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Assessing the Productivity of the Scallop Stocks in Scallop Production Areas in the Bay of Fundy and Scallop Fishing Area 29W and the Impact of Two-Year Projection Advice

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The Bay of Fundy (BoF) Scallop Production Areas (SPAs) 1A, 1B, 3, 4, and 6, and Scallop Fishing Area 29 West (SFA 29W) Subareas A, B, C, and D, comprise the majority of catches from the Inshore Scallop fishery in the Fisheries and Oceans Canada Maritimes Region. Each stock area is managed using total allowable catches (TACs) and have annual analytical assessments which use modified versions of a state-space delay-difference population model that provides one-year biomass projections to inform the setting of the harvest level. However, in 2020, the DFO Science Inshore Scallop surveys were cancelled. In the absence of survey data, two-year model projections were used to inform the scallop fisheries in these areas for the 2020/21 fishing season. The objectives of this document are to evaluate the productivity of the BoF and SFA 29W stocks based on the population assessment models, to derive two-year model projections to inform the final TAC decisions for the 2020/21 season, and to evaluate the impact and uncertainty of the two-year model projections. The scallop stocks within the BoF and SFA 29W demonstrate substantial interannual variability in their productivity such that, relative to the use of one-year projections, use of two-year projections as the basis for management decisions over the long term would result in substantial risk of either loss in potential catch or overharvesting. However, for the BoF stocks and in the context of tactical one-year decision making and in the absence of 2020 survey data, these two-year projections provide context for decision making for the 2021 harvest levels. For SFA 29W, the two-year projections are not sufficiently reliable given challenges associated with projecting low biomasses; therefore, these projections are not recommended to inform the 2021 harvest levels for SFA 29W.

INTRODUCTION

The Scallop Production Areas (SPAs) in the Bay of Fundy (BoF) and Scallop Fishing Area 29 West (SFA 29W) comprise the majority of catches from the Inshore Scallop fishery in the Fisheries and Oceans Canada (DFO) Maritimes Region (Figure 1). Analytical assessments are conducted annually for SPAs 1A, 1B, 3, 4 and 5, and 6 in the BoF and for each of the 5 subareas in SFA 29W (Subareas A, B, C, D, and E). The population dynamics are modelled for nine of the ten areas (all except SFA 29W Subarea E) using modified versions of a state-space delay-difference population model (Hilborn and Walters 1992). The scallop species fished is the sea scallop (*Placopecten magellanicus*). The fishery season within the BoF runs from October 1 to September 30 of the following year, further details can be found in Nasmith et al. (2016). For SFA 29W, the fishery occurs in the summer, generally between mid-June and August (Sameoto et al. 2015).

The operational models for the BoF SPAs and for the subareas in SFA 29W are used to estimate population biomass (and biomass density for SFA 29W), recruitment (to the fishery), exploitation rate, and provide advice on catch levels in the following year (*t+1*). For SPAs 1A, 1B, 3, and 4, the model is also projected ahead two years (*t+2*) under an assumption of zero surplus production to provide interim harvest advice and inform the setting of interim total allowable catches (TACs) for when the fishery starts in October. The final TACs are set in December. The use of two-year projections in the BoF to inform interim TACs was first implemented in 2005 as advice for setting the 2006/07 interim TAC for SPA 4 (Smith et al. 2005); however, to date, the process error has not been propagated to the second-year forecasts.

Indices used in the model come from annual survey and commercial catch data. DFO Science monitoring surveys occur annually in June through August for SPAs within the BoF and in September–October for SFA 29W. The operational timeline from data collection to advice for the BoF stocks is that survey data collected in summer (year *t*) are processed, analyzed, and combined with fishing season data up to September 30 (year *t*), within an analytical assessment presented through the Canadian Science Advisory Secretariat (CSAS) in late November of the same year (*t*) to inform the setting of final TACs in December. For SFA 29W, survey (September–October) and fishery data (summer) (year *t*) are presented through a formal CSAS process in March (year *t+1*) to inform the setting of the TAC for the fishing season in summer (year *t+1*). Final TACs are typically informed by one-year projections from the models; thus, data up to year *t* are used by the model to forecast commercial biomass for fishing season *t+1*. This time frame, between data acquisition and operational science advice, enables the broad fisheries management objective of maximizing present catches, subject to the constraints of a sustainable harvesting regime, to be achieved.

However, in 2020, the DFO Science Inshore Scallop surveys for the BoF and SFA 29W were cancelled. In the absence of survey data, two-year model projections (i.e., the model run up to 2019 and projected for 2021) were evaluated for use in updating the stock status for the BoF SPAs and for the SFA 29W subareas for the 2020/21 fishing season. Although two-year projections have been operationalized in the BoF since 2005, they have only been used to inform the interim TAC; with the exception of being used for the final TAC for the 2019/20 season. Further, to date, a quantitative evaluation of their performance has not been conducted. The objectives of this document are to evaluate the productivity of the BoF and SFA 29W stocks based on the population assessment models, to derive two-year model projections to inform the final TAC decisions for the 2020/21 seasons, and to evaluate the impact and uncertainty of the two-year model projections.

