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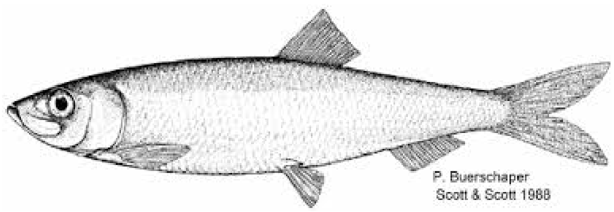
Maritimes Region

Canadian Science Advisory Secretariat
Science Advisory Report 2024/048

SCIENCE ADVICE ON A PERFORMANCE THRESHOLD FOR THE MANAGEMENT STRATEGY EVALUATION FOR SOUTHWEST NOVA SCOTIA/BAY OF FUNDY ATLANTIC HERRING (*CLUPEA HARENGUS*)



Atlantic Herring *(Clupea harengus)*

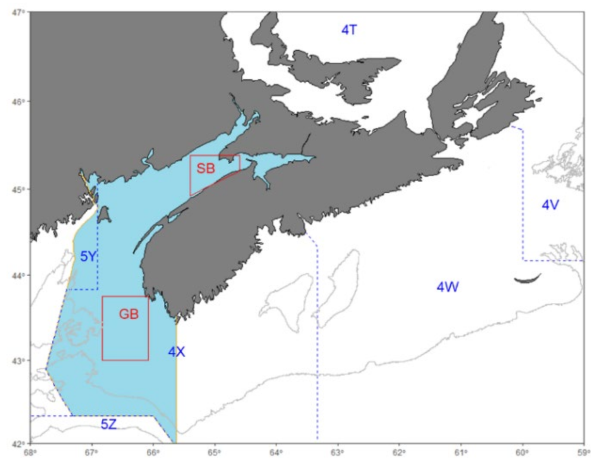


Figure 1. Spatial boundary (blue shading) of the southwest Nova Scotia/Bay of Fundy Atlantic Herring fishery in NAFO areas 4X5Y. Primary spawning grounds are Scots Bay (SB) and German Bank (GB).

Context:

Fisheries and Oceans Canada (DFO) undertook development of a framework to provide science advice to resource managers, using Management Strategy Evaluation (MSE), for the southwest Nova Scotia/Bay of Fundy Atlantic Herring stock (SWNS/BoF Herring). As part of this process, performance thresholds were to be defined to help evaluate candidate management procedures in the MSE.

A method to define a performance threshold for spawning stock biomass was selected from a set of candidate methods, to be used in the MSE for Southwest Nova Scotia/Bay of Fundy Atlantic Herring in NAFO areas 4X5Y. The evaluation of methods focused on identifying a performance threshold consistent with DFO's Fishery Decision-Making Framework Incorporating the Precautionary Approach with the goal of avoiding "serious harm" to the productivity of the stock.

The selected performance threshold would be used to remove candidate management procedures in the management strategy evaluation that do not have a high probability of exceeding the threshold in the projection period.

*This Science Advisory Report is from the November 12 and 13, 2020 and January 18, 2021 regional advisory meeting on the Identification of a Limit Reference Point for Southwest Nova Scotia/Bay of Fundy Atlantic Herring (*Clupea harengus*). Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.*

September 2024

SUMMARY

- Potential performance thresholds for the Southwest Nova Scotia/Bay of Fundy Atlantic Herring stock were evaluated to ensure that the selection of a management procedure in the Management Strategy Evaluation (MSE) process be consistent with the objectives of DFO's *Fishery Decision-Making Framework Incorporating the Precautionary Approach* (PA Policy).
- The performance threshold is to be used in the Management Strategy Evaluation (MSE) to identify candidate management procedures that result in a high probability of spawning stock biomass (SSB) remaining above the threshold during the projection period.
- Several empirical and theoretical approaches were identified as potential thresholds.
- Empirical approaches were based on a historical biomass from which the stock has recovered or remained stable, as well as a biomass below which recruitment dynamics are unknown.
- Theoretical approaches were evaluated for defining an equilibrium biomass at a fishing mortality rate based on the concepts of maximum sustainable yield, yield-per-recruit or spawning stock biomass-per-recruit, and replacement fishing mortality rate, as well as methods based on unfished biomass.
- The suite of operating models (OMs) implemented in the MSE represent a broad range of simulated stock recruitment dynamics. It was agreed that a theoretical approach for defining the threshold is more consistent with the simulated population dynamics in each OM and thus a more comparable performance metric across OMs.
- A threshold was defined as 70% of the SSB at maximum sustainable yield, 0.7 SSB_{MSY}.
- The recommended probability and time period to apply the performance threshold in the MSE was P(SSB > 0.7 SSB_{MSY}) > 75% in each year beginning in year 10 of the 25-year projection period.
- A dynamic SSB_{MSY} is to be used for evaluating the performance of management procedures in the MSE. The dynamic SSB_{MSY} was estimated separately for each simulation using annual time-varying growth, maturity, and selectivity, as well as the annual simulation specific recruitment deviations.
- It was recommended that the dynamic SSB_{MSY} be used only in the evaluation of management procedures in the closed-loop simulations and not used for evaluating stock status.

BACKGROUND

Fisheries and Oceans Canada (DFO) has developed a general fishery decision-making framework (DFO 2009) for implementing harvest strategies that incorporate the Precautionary Approach (PA). This framework, herein referred to as the PA Policy, applies to key harvested stocks managed by DFO, including the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) Atlantic Herring stock in NAFO divisions 4X5Y. In general, the PA is about being cautious when there is insufficient scientific information and not using the lack of scientific information as a reason to postpone or fail to take action to avoid harm to the stock (DFO 2009). The primary components of the PA Policy consist of reference points and stock status zones, harvest strategy and harvest decision rules, accounting for uncertainty and risk when developing reference points, and developing and implementing decision rules.

DFO undertook a framework review for the SWNS/BoF Herring stock to provide science advice to resource managers, using a Management Strategy Evaluation (MSE) approach. Although the PA Policy has been presented in the context of a stock assessment, aspects of the policy can be applied to an MSE framework. Reference points are needed to define performance thresholds and targets for the stock, harvest control rules with operational control points can be defined as candidate management procedures, and uncertainty and risk are taken into account by the uncertainties captured in the operating models (OMs) within the MSE and in the selection of performance metrics.

The objective of this meeting was initially to define a limit reference point (LRP) for the SWNS/BoF Herring stock. The LRP, as defined in the PA Policy, represents the stock level below which there is a high probability that the stock's productivity is so impaired that serious harm will occur (DFO 2009). The policy states "At this stock status level, there may also be resultant impacts to the ecosystem, associated species, and a long-term loss of fishing opportunities" (DFO 2009). Based on this definition, the LRP applies not only to protecting the stock's productivity, but also to dependent species (e.g., predators) and other ecosystem resources (e.g., habitat). The LRP should be set at a point before serious harm is observed and not at the point when serious harm is observed (Kronlund et al. 2018).

The two general categories of reference points are for identifying the act of *overfishing* (limit based on F, the fishing mortality rate) and for identifying when the stock is *overfished* (limit based on biomass). The PA Policy does not require LRPs to be set for both F and biomass and suggests to use spawning stock biomass (SSB) or egg production as the indicator of productivity for stocks with age-structured analytical models (DFO 2009). Thresholds for F are intended to prevent serious harm to production by controlling the rate of harvest; however, it is the SSB that must be maintained to ensure future productivity (Myers et al. 1994). The focus of this evaluation of methods to define a performance threshold (based on reference point definitions) was for SSB and F-based approaches evaluated in terms of the equilibrium SSB that results from fishing at the specified F.

Although the focus of the definition of an LRP is on avoiding serious harm (and therefore the considerations for a performance threshold for the MSE), it is difficult to define a point of serious harm until the stock falls below that point (Hilborn and Walters 1992). Serious harm can be interpreted as avoiding irreversible, slowly reversible, or long-term impacts of fishing, so the emphasis on defining an LRP is generally on avoiding recruitment overfishing, stock collapse, and depletion of long-lived species (Sainsbury 2008). Recruitment overfishing results when adults are removed to such a low level that they cannot reproduce sufficient offspring to replenish the stock. To estimate a threshold for recruitment overfishing, a good understanding of the stock recruitment relationship is required (including variability); this is a gap in information for some species. Allee effects (or depensatory effects) are also considered to be serious harm (Kronlund et al. 2018). Allee effects occur when the per capita population growth rate decreases and the population abundance declines. There is evidence to support the presence of Allee effects in Atlantic Herring populations (e.g., Saha et al. 2013, Perälä and Kuparinen 2017). Causes of Allee effects in Atlantic Herring (a schooling fish) include decreased predator avoidance at lower abundances and loss of subpopulations (e.g., spawning components) of the stock (Saha et al. 2013). Similar to recruitment overfishing, the ability to detect Allee effects requires passing the threshold which creates challenges for estimating such a threshold.

