPEL, E. A., 1999. Estimation of stock reproductive potential: history and challenges for Canadian Atlantic gadoid stock assessments. *J. Northw. Atl. Fish. Sci.,* **25**: 61-81.

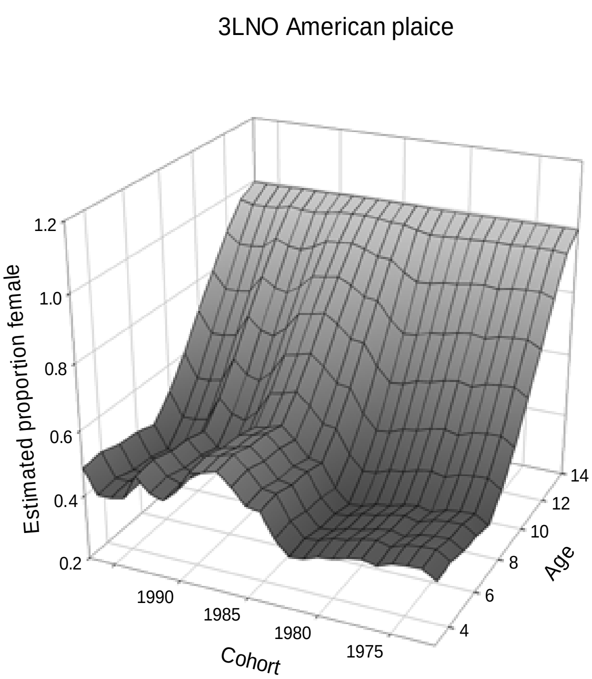

Fig. 1. Estimated proportion female by cohort and age for Div. 3LNO American plaice.

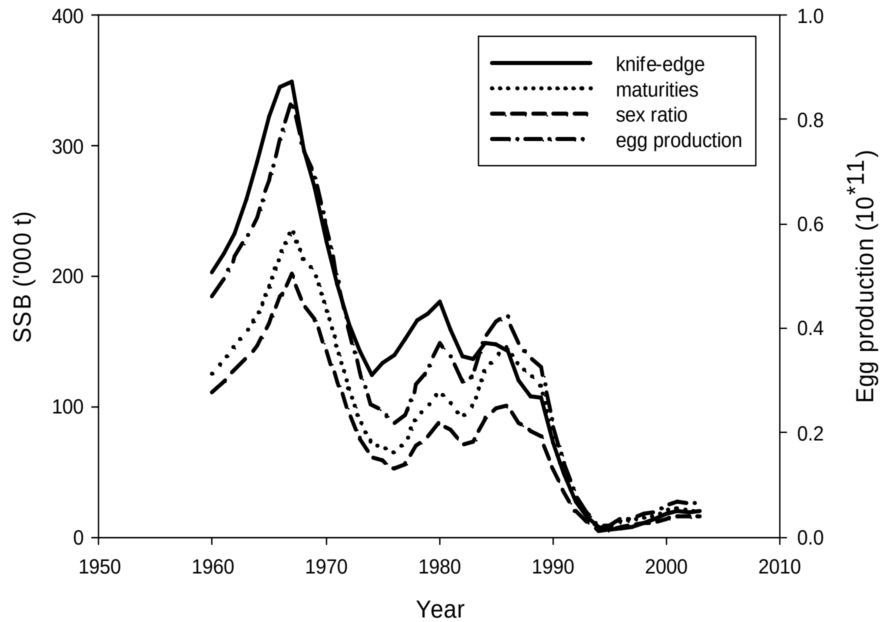

Fig. 2. Estimates of reproductive potential as biomass or egg production for Div. 3LNO American plaice. Estimates are produced using the biomass of all fish greater than 9+ (knife edge), using estimates of proportion mature-at-age (maturities), using maturities and estimated sex ratio (sex ratio) and by calculating egg production using variable maturity, sex ratio and estimated fecundity-at-age.