METHODS

DELAY DIFFERENCE MODEL

The operational model for the BoF SPAs is a Bayesian state-space modified delay difference assessment model that integrates both fishery and survey data (Nasmith et al. 2016). The model is fit to the survey estimates of commercial (≥ 80 mm shell height) and recruit (65–79 mm shell height) biomass. The formulation of the process equation is:

$$B_{t+1} = [e^{-m_t} g_t (B_t - C_t) + e^{-m_t} g_{r(t)} R_t] \eta_t$$

Biomass in the next year (B_{t+1}) is a function of the previous year commercial biomass (B_t), with gains (inputs) due to recruitment (R_t) and growth (g and g_r), and losses (outputs), due to natural mortality (m) and catch (C). The process error term (η_t) represents the uncertainty in the model dynamics. Growth is the somatic growth of individual animals (meat weight), and recruit size scallop are those that are expected to grow to commercial size the following year. The modelled parameters were B, R, m, and η while the growth estimates enter the model as fixed parameters that are calculated each year (see details in Nasmith et al. 2016). The natural mortality (m) is modelled based on survey observations of empty, hinged scallop shells, called “clappers” (Smith and Lundy 2002).

The operational model for SFA 29W is a state-space habitat-based assessment model that integrates both fishery and survey data and is informed by a scallop species distribution model (Smith and Sameoto 2016). The model is fit to the survey estimates of commercial (≥ 100 mm shell height) biomass and recruit (90–99 mm shell height) numbers for each habitat suitability category within each subarea (Sameoto et al. 2015, Smith and Sameoto 2016, Smith et al. 2017). The formulation of the process equation is:

$$B_{h,t+1} = (e^{-m_{h,t}} (g_{h,t} \times B_{h,t} + w_{h,t} R_{h,t}) - C_{h,t}) \eta_{h,t}$$

Where $B_{h,t}$, $C_{h,t}$, $R_{h,t}$, and $m_{h,t}$ are the population biomass of commercial size animals, commercial catch, recruit numbers, and mortality, respectively, for each habitat suitability class h (Low, Medium, and High) in year t. Within each subarea, within each habitat category, biomass in the next year (B_{t+1}) is a function of the previous year commercial biomass (B_t), with gains (inputs) due to recruitment (R) and growth (g), and losses (outputs), due to natural mortality (m) and catch (C). The process error term (η) is calculated for each habitat category and represents the uncertainty in the model dynamics. The term w is the average weight of the recruit size scallops when they recruit to the fishery in year t. Growth is the somatic growth of individual animals (meat weight), and recruit size scallop are those that are expected to grow to commercial size the following year. The modelled parameters were B, R, m, and η. Note that natural mortality (m) is modelled based on survey observations of empty, hinged scallop shells, called “clappers” (Smith and Lundy 2002). The growth estimates (g) and average weight of the recruit size scallops (w) enter the model as fixed parameters that are calculated each year (Sameoto et al. 2015, Nasmith et al. 2016, Smith and Sameoto 2016).

Operational advice to inform harvesting decisions for the following fishing year, for both the BoF SPAs and SFA29W subareas, is derived by projecting the respective models forward one year. These projections assume that natural mortality (m) is the average of the past five years (e.g., $m_{2020} = \bar{m}_{2015:2019}$) and the process error (η) is unchanged from the current year. Further, the growth calculations for the one-year projections utilize the size and condition of commercial scallop from the most recent survey. A projection is then evaluated for a range of potential catches to derive a catch scenario table. A catch scenario table presents a range of catches, and the associated exploitation rates, probabilities of biomass (or biomass density) increase, expected change in biomass (or biomass density), and, if biomass-based reference points are adopted for the respective modelled area, the probabilities that the biomass (or biomass density) will exceed the upper stock reference (USR) and limit reference point (LRP) (DFO 2019, 2020).

PRODUCTIVITY AND SURPLUS PRODUCTION

The productivity of scallop stocks in the Maritimes Region has previously been discussed by Smith and Hubley (2012) in the context of reference points; however, in this document the drivers of scallop productivity for the BoF and SFA 29W stocks as it relates to informing projections from the operational models are reviewed. In the context of the BoF and SFA 29W scallop stocks, the productivity is described by the amount or rate of production of new biomass by the stock each year. The overall productivity of a stock is important to its sustainable management and influences how much can be harvested annually. For a population to increase from its current size, gains due to recruitment and growth need to exceed losses due to natural mortality and catch. When a population decreases from its current size, losses due to natural mortality and catch exceed gains due to recruitment and growth. Further, a population can remain the same size if gains and losses are equal.

The balance between gains and losses that includes catch, can be used to determine the change in commercial biomass (ΔB_{t+1}) between years:

$$\Delta B_{t+1} = B_{t+1} - B_t$$

The percentage biomass change (ΔPB_{t+1}) is defined as:

$$\Delta PB_{t+1} = 100 \times \frac{B_{t+1} - B_t}{B_t}$$

Further, surplus production (SP) for the stock can be defined as the difference between the biomass added to the population through growth and recruitment to the fishery, and the biomass removed by natural mortality. Therefore, at any level of commercial biomass, if catch removes less (more) than the biomass added due to surplus production, then the commercial biomass will increase (decrease). Walters et al. (2008) succinctly summarized SP as “the change in stock size that would have taken place if there had been no harvesting”:

$$SP_t = \Delta B_{t+1} + C_t$$

With the surplus production rate (SP_{rate}) defined by:

$$SP_{rate(t)} = \frac{SP_t}{B_t}$$

To explore the productivity of the BoF and SFA 29W scallop stocks, time series trends were developed for commercial biomass (B), recruit biomass (R), commercial natural mortality (m), commercial and recruit growth (g and g_r), and surplus production (SP). For all modelled parameters (B, R, m), the posterior medians were used, and the fixed parameters estimates for g, g_r, and w were used; time series medians were calculated using the full time series for each respective parameter. The relationships between surplus production (SP) and biomass (B) were explored by plotting SP against biomass, while phase plots of commercial biomass and exploitation were also evaluated.