LRPs have frequently been defined over the past few decades based on the concept of maximum sustainable yield (MSY, the largest catch that can be continuously removed from the stock assuming constant environmental conditions) in terms of F_{MSY} (fishing mortality rate at

MSY) and B_{MSY} (biomass at MSY) (PEW 2019). The guidance to identify reference points in DFO's PA Policy in the absence of stock-specific information is based on MSY (or MSY proxies); specifically, 0.4 B_{MSY} as the LRP and 0.8 B_{MSY} as the upper stock reference point. LRPs have been defined for 97 of Canada's major fish stocks or subunits and 39% of these cases use a 0.4 B_{MSY} or suitable proxy as the LRP (Marentette et al. 2021). The other most common approaches used to define an LRP for Canada's major fish stocks are empirical or historical approaches where the limit is set based on survey indices at low abundance or low abundance from which stock recovery was observed.

An analytical model has not been used to estimate stock size for the SWNS/BoF Herring stock since the late 1990s. Science advice has been provided primarily based on trends in an acoustic index of SSB. An empirical LRP has been defined for the stock as the mean value of the index from 2005–2010 (Clark et al. 2012). Under the framework review where analytical models were developed for the MSE simulation environment (Carruthers et al. 2023), a performance threshold was necessary to eliminate management procedures that result in the stock falling below the level at which there is a high probability that the stock's productivity is so impaired that serious harm will occur.

The MSE modeling framework consists of a reference set of OMs that represent a range of uncertainties in fishery and fish population dynamics. A performance threshold eliminates management procedures that do not have a high probability of avoiding serious harm to the productivity of the stock, as defined by the performance threshold. Various methods of defining a reference point or performance threshold were presented. There was consensus on one method to be used strictly as a performance threshold for evaluating management procedures within the MSE simulations, and not to use the reference point as an LRP to inform stock status.

ANALYSIS

Data

The fishery population dynamics have been modeled for an MSE using a multi-fleet stock reduction analysis with 24 OMs (Carruthers et al. 2023) that result from a cross of all levels of four axes of uncertainty (Table 1). The models assume a Beverton-Holt stock recruitment (SR) relationship with steepness of 0.65 or 0.95 to represent low and high scenarios of resilience at low SSB. Herring was assumed to have a relatively high steepness and the range of steepness values was selected based on likelihood profiles (Carruthers et al. 2023). The models were conditioned to catch and size composition data (1978–2018), an acoustic survey of SSB (1999–2018), and a larval survey used as an index of spawning stock abundance (1972–1998 and 2009). The fleets consist of a purse seine fleet (generally > 90% of landings) with logistic selectivity, a gillnet fleet with dome-shaped selectivity, and an "other" fleet that consists of all other gear types with dome-shaped selectivity. The weir catch axis of uncertainty involves the addition of a fourth fleet "weir" that consists of weir and shut-off (near shore seining) catch and size composition data from southwest New Brunswick. The weir catches were not considered as part of the SWNS/BoF stock; however, there are data to suggest connectivity between the SWNS/BoF stock and the Herring caught in the weir fishery. This weir fleet was modeled assuming dome-shaped selectivity and catch proportions are variable, with the 5^{th}, 50^{th}, and 95^{th} percentiles of the weir catch from 1968 to 2018 being 4%, 18%, and 27% of the total catch for all four fleets. Future recruitment in the projections for the reference set of OMs was based on the recruitment deviations from 1990–2016.

Table 1. Reference set operating model axis of uncertainty and levels.

Axis of Uncertainty	Level	Level Description
Natural Mortality	1	M = 0.35 (all ages)
Natural Mortality	2	M = 0.49 (ages 1–2) M = 0.26 (ages 3+)
Natural Mortality	3	M = 0.72 (ages 1–2) M = 0.45 (ages 3+)
Future Growth	A	Future growth = mean of last 3 historical years (2016–2018).
Future Growth	B	Future growth determined by a linear extrapolation of the temporal trend in weight-at-age.
Resilience	H	Steepness of Beverton-Holt stock recruitment relationship h = 0.95
Resilience	L	Steepness of Beverton-Holt stock recruitment relationship h = 0.65
Weir Catches	-	Southwest New Brunswick weir and shutoff catch and size composition data are excluded from the SWNS/BoF stock.
Weir Catches	+	Southwest New Brunswick weir and shutoff catch and size composition data are included from the SWNS/BoF stock.

Significant changes in Herring growth have been observed over time (Figure 2). For example, the mean weight of a 10 year old fish has dropped by 43% from 1970–1972 to 2016–2018. Two future growth scenarios were considered in the projections for the reference set of OMs (status quo: the mean of the last three years; and a continuation of the change in weight-at-age observed over time: based on the regression of $\log_{10}$(weight) vs. year by age). There has also been a decrease (linear regression, $p < 0.001$) in the age-at-maturity over this time period (Figure 3) with a decrease of 0.11 years and 0.92 years for the mean age at 50% maturity and mean age at 90% maturity, respectively, from 1970–1972 to 2016–2018.

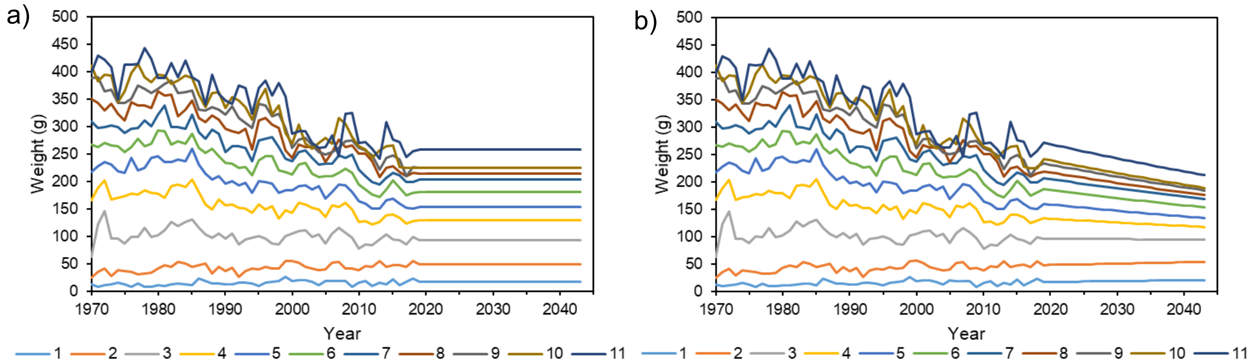


Figure 2. Empirical weight-at-age 1970–2018 with a) 25-year projections based on the mean weight-at-age for 2016–2018 and b) 25-year projections based on the regressions of log₁₀(weight) vs. year by age

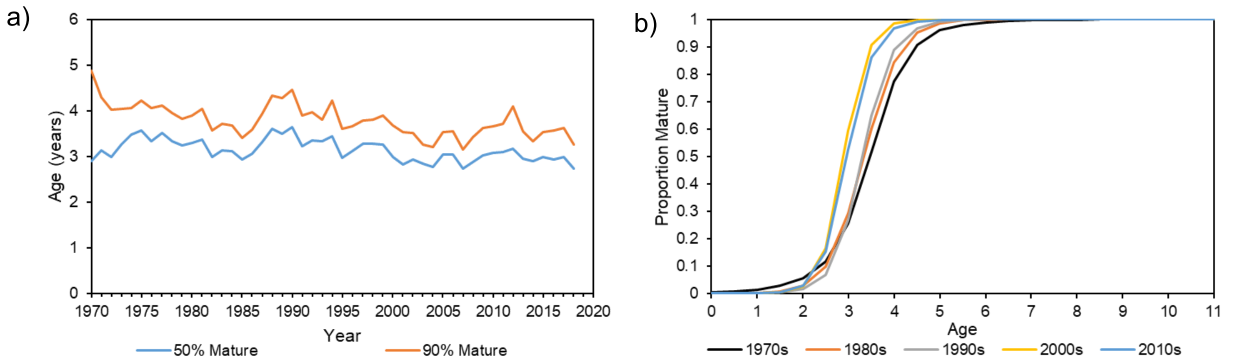


Figure 3. a) Time series of the estimated age at 50% and 90% maturity from 1970–2018 and b) Maturity ogives by decade from 1970 to 2018.

The reference set of OMs consists of 24 OMs (Table 2). The plots of model-estimated SSB over time for each OM shows a steep decline in SSB from 1968 to a minimum biomass in 1978 (Figure A.1). SSB increases to a maximum in 1987, driven by successful recruitment years in 1977–1978 and 1983–1984 (Figure A.2). SSB then declines over time for a period of about 15 years and has been stable at a low biomass for approximately the last 15 years. Surplus production shows an increasing trend from 1968 to approximately 1985 followed by a drop to a lower and fairly stable level (Figure A.3). The increasing trend in production appears to be driven by some high recruitment events in the 1970s and 1980s (Figure A.2). The plots of recruitment and surplus production over time suggest there has been a shift at the end of the 1980s (Figures A.2 and A.3). A changepoint analysis identified a shift for mean surplus production (1985) and mean recruitment (1990) where the year represents the beginning of the second period of the shift. The identification of a shift was consistent among all OMs for surplus production and consistent for recruitment (with the exception of OMs 7 and 8: 1989 and OMs 19 and 20: 1985). There is no evidence that the low production observed since the shift is driven by stock size (no relationship between production and total biomass or production and SSB).