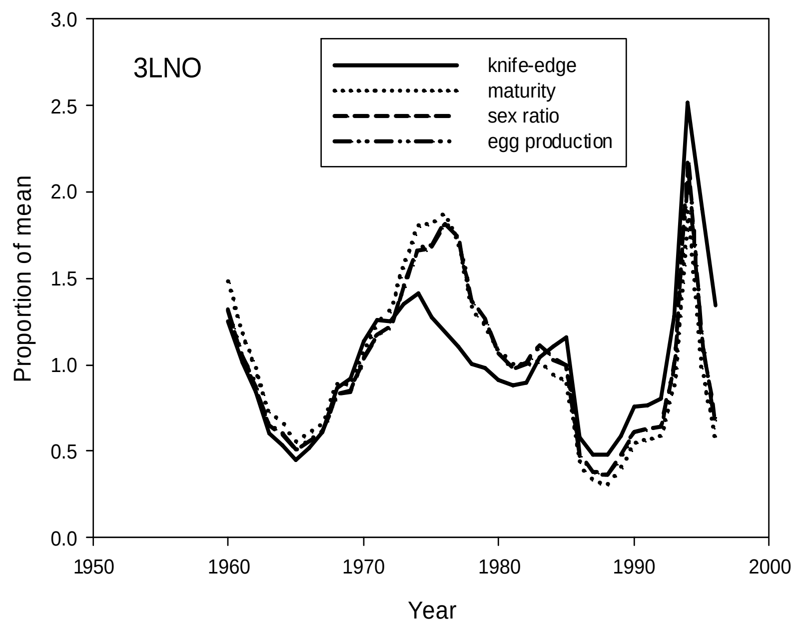

Fig. 3. Standardized recruitment rate (recruits/spawner: RPS) from each estimate of reproductive potential for Div. 3LNO American plaice.

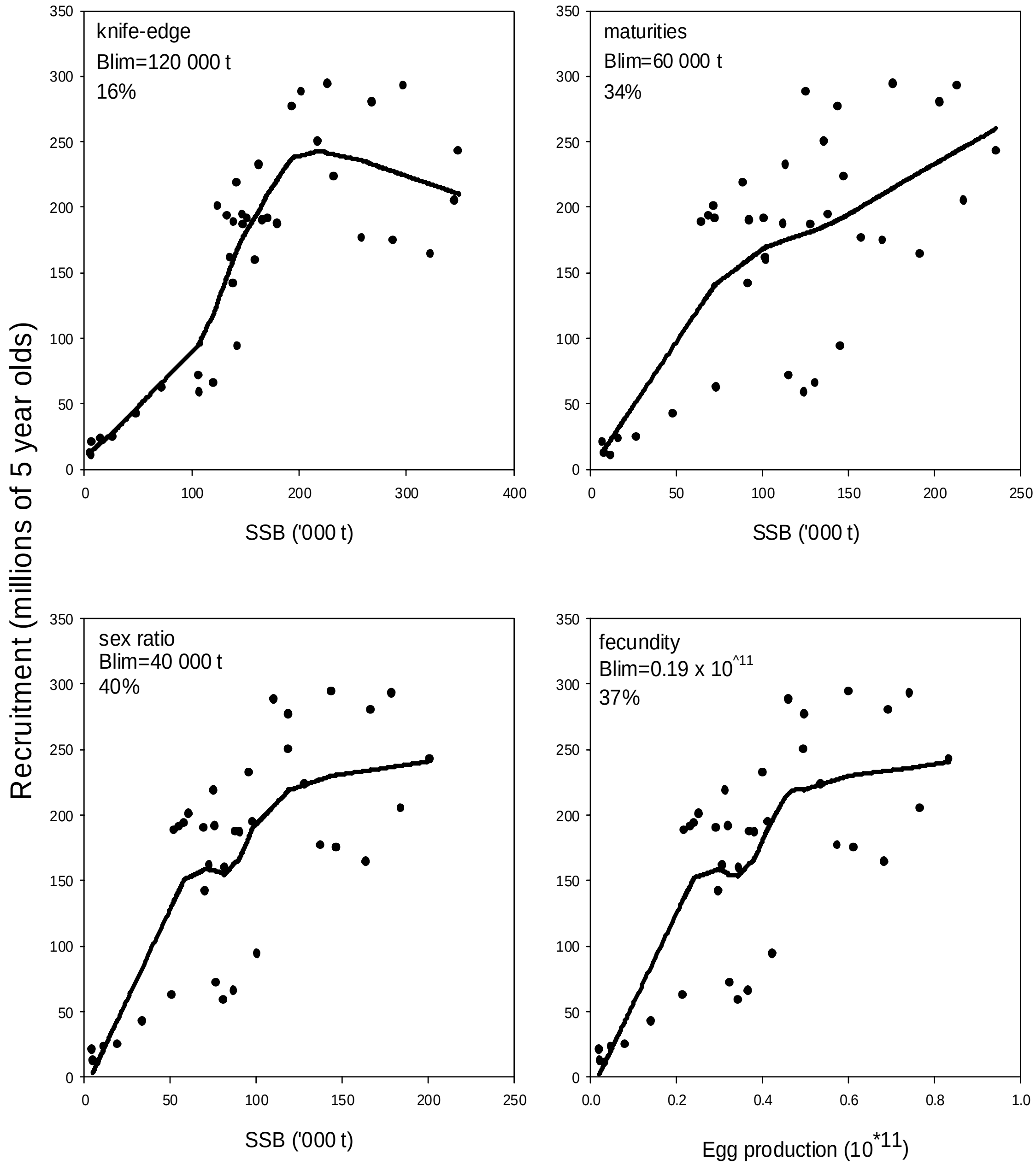

Fig. 4. Example of setting B_{lim} using different indices of reproductive potential. The percentage that the current stock size is of B_{lim} is given for each index of RP.