A heuristic approach was taken to evaluate how exploitation (e_t) influences changes in commercial biomass (ΔPB_t):

$$\Delta PB_t = \alpha + \beta e_t + \epsilon_t$$

$$\epsilon_t \sim N(0, \sigma^2)$$

The exploitation associated with 0% change in biomass (ΔPB) is estimated from the X-intercept of these models.

The one-year projections (for $t+1$) rely upon observed R in year t, assume that the current year parameter estimates of growth (g, g_r) are reliable estimates of these parameters in the following year, and that the average mortality in the last five years is a reliable estimate of mortality in the following year (DFO 2019, 2020). An analysis was undertaken to explore if there was autocorrelation in the main model parameters (B, R, m, g, and g_r) or SP. Correlograms were developed using the time series of each of these parameters with the significance of the autocorrelation assessed using the 95% confidence intervals.

TWO-YEAR PROJECTIONS AND IMPACT ASSESSMENT

One-year model projections have been operationalized for harvest advice for BoF and SFA 29W since the adoption of the current analytical frameworks of their respective Bayesian state-space delay difference models were implemented (Smith et al. 2003, 2007, Sameoto et al. 2015, Nasmith et al. 2016). These one-year projections assume natural mortality is the average of the last five years (e.g., $m_{2020} = \bar{m}_{2015:2019}$) and use the growth of commercial (g) and recruit (g_r; BoF only) size scallop calculated from the most recent survey. To evaluate the performance of the one-year model projections, the catch assumption for the one-year model projections was set to the realized catch for each respective year.

An analysis of productivity parameters based on the stock assessment model and three surplus production scenarios was conducted and used to inform the scenarios for two-year projections. The selection of the three surplus production scenarios was informed based on an evaluation of productivity parameters (e.g., commercial biomass, recruit biomass, natural mortality, growth, and surplus production). To derive two-year model projections, the one-year projections of the commercial biomass posteriors (where catch was set to the realized catch for each respective year) were projected forward under 3 scenarios: 1) zero surplus production, 2) median surplus production (for the respective stock), and 3) assuming the same R, m, g, g_r, and η as the one-year projection (i.e., same conditions as the one-year projection), hereafter referred to as the ‘status’ quo’ assumption. For all two-year model projections, the process error was propagated using η.

The performance of the model’s predictions of biomass in the following year (P_{y1}: one-year projection) and in two years (P_{y2}: two-year projection) were evaluated by comparing model predictions from fits to the data up to year t (e.g., 2012) to the posterior distribution of the commercial biomass in year t based on model fit to year $t-1$ (e.g., 2011), and to the posterior distribution of the commercial biomass in year t based on model fit to year $t-2$ (e.g., 2010). The performance of the two-year model projections was compared to the currently operationalized one-year projections by taking the difference in median biomass of the one-year and two-year projections (ΔP_{y2-y1}):

$$\Delta P_{y2-y1} = P_{y2} - P_{y1}$$

The proportional change in the projections between year 2 and year 1 (ΔPP_{y2-y1}) was also calculated using:

$$\Delta PP_{y2-y1} = \frac{P_{y2} - P_{y1}}{P_{y1}}$$

Change was considered different from 0 if it was $> |0.05|$ (i.e., $> |5\%|$).

To evaluate the impact of two-year model projections on harvest advice, the potential maximum catch and the difference in potential maximum catch, derived from the one- and two-year projections were assessed for each year from 2012 to 2020 for each area assuming a simple Harvest Control Rule (HCR) where exploitation was set at a constant value (Table 1). The chosen exploitation was based on the removal reference (RR) limit for each respective area (e.g., RR = 0.15 for SPA 4, DFO 2021). Since SFA 29W Subarea A and BoF SPA 6 do not have reference points, or reference points in terms of biomass, respectively, the exploitations associated with the observed zero change in commercial biomass from the productivity analyses were used (0.05, 0.18, respectively, Table 1).

All analyses were performed in R and the figures were developed using the tidyverse packages (Wickham 2016, R Core Team 2019).

RESULTS

BAY OF FUNDY SCALLOP PRODUCTION AREAS

Stock Productivity

Commercial biomass was above the long-term medians in 2019 in all SPAs (1A, 1B, 3, 4, and 6) and has been above the long-term medians since 2013, 2013, 2012, 2013, and 2014, for each area respectively (Figure 2). Recruitment has varied significantly over the time series in all areas and was below the long-term medians in 2019 for all SPAs (Figure 3). Natural mortality of commercial size scallops has been relatively variable across the time series and was at or above the long-term medians in all SPAs in 2019 (Figure 4). Growth rates of commercial and recruit size scallops have displayed substantial interannual variability and in 2019 were all below their respective long-term medians (Figure 5). The commercial growth rate has also dropped below 1 (negative growth) in all SPAs throughout the time series, although infrequently (Figure 5). The median yearly SP for SPAs 1A, 1B, 3, 4, and 6, was 305 mt, 436 mt, 238 mt, 143 mt, 165 mt, respectively. The corresponding median SP rates were 0.22, 0.20, 0.19, 0.14, and 0.21, respectively. However, substantial interannual variability in SP has been observed in each SPA, ranging from negative SP as low as −0.47 (SPAs 4 and 6) to a positive SP as high as 4.95 (SPA 4); negative SP has been observed for each SPA (Figures 6 and 7).