Table 2. Assumed natural mortality (M), growth ("—" = status quo, "Δ" = projected changes to growth), steepness (h), and weir fleet ("-" = excluded; "+" = included) for the reference set of 24 OMs.

OM	M	Growth	h	Weir
1	0.35	—	0.95	-
2	0.26/0.49	—	0.95	-
3	0.45/0.72	—	0.95	-
4	0.35	Δ	0.95	-
5	0.26/0.49	Δ	0.95	-
6	0.45/0.72	Δ	0.95	-
7	0.35	—	0.65	-
8	0.26/0.49	—	0.65	-
9	0.45/0.72	—	0.65	-
10	0.35	Δ	0.65	-
11	0.26/0.49	Δ	0.65	-
12	0.45/0.72	Δ	0.65	-
13	0.35	—	0.95	+
14	0.26/0.49	—	0.95	+
15	0.45/0.72	—	0.95	+
16	0.35	Δ	0.95	+
17	0.26/0.49	Δ	0.95	+
18	0.45/0.72	Δ	0.95	+
19	0.35	—	0.65	+
20	0.26/0.49	—	0.65	+
21	0.45/0.72	—	0.65	+
22	0.35	Δ	0.65	+
23	0.26/0.49	Δ	0.65	+
24	0.45/0.72	Δ	0.65	+

Candidate Performance Thresholds

B_{lim} Estimates

The biomass below which mean recruitment declines or stock dynamics are uncertain is defined as B_{lim} (Sainsbury 2008). The SWNS/BoF Herring SR dynamics (Figure A.4) could be considered to be Type 1: spasmodic (occasional large year classes) or Type 5: no evidence of impaired recruitment or no clear stock recruitment relationship defined in ICES (2016). A B_{lim} for these SR dynamics is defined as the minimum observed biomass (ICES 2016). Two candidates for the minimum observed SSB were presented as SSB_{1978} and SSB_{2007} (Figure A.5), the minimum SSB in the time series and a minimum SSB during a period from 1990–2016 that represents a period of low recruitment (Figure A.2) and low productivity (Figure A.3). Another candidate $SSB_{0.5R0}$ was presented that is the SSB for which recruitment declines to 50% of R_0 (initial recruitment) in the SR relationship (Mace 1994).

Equilibrium Estimates

Equilibrium SSB estimates represent the average SSB that results from fishing at a specified fishing mortality rate F. Equilibrium SSB estimates were presented based on maximum sustainable yield (MSY), unfished biomass, yield-per-recruit, and SSB-per-recruit. The per-recruit methods were calculated as described in Walters and Martel (2004). The approach uses the survivorship-at-age, along with at-age estimates of weight, vulnerability, natural mortality rate, and maturity to calculate equilibrium metrics. Their estimation is challenged by the fact that they assume the system is at equilibrium (including life history characteristics and environmental conditions). Biological parameters (i.e., growth, maturity, and recruitment) can be estimated as a mean over a productivity regime, but may not represent conditions assumed in the projection period.

Three productivity regimes were used to estimate static (equilibrium) SSB_{MSY} estimates in Figures A.5 and A.6:

- Historical: 1968–2018 productivity (mean historical selectivity, growth, and maturity from 1968–2018 and recruitment estimated as R_0)
- Recruitment Shift: 1990–2018 productivity (mean selectivity, growth, and maturity, from 1990–2018 and recruitment estimated from mean recruitment deviations from 1990–2015)
- Projected: productivity assumed in the projection period (the assumed projected selectivity, growth (mean of last 3 years), maturity, and recruitment)

Non-Parametric Estimates

A non-parametric method for defining F for recruitment overfishing in the absence of a well-fitting SR relationship has been developed by Sissenwine and Sheppard (1987). The theory is that the persistence of a population requires that each recruited year class replaces the SSB of its parents on average. The slope of a straight line through each point on the SR plot and the origin represents an F that would be applied over the lifetime of those recruits in order to obtain SBB. Sissenwine and Sheppard (1987) define recruitment overfishing as a level of F that reduces the SSB produced by a year class below the SSB of its parents on average. The slope of the replacement line is defined as the median ratio of recruitment to SSB. The SSB that results from fishing at F_{rep} (i.e., SSB_{rep}) is estimated as the SSB where the median replacement line intersects the SR curve. In the absence of an SR relationship, the SR curve can be represented as the median recruitment (e.g., DFO 2002). Fishing at F_{rep} will result in SSB_{rep} on average. A lower threshold for recruitment overfishing in terms of SSB can be defined as F_{rep90} which is the 90th percentile of the ratio of recruitment to SSB (DFO 2002). The F_{rep} and F_{rep90} reference points are consistent with the F_{med} and F_{low} defined by ICES (1988).

Dynamic Estimates

A dynamic SSB_{MSY} was presented at the January 18, 2021 meeting. The dynamic SSB_{MSY} differs from an equilibrium SSB_{MSY} in that it is estimated separately for each simulation using the estimated annual recruitment deviation and annual estimates of growth, maturity, and selectivity (Figure A.5). SSB_{MSY} is estimated by first estimating a dynamic SSB_{unf} (unfished SSB) by projecting SSB from the initial historical year under an F = 0 management procedure (Figure A.6). SSB_{MSY} is then estimated as a proportion of SSB_0 and this proportion is estimated as the ratio of SSB_{MSY} to SSB_0 estimated using the mean of the annual asymptotic values over the last three historical years.

Sources of Uncertainty

In a stock assessment where a single analytical model is used with the best estimate of parameters in the model, the model uncertainty must be captured by the error estimates of the input parameters and propagated to the estimation of reference points. In an MSE, the major sources of uncertainty in population dynamics are captured by a set of OMs that represent different potential realities. For SWNS/BoF Herring, a reference set of OMs has been defined that represents a cross of all levels of four axes of uncertainty (Table 1). These uncertainties are the natural mortality rate, future growth, resilience, and inclusion of the weir catch and size composition data from southwest New Brunswick.

In an MSE, a level of precaution in performance thresholds (in units of absolute biomass) is captured by the uncertainties in the different OMs. Another level of precaution is captured by the selection of the method of defining the performance threshold (the magnitude, as well as, the probability of exceeding the magnitude).

An assumption of the dynamic reference points is that the changes in biological parameters (growth, maturity, and recruitment) over time are independent of fishing pressure (Berger 2019). The degree to which observed temporal changes in growth, maturity, and recruitment for SWNS/BoF Herring are related to fishing pressure or environmental conditions is an uncertainty. The dynamic reference point was identified as the most suitable metric for evaluating the performance of management procedures in the MSE simulations, but was identified as inappropriate for use as an LRP (i.e., not an appropriate metric of stock status of SWNS/BoF Herring).

CONCLUSIONS AND ADVICE

This science advice on a performance threshold was generated by progressing through a series of decision points in the meetings to select an approach:

Role of the Performance Threshold in the MSE

The performance threshold is to be used to evaluate candidate management procedures. Management procedures that do not result in a high probability of being above the threshold in a reasonable timeframe in the projections will be eliminated from further consideration. This is not intended to provide a determination of the overall stock status, but to evaluate the performance of individual management procedures.

Empirical Approach vs. Theoretical Approach

On the first day of the meeting there was a general consensus that an empirical approach would be appropriate. After a lengthy discussion, the general consensus shifted to a theoretical approach because this approach is more consistent with the simulated population dynamics in each OM and, thus, a more comparable performance metric across OMs.

Method

Of the various theoretical candidate methods, SSB_{MSY} was identified as the most appropriate. Methods based on SSB-per-recruit and based on unfished SSB are generally used as proxies for SSB_{MSY} and were deemed redundant.

Threshold

The threshold was defined as 0.7 SSB_{MSY}. The choice of the proportion 0.7 compared to the 0.4 provisional proportion for LRPs in the PA Policy (DFO 2009) was made because of the role of Herring as a forage fish in the ecosystem. The proportion 0.4 that has been used elsewhere (e.g., for gadoids; DFO 2011) has been selected arbitrarily (although based on expert judgement) with no direct relationship with the ability for a stock to recover (Reuchlin-Hugenholtz et al. 2016). The threshold will be used in the MSE to remove candidate management procedures that do not have a high probability of exceeding the threshold in the projections where:

> P(SSB > 0.7 SSB_{MSY}) > 75% in each year beginning in year 10 of the 25-year projection period.