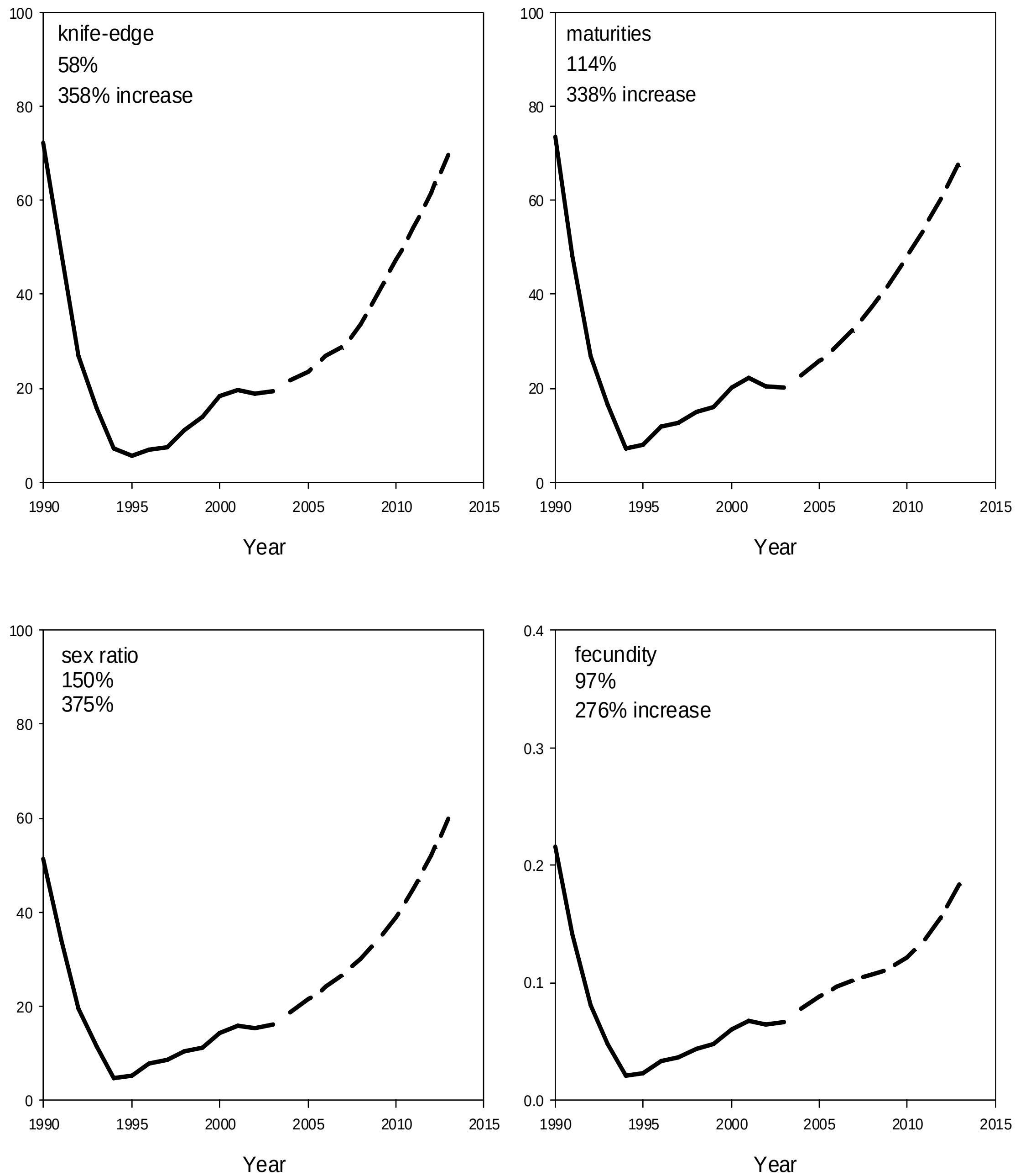

Fig. 5. Example 10-year deterministic projections using different indices of reproductive potential. The level of the stock at the end of the projection period is given as percent of B_{lim}, as well as the projected percentage increase in stock size over the period of the projection.