Correlograms indicated that commercial biomass was significantly autocorrelated at a lag of 1 year for each SPA (Figure 8). Recruit biomass was only marginally significant at a lag of 1 year for SPA 3 and showed no autocorrelation for the other areas (Figure 9). Natural mortality was autocorrelated at a lag of 1 year in SPAs 1A and 4, and was marginally significant at 1- and 2-year lags in SPA 1B, and showed no autocorrelation in SPAs 3 or 6 (Figure 10). Growth rates and SP displayed no consistent autocorrelation between years for any SPA (Figures 11–13).

Highly variable SP has been observed within each SPA and at similar biomass levels within SPA; low and negative SP have also been observed in all areas (Figure 14). Biomass reference points are adopted for all SPAs except SPA 6 and biomass in the recent time period has been above the USRs and exploitation has generally been below the RR (0.15 for SPAs 1A, 1B, 3, and 4) with the exception of 2018 in SPAs 1A and 1B (Figure 15). Change in commercial biomass was significantly ($p < 0.05$) related to exploitation for SPA 1A, 1B, and marginally insignificant in SPA 4 ($p = 0.06$); it was not significant in SPA 3 or SPA 6 ($p > 0.10$). The predicted exploitations corresponding to zero change in biomass over the time series were 0.16, 0.13, 0.20, 0.22, and 0.18, for SPA 1A, 1B, 3, 4, and 6, respectively (Figure 16).

Two-Year Projections

SPA 1A

For SPA 1A, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 17. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in: 8 of 9 years under the zero surplus production scenario, in 9 of 9 years under the median surplus production scenario, and in 9 of 9 years for the status quo scenario.

For SPA 1A, the LRP is 480 mt and the USR is 1,000 mt (Nasmith et al. 2016, DFO 2021). For all three two-year projection scenarios, the probability that the 2021 commercial biomass would be above the USR and in the Healthy Zone after removing 270 mt (the 2021 interim TAC) was between 0.78 and 0.87, the probability that the 2021 biomass would be above the LRP was between 0.97 and 0.98, and the expected exploitation ranged between 12 and 14% (Figure 18, Tables 2–4).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 19, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 7 of 9 years and was higher in 2 of 9 years; this difference ranged from −50% to 11% (−1,530 mt to 215 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 5 of 9 years, higher in 2 of 9 years, and not different in 2 of 9 years; the differences ranged from −39% to 33% (−1,200 mt to 626 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 6 of 9 years, higher in 1 of 9 years, and not different in 2 of 9 years; the differences ranged from −47% to 13% (−1,450 mt to 376 mt).

The impact of the two-year model projections on harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.15 and the resulting catch from a two-year projection for year t at an exploitation of 0.15. The catch values associated with an exploitation of 0.15 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 20. The relative difference between the one- and two-year catch values associated with an exploitation of 0.15 are shown in Figure 21. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 7 of 9 years, higher in 1 of 9 years, and no different in 1 of 9 years; the difference in resulting catch ranged from −44% to 7.2% (−220 mt to 25 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 3 of 9 years, higher in 2 of 9 years, and no different in 4 of 9 years; the difference in resulting catch ranged from −33% to 26 (−170 mt to 90 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 5 of 9 years, higher in 1 of 9 years, and no different in 3 of 9 years; the difference in resulting catch ranged from −42% to 12% (−210 mt to 58 mt).

SPA 1B

For SPA 1B, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 22. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in: 8 of 9 years under the zero surplus production scenario, in 9 of 9 years under the median surplus production scenario, and in 8 of 9 years for the status quo scenario.

For SPA 1B, the LRP is 880 mt and the USR is 1,800 mt (Nasmith et al. 2016, DFO 2021). For all three two-year projection scenarios, the probability that the 2021 commercial biomass would be above the USR and in the Healthy Zone after removing 400 mt (the 2021 interim TAC) was between 0.67 to 0.80, the probability that the 2021 biomass would be above the LRP was between 0.96 to 0.98, and the expected exploitation ranged between 12 and 15% (Figure 23, Tables 5–7).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 24, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 6 of 9 years, was higher in 1 of 9 years, and no different in 2 of 9 years; this difference ranged from −50% to 18% (−2,080 mt to 477 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 3 of 9 years, higher in 5 of 9 years, and not different in 1 of 9 years; the differences ranged from −40% to 40% (−1,670 mt to 1,080 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 4 of 9 years, higher in 4 of 9 years, and not different in 1 of 9 years; the differences ranged from −47% to 34% (−1,940 mt to 1,260 mt).

The impact of the two-year model projections on harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.15 and the resulting catch from a two-year projection for year t at an exploitation of 0.15. The catch values associated with an exploitation of 0.15 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 25. The relative difference between the one- and two-year catch values associated with an exploitation of 0.15 are shown in Figure 26. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 6 of 9 years, higher in 1 of 9 years, and no different in 2 of 9 years; the difference in resulting catch ranged from −45% to 15% (−326 mt to 71.8 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 3 of 9 years, higher in 4 of 9 years, and no different in 2 of 9 years; the difference in resulting catch ranged from −35% to 36% (−249 mt to 176 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 4 of 9 years, higher in 3 of 9 years, and no different in 2 of 9 years; the difference in resulting catch ranged from −44% to 31% (−314 mt to 195 mt).

SPA 3

For SPA 3, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 27. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in 9 of 9 years under all three two-year projection scenarios.

For SPA 3, the LRP is 600 mt and the USR is 1,000 mt (Nasmith et al. 2016, DFO 2021). For all three two-year projection scenarios, the probability that the 2021 commercial biomass would be above the USR and in the Healthy Zone after removing 200 mt (the 2021 interim TAC) was between 0.77 to 0.86, the probability that the 2021 biomass would be above the LRP was between 0.94 to 0.97, and the expected exploitation ranged between 9 and 11% (Figure 28, Tables 8–10).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 29, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 6 of 9 years and was higher in 3 of 9 years; this difference ranged from −45% to 35% (−1,190 mt to 636 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 5 of 9 years and higher in 4 of 9 years, the differences ranged from −35% to 59% (−875 mt to 1,010 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 6 of 9 years and higher in 3 of 9 years; the differences ranged from −41% to 48% (−1,110 mt to 976 mt).