The 75% was selected to represent the minimum level of a high percentage defined in the PA Policy (DFO 2009). Year 10 represents approximately two generations for SWNS/BoF Herring.

Static vs. Dynamic Reference Points

The SSB_{MSY} estimates presented at the November 2020 meeting were based on mean selectivity, growth, and maturity for the last three years of the time series (2016–2018). During this meeting it was suggested that this time period may not be appropriate and that a longer time series may be more justified. At the January 2021 meeting, it was decided that a dynamic SSB_{MSY} would be adopted, solely to be used in the performance threshold to eliminate candidate management procedures in the MSE and that the use of dynamic reference points in determination of stock status is not appropriate. The influence of this decision is presented in Table A.1 where a comparison of the performance of some example management procedures (Figure A.7) is illustrated using a dynamic SSB_{MSY} and an equilibrium SSB_{MSY} under the three regimes (historical, recruitment shift, and projected) presented above.

OTHER CONSIDERATIONS

This advice on a performance threshold is specific to the SWNS/BoF Herring MSE and the uncertainties that were defined in the reference set of OMs. The decision to use a dynamic SSB_{MSY} in the performance threshold for eliminating management procedures was specific to the MSE simulation framework where each projected simulation represents a theoretical known true state of the population. The use of a dynamic reference point as a performance threshold assumes that changes in recruitment and biological parameters (e.g., growth, maturity) over time are not density dependent or influenced by fishing pressure (Berger 2019). Uncertainty in model parameters (e.g., steepness and natural mortality rate) is captured by the range of OMs and this uncertainty (unlike in an assessment) is not captured in the choice of the performance threshold.

Following the November meetings, a key decision point in the implementation of the theoretical SSB_{MSY} reference point was identified. Meeting participants reconvened on January 18, 2021 to discuss whether a static (equilibrium) or dynamic SSB_{MSY} would be more appropriate for evaluating the performance of management procedures in the MSE. The focus of the discussion was on differences in historical mean recruitment (assumed in a static, equilibrium SSB_{MSY}) and the assumed recruitment in the projections (based on a subset of the historical time series). A dynamic SSB_{MSY} was selected to be used in the context of the MSE for evaluating the performance of MPs, but a dynamic reference point may not be appropriate for determining stock status. An LRP and method of determining stock status was not determined in the meeting. A comparison of the dynamic SSB_{MSY} estimates to static SSB_{MSY} estimates (for different productivity regimes) was requested during the review and is shown in Figure A.5.

LIST OF MEETING PARTICIPANTS

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SOURCES OF INFORMATION

This Science Advisory Report is from the November 12–13, 2020 and January 18, 2021 regional advisory meeting on the Identification of a Limit Reference Point for Southwest Nova Scotia/Bay of Fundy Atlantic Herring (*Clupea harengus*). Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Berger, A.M. 2019. Character of temporal variability in stock productivity influences the utility of dynamic reference points. Fisheries Research 217: 185–197.

Carruthers, T.R., Hordyk, A.R., Huynh, Q.C., Singh, R., and Barrett, T.J. 2023. A Framework for Conditioning Operating Models for the Southwest Nova Scotia/Bay of Fundy Spawning Component of 4VWX Herring. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/022. v + 103 p.

Clark, D.S., Clark, K.J., Claytor, R., Leslie, S., Melvin, G.D., Porter, J.M., Power, M.J., Stone, H.H., and Waters, C. 2012. Limit reference point for southwest Nova Scotia/Bay of Fundy spawning component of Atlantic Herring, *Clupea harengus* (German Bank and Scots Bay). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/025.

DFO. 2002. Proceedings of the national workshop on reference points for gadoids. November 5–8, 2002. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2002/033.

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach. Fisheries and Oceans Canada.

DFO. 2011. Proceedings of the Newfoundland and Labrador Regional Atlantic Cod Framework Meeting: Reference Points and Projection Methods for Newfoundland cod stocks; November 22–26, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2010/053.

Hilborn R. and Walters, C.J. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York. 570 pp.

ICES. 1988. Reports of the ICES Advisory Committee on Fishery Management, 1987. ICES Co-operative Research Report, 153. 415 pp.

ICES. 2016. Technical Guidelines - ICES fisheries management reference points for category 1 and 2 stocks (2017). ICES Advice Technical Guidelines. 19 pp.

Kronlund, A.R., Forrest, R.E., Cleary, J.S., and Grinnell, M.H. 2018. The Selection and Role of Limit Reference Points for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/009. ix +125 p.

Mace, P.M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Canadian Journal of Fisheries and Aquatic Sciences 51: 110–122.

Marentette, J.R., Kronlund, A.R., and Cogliati, K.M. 2021. Specification of Precautionary Approach Reference Points and Harvest Control Rules in Domestically Managed and Assessed Key Harvested Stocks In Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/057. vii + 98 p.

Myers, R. A., Rosenberg, A. A., Mace, P. M., Barrowman, N., and Restrepo, V. R. 1994. In search of thresholds for recruitment overfishing. ICES Journal of Marine Science 51:191–205.

Perälä, T. and Kuparinen, A. 2017. Detection of Allee effects in marine fishes: analytical biases generated by data availability and model selection. Proceedings of the Royal Society B: Biological Sciences 284: 20171284.

PEW. 2019. Reference points: measuring success in fisheries management. A brief from the PEW Charitable Trusts.

Reuchlin-Hugenholtz, E., Shackell, N.L., and Hutchings, J.A. 2016. Spatial reference points for groundfish. ICES Journal of Marine Science 73: 2468–2478.

Saha, B., Bhowmick, A.R., Chattopadhyay, J., and Bhattacharya, S. 2013. On the evidence of an Allee effect in herring populations and consequences for population survival: a model-based study. Ecological Modelling 250: 72–80.

Sainsbury, K. 2008. Best Practice Reference Points for Australian Fisheries. Australian Fisheries Management Authority Report R2001/0999.

Sissenwine, M.P. and Shepherd, J.G. 1987. An alternative perspective on recruitment overfishing and biological reference points. Canadian Journal of Fisheries and Aquatic Sciences 44: 913–918.

Walters, C.J. and Martell, S.J.D. 2004. Fisheries Ecology and Management. Princeton University Press, Princeton. 399 pp.

APPENDIX A

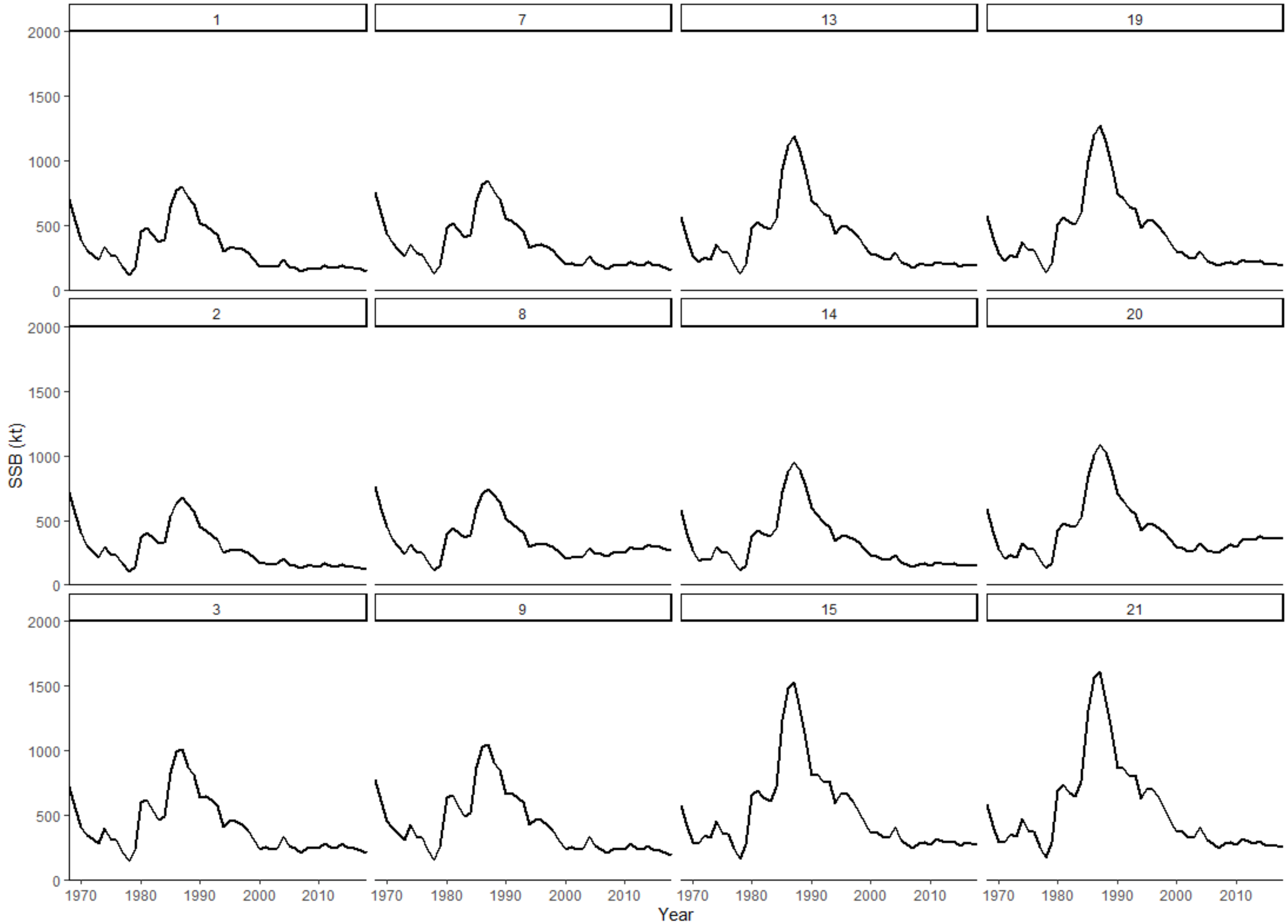

Figure A.1. Line plots of model estimated spawning stock biomass versus year (1968–2018) by operating model.