The impact of using the two-year model projections as harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.15 and the resulting catch from a two-year projection for year t at an exploitation of 0.15. The catch values associated with an exploitation of 0.15 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 30. The relative difference between the one- and two-year catch values associated with an exploitation of 0.15 are shown in Figure 31. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 6 of 9 years and higher in 3 of 9 years; the difference in resulting catch ranged from −39% to 33% (−177 mt to 94 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 5 of 9 years and higher in 4 of 9 years; the difference in resulting catch ranged from −28% to 56% (−126 mt to 151 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 6 of 9 years and higher in 3 of 9 years; the difference in resulting catch ranged from −40% to 43% (−165 mt to 145 mt).

SPA 4

For SPA 4, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 32. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in 9 of 9 years under all three two-year projection scenarios.

For SPA 4, the LRP is 530 mt and the USR is 750 mt (Nasmith et al. 2016, DFO 2021). For all three two-year projection scenarios, the probability that the 2021 commercial biomass would be above the USR and in the Healthy Zone after removing 175 mt (the 2021 interim TAC) was between 0.61 to 0.70, the probability that the 2021 biomass would be above the LRP was between 0.78 to 0.84, and the expected exploitation ranged between 14 and 16% (Figure 33, Tables 11–13).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 34, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 7 of 9 years and was higher in 2 of 9 years; this difference ranged from −44% to 18% (−759 mt to 201 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 5 of 9 years, higher in 3 of 9 years, and no different in 1 of 9 years; the differences ranged from −36% to 35% (−626 mt to 378 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 6 of 9 years, higher in 2 of 9 years, and no different in 1 of 9 years; the differences ranged from −47% to 12% (−804 mt to 218 mt).

The impact of using the two-year model projections as harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.15 and the resulting catch from a two-year projection for year t at an exploitation of 0.15. The catch values associated with an exploitation of 0.15 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 35. The relative difference between the one- and two-year catch values associated with an exploitation of 0.15 are shown in Figure 36. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 6 of 9 years, higher in 2 of 9 years, and no different in 1 of 9 years; the difference in resulting catch ranged from −42% to 18% (−118 mt to 32 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 4 of 9 years, higher in 3 of 9 years, and no different in 2 of 9 years; the difference in resulting catch ranged from −34% to 34% (−95 mt to 62 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 6 of 9 years, higher in 2 of 9 years, and no different in 1 of 9 years; the difference in resulting catch ranged from −45% to 15% (−125 mt to 43 mt).

SPA 6

For SPA 6, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 37. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in: 7 of 9 years under the zero surplus production scenario, in 9 of 9 years under the median surplus production scenario, and in 9 of 9 years for the status quo scenario.

For SPA 6, the LRP and the USR are set in terms of the commercial catch rate and not the modelled biomass (DFO 2021); therefore, an evaluation of stock status relative to the population model is not possible. However, for all three two-year projection scenarios for 2021, assuming the total allowable catch of 210 mt is caught from the modeled area, the expected exploitation range is expected to be between 20 and 24% which corresponds to an expected range of biomass change between −28% and −11% (Figure 38, Tables 14–16).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 39, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 7 of 9 years, was higher in 1 of 9 years, and no different in 1 of 9 years; this difference ranged from −76% to 20% (−728 mt to 202 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 3 of 9 years, higher in 4 of 9 years, and no different in 2 of 9 years; the differences ranged from −71% to 37% (−603 mt to 374 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 5 of 9 years, higher in 2 of 9 years, and no different in 2 of 9 years; the differences ranged from −55% to 51% (−486 mt to 459 mt).

The impact of using the two-year model projections as harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.18 and the resulting catch from a two-year projection for year t at an exploitation of 0.18. The catch values associated with an exploitation of 0.18 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 40. The relative difference between the one- and two-year catch values associated with an exploitation of 0.18 are shown in Figure 41. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 8 of 9 years, and higher in 1 of 9 years; the difference in resulting catch ranged from −57% to 16% (−124 mt to 31 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 3 of 9 years, higher in 4 of 9 years, and no different in 2 of 9 years; the difference in resulting catch ranged from −49% to 31% (−96 mt to 62 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 5 of 9 years, higher in 2 of 9 years, and no different in 2 of 9 years; the difference in resulting catch ranged from −36% to 38% (−79 mt to 75 mt).

SFA 29 WEST

Stock Productivity

In SFA 29 West, commercial biomass was at the long-term median in 2019 in Subareas A and C, above the median in Subarea B, and below the median in Subarea D (Figure 42). Recruitment has varied significantly over the time series in all Subareas and was below the long-term medians in 2019 for Subareas A, C, and D, and at the median in Subarea B (Figure 43). Natural mortality has been relatively variable across the time series and was above the long-term medians in all Subareas in 2019 (Figure 44). Growth rates of commercial size scallops have displayed substantial interannual variability and in 2019 were below their respective long-term medians (Figure 45). The average meat weight of a recruit size scallop has also varied significantly over time with a range of up to 6 grams (Figure 46). The median yearly SP for Subareas A, B, C, and D, were 15 mt, 20 mt, 4 mt, and 39 mt, respectively. The corresponding median SP rates were 0.07, 0.17, 0.02, and 0.15, respectively. However, substantial interannual variability in SP has been observed throughout each Subarea, ranging from negative SP as low as −0.64 (Subarea C) to a positive SP as high as 1.77 (Subarea C); negative SP has been observed for each Subarea (Subarea A: 6 of 18, Subarea B: 8 of 18, Subarea C: 9 of 18, and Subarea D: 6 of 18 years; Figures 47 and 48).