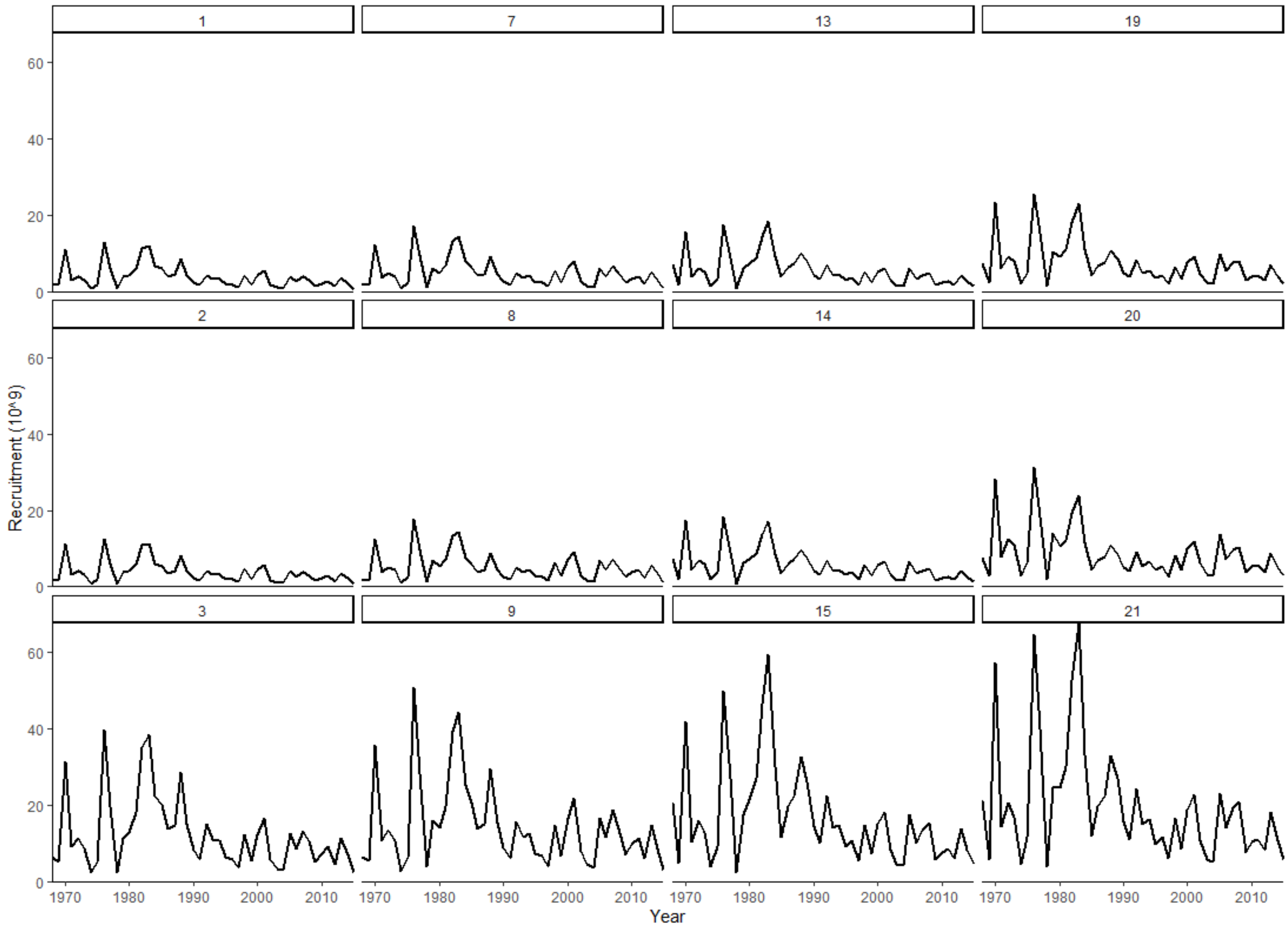

Figure A.2. Line plots of model estimated recruitment versus year (1968–2015) by operating model.

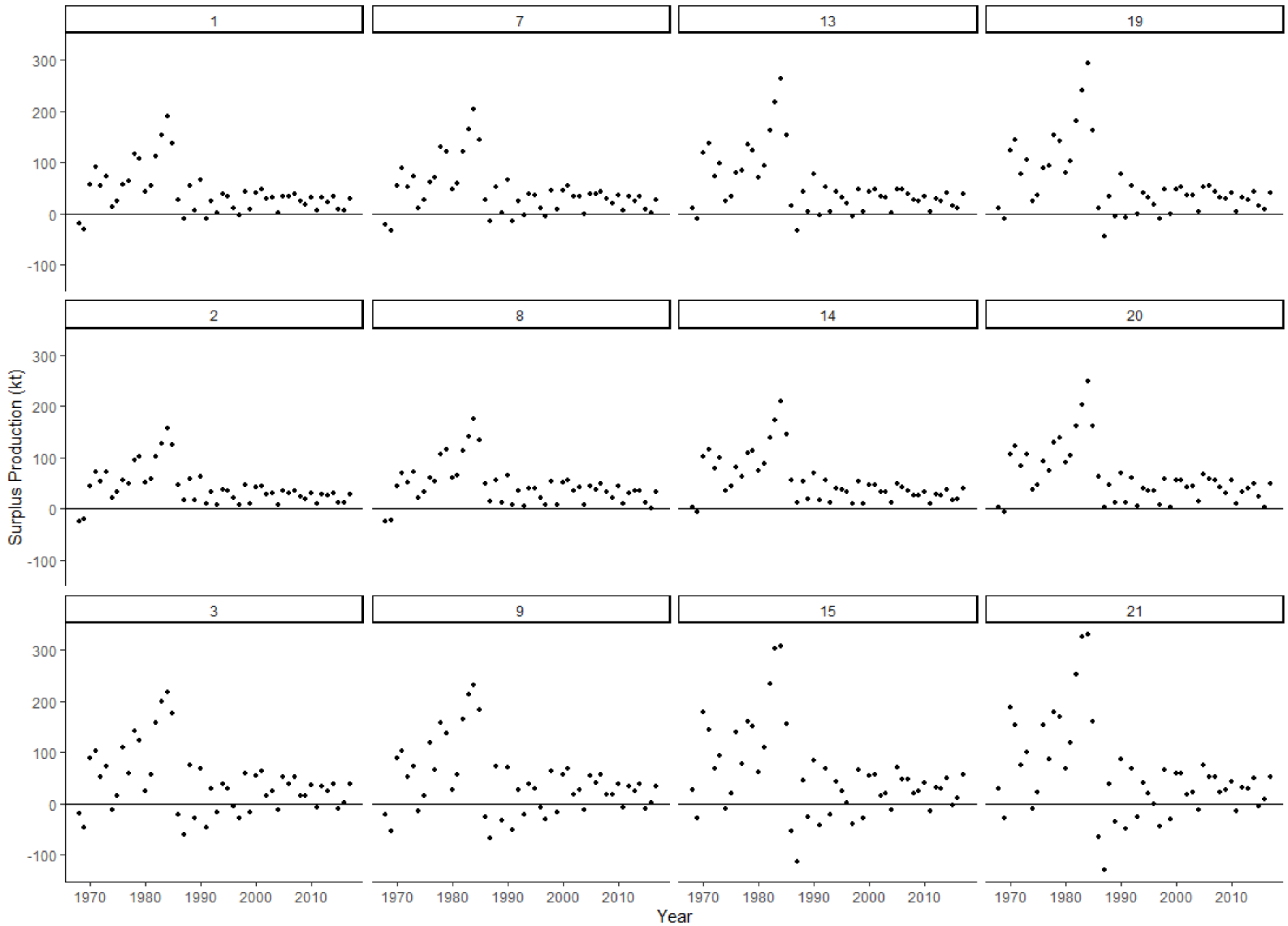

Figure A.3. Scatterplots of surplus production versus year (1968–2017) by operating model.