Correlograms indicated that commercial biomass was significantly autocorrelated at a lag of one year for Subareas B and D, and was marginally significant at lags of one year in Subareas A and C (Figure 49). Subarea D also showed autocorrelation at a lag of two years. Recruit biomass was marginally significant at a lag of one year in Subarea D and showed no autocorrelation for the other Subareas (Figure 50). Natural mortality was autocorrelated at a lag of one year in Subareas A and C, and showed no autocorrelation in Subareas B or D (Figure 51). The average recruit weight, commercial growth rate, and SP displayed no consistent autocorrelation between years for any Subarea (Figures 52–54).

Highly variable SP has been observed within each Subarea and for similar biomass levels within Subareas; low and negative SP have also been observed in all Subareas (Figure 55). Biomass reference points are adopted in terms of commercial biomass densities for all Subareas except Subarea A, which does not have reference points adopted. Biomass densities have been above their respective USRs since 2016 for Subareas C and D, and since 2018 for Subarea B (Figure 56). Exploitation levels early in the time series in each Subarea had been relatively high, but have tended to be < 0.15 since 2015 (Figure 56). Harvest control rules and removal reference limits in Subareas B, C, and D were adopted in 2019 (DFO 2020). Change in commercial biomass was significantly related to exploitation for Subareas B, C, and D (p = 0.01) and marginally significant in Subarea A (p = 0.05). The predicted exploitations corresponding to zero change in biomass over the time series were 0.05, 0.17, 0.17, and 0.21, for Subareas A, B, C, and D, respectively (Figure 57).

Two-Year Projections

SFA 29W Subarea A

For SFA 29W Subarea A, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 58. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in: 7 of 9 years under the zero surplus production scenario, in 7 of 9 years under the median surplus production scenario, and in 6 of 9 years for the status quo scenario.

For SFA 29W Subarea A, reference points are not yet adopted (DFO 2020); therefore, an evaluation of stock status relative to the population model is not possible. However, for all three two-year projection scenarios for 2021, assuming removals are the same as in 2020 (6.5 mt), the expected exploitation range is expected to be between 3 and 5% and correspond to an expected range of biomass change between −33% and −4% (Figure 59, Tables 17–19).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 60, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 4 of 9 years, was higher in 2 of 9 years, and was no different in 3 of 9 years; this difference ranged from −48% to 47% (−85 mt to 34 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 4 of 9 years and was higher in 5 of 9 years; the differences ranged from −44% to 57% (−79 mt to 41 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 5 of 9 years, higher in 1 of 9 years, and no different in 3 of 9 years; the differences ranged from −56% to 27% (−99 mt to 32 mt).

The impact of using the two-year model projections as harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.05 and the resulting catch from a two-year projections for year t at an exploitation of 0.05. The catch values associated with an exploitation of 0.05 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 61. The relative difference between the one- and two-year catch values associated with an exploitation of 0.05 are shown in Figure 62. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 3 of 9 years, higher in 5 of 9 years, and no different in 1 of 9 years; the difference in resulting catch ranged from −51% to

59% (−8 mt to 5 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 2 of 9 years, higher in 6 of 9 years, and no different in 1 of 9 years; the difference in resulting catch ranged from −47% to 70% (−7 mt to 6 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 6 of 9 years, and higher in 3 of 9 years; the difference in resulting catch ranged from −60% to 54% (−9 mt to 5 mt).

SFA 29W Subarea B

For SFA 29W Subarea B, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 63. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in: 5 of 9 years under the zero surplus production scenario, in 6 of 9 years under the median surplus production scenario, and in 5 of 9 years for the status quo scenario.

For SFA 29W Subarea B, reference points are in terms of biomass densities, the LRP is 1.12 $mt \cdot km^{-2}$ and the USR is 2.24 $mt \cdot km^{-2}$ (DFO 2020). For all three two-year projection scenarios for 2021, assuming removals are the same as in 2020 (55 mt), the probability that the 2021 commercial biomass density would be above the USR and in the Healthy Zone was between 0.66 to 0.75, the probability that the 2021 biomass density would be above the LRP was between 0.89 to 0.92, the expected exploitation range is expected to be between 9 and 12% (Figure 64, Tables 20–22).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 65, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 7 of 9 years, was higher in 1 of 9 years, and no different in 1 of 9 years; this difference ranged from −93% to 120% (−92 mt to 18 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 7 of 9 years and higher in 2 of 9 years; the differences ranged from −89% to 230% (−82 mt to 33 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 7 of 9 years and higher in 2 of 9 years; the differences ranged from −87% to 280% (−72 mt to 40 mt).

The impact of using the two-year model projections as harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.06 and the resulting catch from a two-year projection for year t at an exploitation of 0.06. The catch values associated with an exploitation of 0.06 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 66. The relative difference between the one- and two-year catch values associated with an exploitation of 0.06 are shown in Figure 67. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 5 of 9 years, and higher in 4 of 9 years; the difference in resulting catch ranged from −50% to 52% (−18.2 mt to 9.47 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 3 of 9 years, higher in 4 of 9 years, and no different in 2 of 9 years; the difference in resulting catch ranged from −41% to 77% (−15 mt to 14 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 6 of 9 years, and higher in 3 of 9 years; the difference in resulting catch ranged from −50% to 54% (−19 mt to 13 mt).