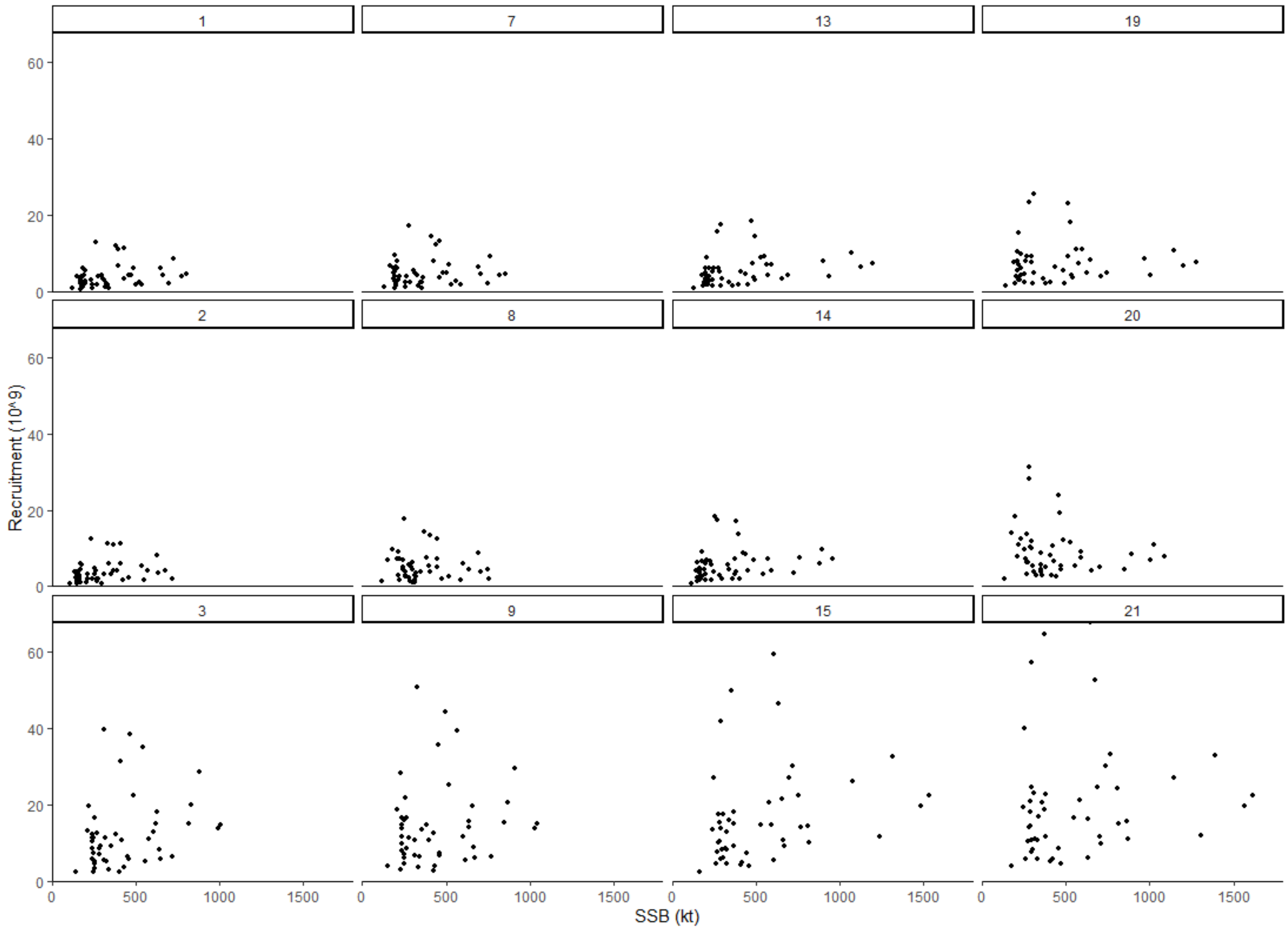

Figure A.4. Scatterplots of model estimated recruitment versus spawning stock biomass (1968–2015) by operating model.

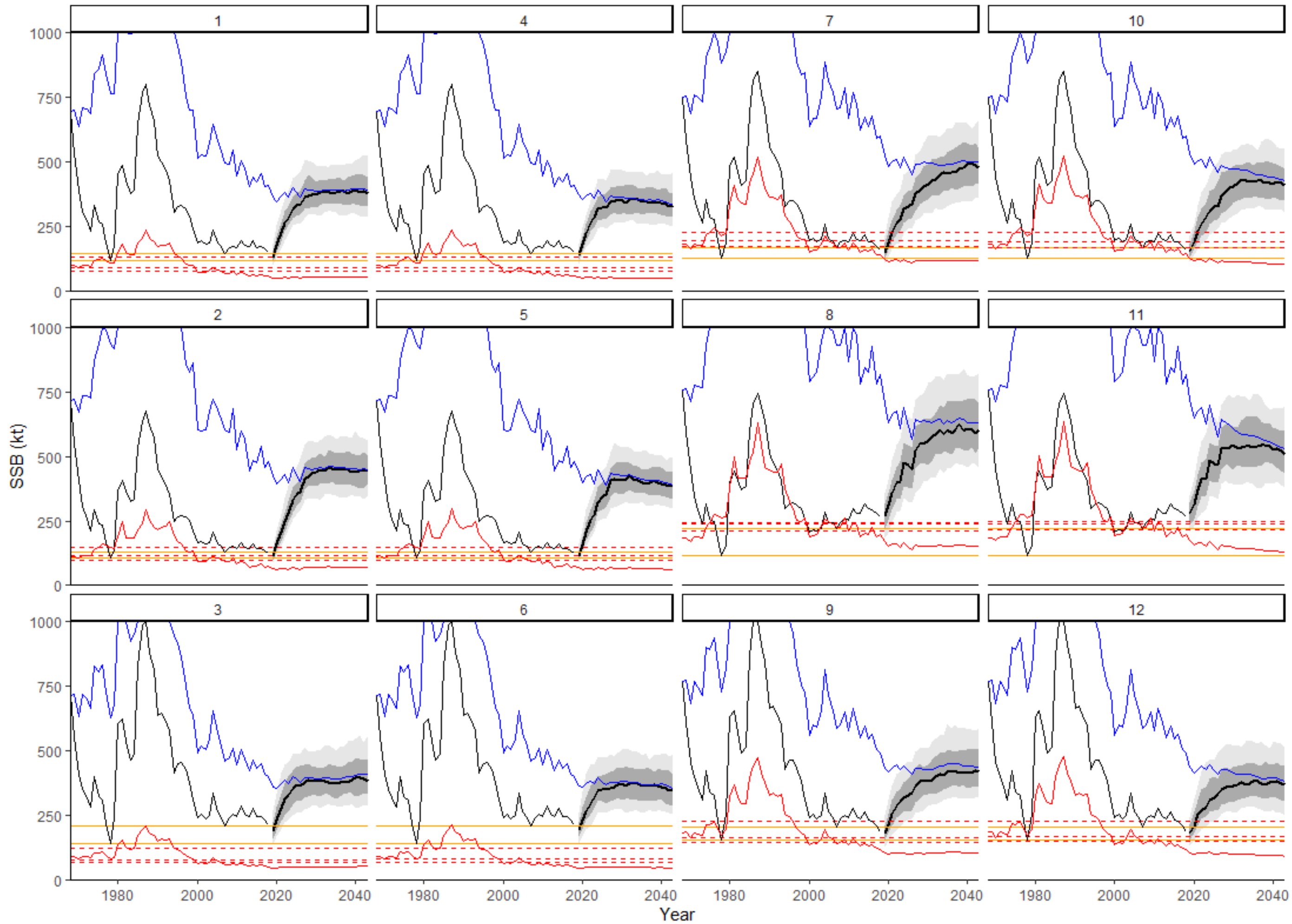

Figure A.5. Scatterplots of model estimated historical Spawning Stock Biomass (SSB) (blue black line, 1968–2018) and projected SSB with F = 0 (thick black line = median projected SSB, grey shading represents the 10th, 25th, 75th, and 90th percentiles of projected SSB, 2019–2043) by operating model. Dynamic SSB_{MSY} (solid red line), equilibrium SSB_{MSY} (dashed red lines) under three productivity regimes, [historical: 1968–2018 (top); recruitment shift: 1990–2018 (mid); projected: projected conditions with no change in growth (bottom)]. Two historical SSB values (solid orange lines): SSB_{2007} (top) and SSB_{1978} (bottom).

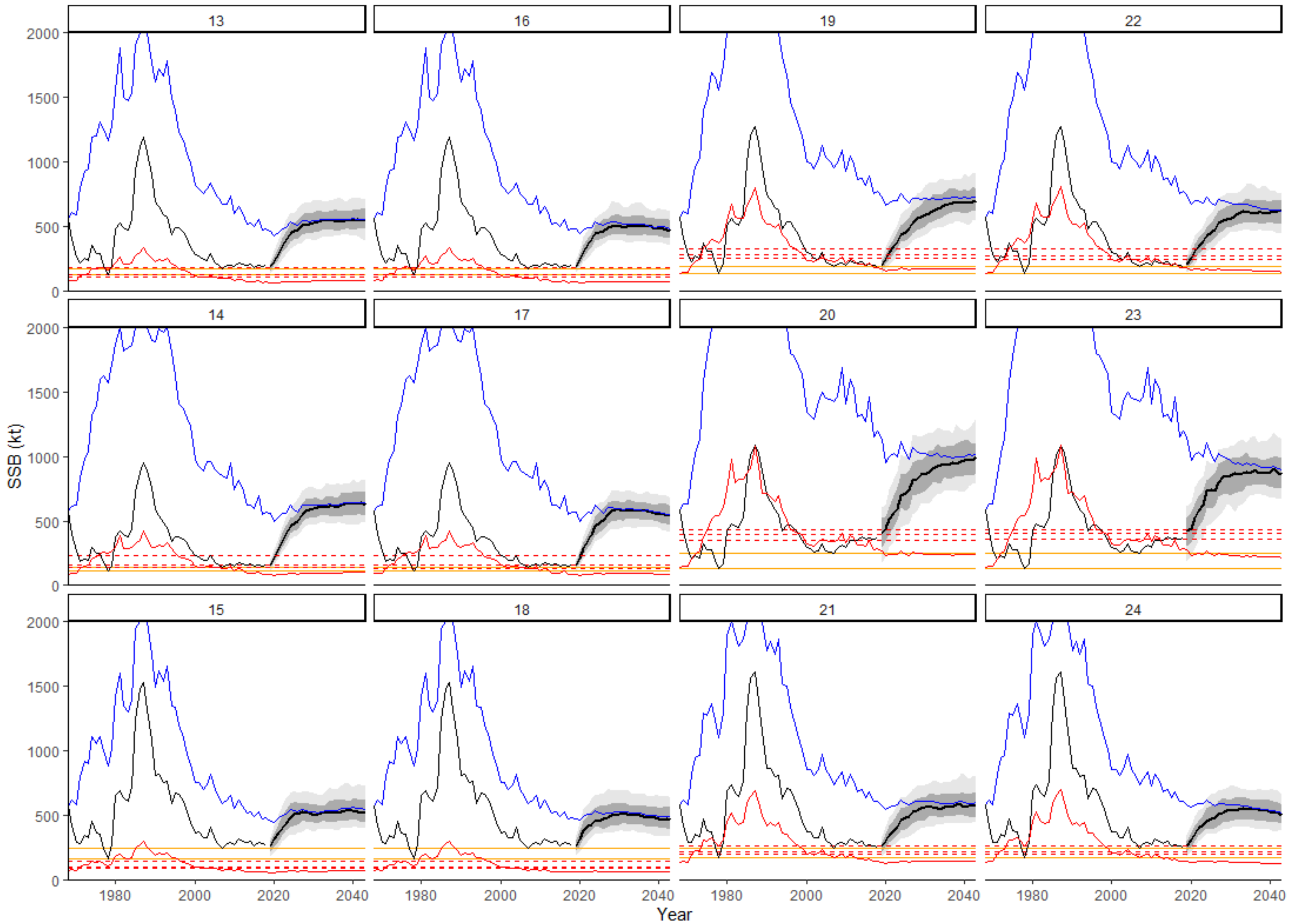

Figure A.5 (continued). Scatterplots of model estimated historical Spawning Stock Biomass (SSB) (blue black line, 1968–2018) and projected SSB with F = 0 (thick black line = median projected SSB, grey shading represents the 10th, 25th, 75th, and 90th percentiles of projected SSB, 2019–2043) by operating model. Dynamic SSB_{MSY} (solid red line), equilibrium SSB_{MSY} (dashed red lines) under three productivity regimes, [historical: 1968–2018 (top); recruitment shift: 1990–2018 (mid); projected: projected conditions with no change in growth (bottom)]. Two historical SSB values (solid orange lines): SSB_{2007} (top) and SSB_{1978} (bottom).

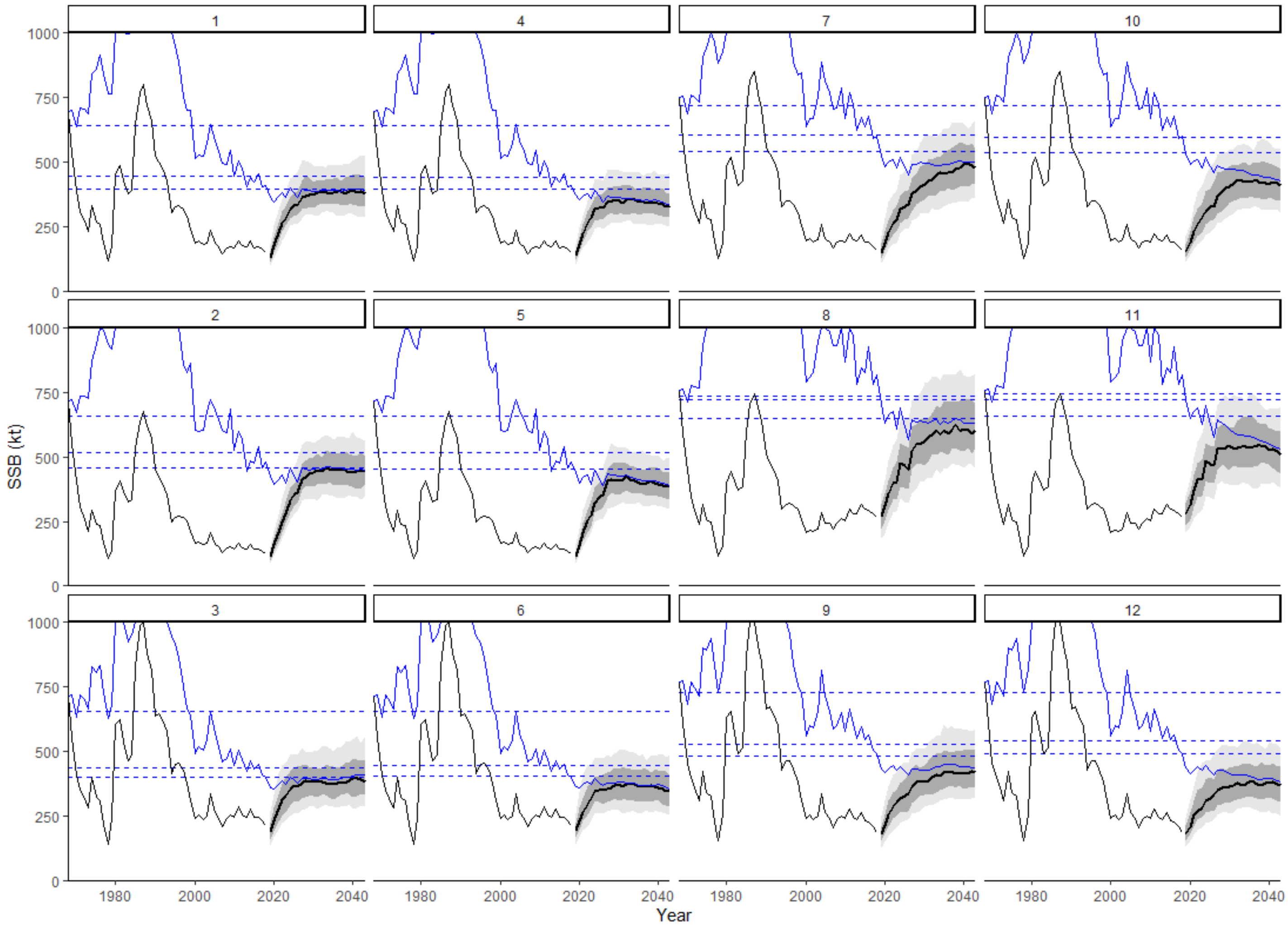

Figure A.6. Scatterplots of model estimated historical Spawning Stock Biomass (SSB) (blue black line, 1968–2018) and projected SSB with F = 0 (thick black line = median projected SSB, grey shading represents the 10th, 25th, 75th, and 90th percentiles of projected SSB, 2019–2043) by operating model. Dynamic SSB_0 (solid blue line) and equilibrium SSB_0 (dashed blue lines) under three productivity regimes, [historical: 1968–2018 (top); recruitment shift: 1990–2018 (mid); projected: projected conditions with no change in growth (bottom)].