SFA 29W Subarea C

For SFA 29W Subarea C, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 68. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in: 5 of 9 years under the zero surplus production scenario, in 5 of 9 years under the median surplus production scenario, and in 5 of 9 years for the status quo scenario.

For SFA 29W Subarea C, reference points are in terms of biomass densities, the LRP is 1.41 $mt \cdot km^{-2}$ and the USR is 2.82 $mt \cdot km^{-2}$ (DFO 2020). For all three two-year projection scenarios for 2021, assuming removals are the same as in 2020 (20 mt), the probability that the 2021 commercial biomass density would be above the USR and in the Healthy Zone was between 0.40 to 0.45, the probability that the 2021 biomass density would be above the LRP was between 0.64 to 0.69, the exploitation is expected to be 9% (Figure 69, Tables 23–25).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 70, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 5 of 9 years and was higher in 4 of 9 years; this difference ranged from −93% to 150% (−128 mt to 74 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 5 of 9 years and was higher in 4 of 9 years; the differences ranged from −92% to 160% (−127 mt to 76 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 4 of 9 years, higher in 4 of 9 years, and no different in 1 of 9 years; the differences ranged from −91% to 200% (−113 mt to 107 mt).

The impact of using the two-year model projections as harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.06 and the resulting catch from a two-year projection for year t at an exploitation of 0.06. The catch values associated with an exploitation of 0.06 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 71. The relative difference between the one- and two-year catch values associated with an exploitation of 0.06 are shown in Figure 72. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 4 of 9 years and higher in 5 of 9 years; the difference in resulting catch ranged from −54% to 110% (−19 mt to 10 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 4 of 9 years and higher in 5 of 9 years; the difference in resulting catch ranged from −53% to 110% (−18 mt to 11 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 5 of 9 years and higher in 4 of 9 years; the difference in resulting catch ranged from −50% to 140% (−17 mt to 18 mt).

SFA 29W Subarea D

For SFA 29W Subarea D, the performance of the model's prediction of biomass in the following year (one-year projection) and in the following two years (two-year projection), where the two-year projection was evaluated for three scenarios, is presented in Figure 73. As measured by the 90% credible interval, there was increased uncertainty in the two-year projections compared to the one-year projections. The two-year projection estimated an increased biomass range relative to the one-year projection in: 5 of 9 years under the zero surplus production scenario, in 6 of 9 years under the median surplus production scenario, and in 4 of 9 years for the status quo scenario.

For SFA 29W Subarea D, reference points are in terms of biomass densities, the LRP is 1.3 $mt \cdot km^{-2}$ and the USR is 2.6 $mt \cdot km^{-2}$ (DFO 2020). For all three two-year projection scenarios for 2021, assuming removals are the same as in 2020 (65 mt), the probability that the 2021 commercial biomass density would be above the USR and in the Healthy Zone was between 0.13 to 0.27, the probability that the 2021 biomass density would be above the LRP was between 0.41 to 0.60, the exploitation is expected to be between 21 and 30% (Figure 74, Tables 26–28).

The plots of the relative difference in median biomass of the one- and two-year projections are in Figure 75, where negative (positive) values indicate that the two-year projected biomass for year t was smaller (larger) than the one-year projected biomass in year t. For the zero surplus production scenario, the two-year projection was lower than the one-year projection for 7 of 9 years and was higher in 2 of 9 years; this difference ranged from −66% to 48% (−103 mt to 43 mt). For the median surplus production scenario, the two-year projection was lower than the one-year projection in 7 of 9 years and was higher in 2 of 9 years; the differences ranged from −56% to 75% (−88 mt to 67 mt). For the status quo scenario, the two-year projection was lower than the one-year projection for 6 of 9 years, higher in 2 of 9 years, and no different in 1 of 9 years; the differences ranged from −65% to 86% (−101 mt to 78 mt).

The impact of the two-year model projections on harvest advice was quantified through the evaluation of the potential difference in catch resulting from a one-year projection for year t at an exploitation of 0.09 and the resulting catch from a two-year projection for year t at an exploitation of 0.09. The catch values associated with an exploitation of 0.09 from the one- and two-year biomass projections from each year from 2012 to 2020 are presented in Figure 76. The relative difference between the one- and two-year catch values associated with an exploitation of 0.09 are shown in Figure 77. Negative (positive) differences indicate that the allowable catch resulting from a two-year projection would be less (greater) than the catch associated with a one-year projection. For the zero surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 6 of 9 years, higher in 2 of 9 years, and no different in 1 of 9 years; the difference in resulting catch ranged from −49% to 43% (−22 mt to 7 mt). For the median surplus production scenario, the catch from a two-year projection was lower than that of a one-year projection in 5 of 9 years and higher in 4 of 9 years; the difference in resulting catch ranged from −42% to 65% (−19 mt to 12 mt). For the status quo scenario, the catch from a two-year projection was lower than that of a one-year projection in 5 of 9 years and higher in 4 of 9 years; the difference in resulting catch ranged from −49% to 50% (−22 mt to 14 mt).

CONCLUSION

The BoF and SFA 29W stocks are managed using TACs in terms of commercial biomass (meats), therefore the determination of harvest levels (TACs) is dependent on reliable stock assessments; this has been documented for quota management systems in general (Walters and Pearse 1996). In the context of enabling the broad fisheries management objective of maximizing present catches, subject to the constraints of a sustainable harvesting regime, to be achieved, annual Inshore Scallop stock assessment advice traditionally consists of current year model runs and one-year projections to inform the setting of final TACs. While two-year projections using a zero surplus assumption are also conducted, they (typically) are only used to inform the setting of the interim TACs for SPAs 1A, 1B, 3, and 4 to allow fishing to begin October 1. This approach to setting the interim TACs is relatively low risk from a conservation perspective since i) final TACs based on one-year projections are provided in December and ii) the zero surplus production two-year projections tend to result in lower biomass estimates than a corresponding one-year projection for the same year.