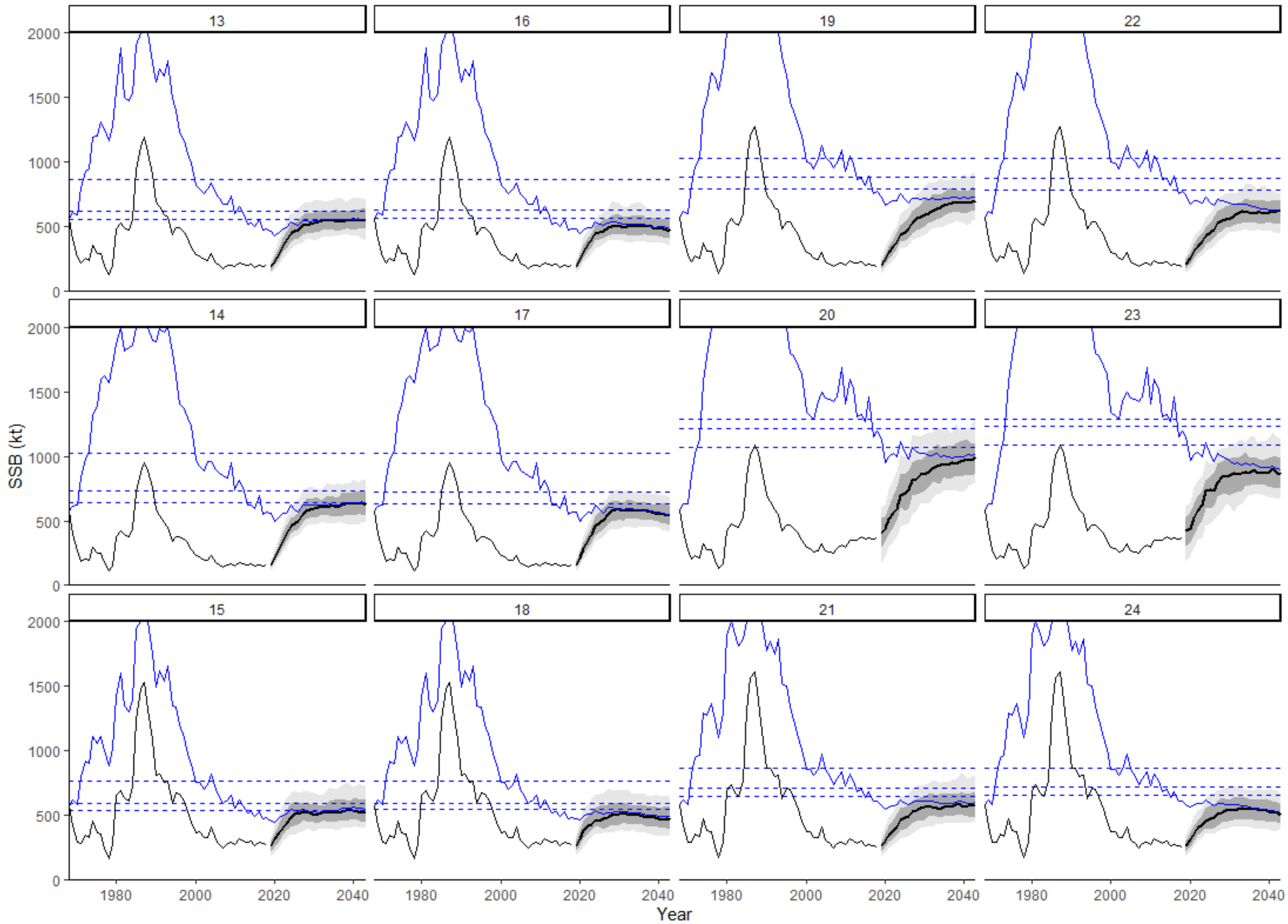

Figure A.6 (continued). Scatterplots of model estimated historical Spawning Stock Biomass (SSB) (blue black line, 1968–2018) and projected SSB with F = 0 (thick black line = median projected SSB, grey shading represents the 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles of projected SSB, 2019–2043) by operating model. Dynamic SSB_0 (solid blue line) and equilibrium SSB_0 (dashed blue lines) under three productivity regimes, [historical: 1968–2018 (top); recruitment shift: 1990–2018 (mid); projected: projected conditions with no change in growth (bottom)].

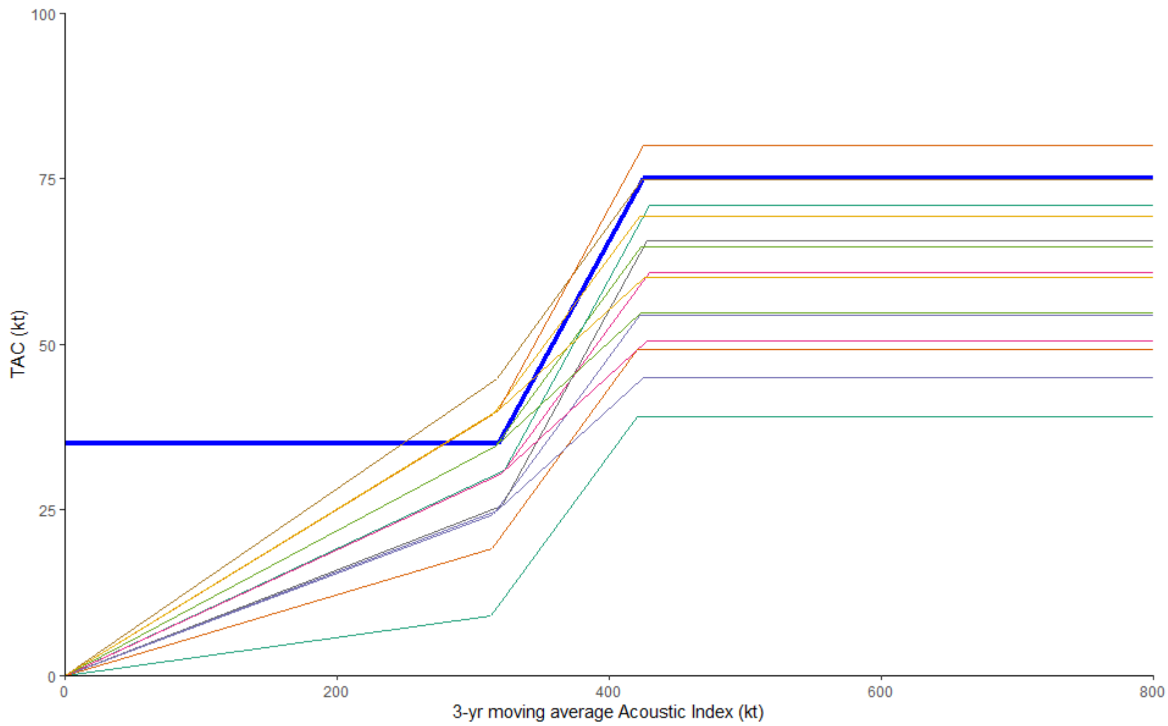

Figure A.7. Graphical representation of the example management procedures in Table A.1. Notes: blue = Status Quo (SQ) management procedure. All other management procedures have varying TAC values at the control points of 318 and 425 kt of the 3-yr moving average acoustic index.

Table A.1. Comparison of management procedure performance using the dynamic and equilibrium SSB_{MSY} estimates as the performance threshold for some example management procedures. Total Allowable Catches (TAC in kt) assuming a value of the acoustic index of 270 kt (3-yr moving average) by method of estimating SSB_{MSY} for some example management procedures.

Management Procedure	Dynamic SSB_{MSY}	Equilibrium SSB_{MSY} by Regime		
		Historical	Recruitment Shift	Projected
NFref (F = 0)	0	0	0	0
MP_10_40_318_425_3	8.5	8.5	8.5	8.5
MP_20_50_318_425_3	17	17	17	17
MP_25_45_318_425_3	21	21	21	21
MP_25_55_318_425_3	21	21	21	21
MP_25_65_318_425_3	21	21	21	21
MP_30_50_318_425_3	26	26	26	26
MP_30_60_318_425_3	26	26	26	26
MP_30_70_318_425_3	26	26	26	26
MP_35_55_318_425_3	30	30	30	30
MP_35_65_318_425_3	30	30	30	30
MP_40_60_318_425_3	34	34	34	34
MP_40_70_318_425_3	34	34	34	34
MP_40_80_318_425_3	34	34	34	34
MP_45_75_318_425_3	38	38	38	38
SQ (status quo)	35	35	35	35

Note: Red shading: management procedure fails the performance threshold $P(SSB > 0.7SSB_{MSY}) > 75\%$ in each year beginning in year 10 the 25 year projection period. MP_TAC1_TAC2_318_425_3 represents a management procedure with a straight line joining points (0,0) and (318, TAC1), a straight line joining (318, TAC1) and (425, TAC2) and a straight line continuing to infinity at TAC2 where the acoustic index is the 3-year moving average of the acoustic index (Figure A.7.).

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