The scallop stocks in the BoF and SFA 29W demonstrate substantial interannual variability in their productivity, reflected by the lack of autocorrelation in the primary model parameters and in surplus production beyond a one-year lag for most areas. The variable interannual surplus production resulted in there being no clear 'best' scenario to assume for the two-year projections. Although no two-year projection scenarios assuming negative surplus production were evaluated, it is acknowledged that negative surplus production has been observed in all stock areas.

All evaluations of two-year projection performance need to be considered as independent trials and not as a time series. For example, had a two-year projection been used to decide harvest levels for a given stock area in year *t*, and the two-year biomass projection overestimated the one-year biomass by 100%, twice as much catch could be taken in that year and the consequences of this potential overharvesting would be carried forward into the following year(s). The evaluation presented in this analysis only evaluates the potential for what the difference in harvest within a given year would have been, given a two-year projection, and not what follow-on effects to future years may have occurred had this decision been taken.

In areas in which the biomass is relatively low (e.g., habitat categories within subareas of SFA 29W), the 90% credible interval of the two-year projection was occasionally smaller than the 90% credible interval for the one-year projection. This occurred only when the median biomass from the two-year projection was smaller than the one-year projection and began to approach 0. The process error term used for the two-year projections is log-normally distributed. As the data approach 0, the range of the data will decline due to this distribution having a lower bound at 0. Rather than being evidence of more certainty in the estimates of these two-year projections, these cases indicate years in which the biomass from the two-year projection is unrealistically low. This was often observed for the two-year projections for the subareas of SFA 29W (Figures 58, 63, 68, 73). As such, the two-year projections for SFA 29W are not deemed sufficiently reliable to provide two-year advice.

Overall, relative to the use of one-year projections, use of two-year projections as the basis for management decisions over the long term would result in substantial risk of either loss in potential catch or overharvesting. However, in the context of tactical one-year decision making and in the absence of 2020 survey data, these two-year projections provide context for decision making for the 2021 harvest levels for the BoF stocks. For SFA 29W, the two-year projections are not sufficiently reliable given the challenges associated with projecting low biomasses (as discussed above). Therefore, these projections are not recommended to be used to inform the 2021 harvest levels for SFA 29W.

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TABLES

*Table 1. Harvest control rule (HCR) scenarios of exploitation (e) to evaluate the impact of two-year model projections relative to one-year model projections on harvest advice for SPAs 1A, 1B, 3, 4, and 6 in the BoF and Subareas A, B, C, and D in SFA 29W. *Informed using the exploitation associated with no change in commercial biomass.*

Area	HCR (e)
SPA 1A	0.15
SPA 1B	0.15
SPA 3	0.15
SPA 4	0.15
SPA 6	0.18*
Subarea A	0.05*
Subarea B	0.06
Subarea C	0.06
Subarea D	0.09

Table 2. Catch scenarios for SPA 1A to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.46	−2.4	0.98	0.84
20	0.01	0.45	−3.4	0.98	0.84
40	0.02	0.43	−4.4	0.98	0.84
60	0.03	0.42	−5.3	0.98	0.83
80	0.04	0.40	−6.3	0.98	0.83
100	0.05	0.39	−7.3	0.97	0.82
110	0.06	0.37	−8.3	0.97	0.82
130	0.07	0.36	−9.2	0.97	0.82
150	0.08	0.34	−10.2	0.97	0.81
170	0.09	0.32	−11.2	0.97	0.81
190	0.10	0.31	−12.2	0.97	0.80
210	0.11	0.29	−13.1	0.97	0.80
230	0.12	0.28	−14.1	0.97	0.79
250	0.13	0.26	−15.1	0.97	0.79
270	0.14	0.25	−16.1	0.97	0.78
290	0.15	0.23	−17.0	0.96	0.78
310	0.16	0.22	−18.0	0.96	0.77
330	0.17	0.20	−19.0	0.96	0.77
340	0.18	0.19	−20.0	0.96	0.76
360	0.19	0.18	−21.0	0.96	0.76
380	0.20	0.16	−21.9	0.96	0.75

Table 3. Catch scenarios for SPA 1A to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.72	16.8	0.99	0.90
20	0.01	0.71	15.7	0.99	0.90
50	0.02	0.69	14.5	0.99	0.90
70	0.03	0.68	13.3	0.99	0.90
90	0.04	0.67	12.2	0.99	0.89
120	0.05	0.65	11.0	0.98	0.89
140	0.06	0.64	9.8	0.98	0.89
160	0.07	0.62	8.7	0.98	0.88
180	0.08	0.61	7.5	0.98	0.88
210	0.09	0.59	6.3	0.98	0.88
230	0.10	0.58	5.2	0.98	0.87
250	0.11	0.56	4.0	0.98	0.87
280	0.12	0.54	2.8	0.98	0.87
300	0.13	0.52	1.7	0.98	0.86
320	0.14	0.51	0.5	0.98	0.86
350	0.15	0.49	−0.7	0.98	0.86
370	0.16	0.47	−1.9	0.98	0.85
390	0.17	0.45	−3.0	0.98	0.85
420	0.18	0.43	−4.2	0.98	0.84
440	0.19	0.41	−5.4	0.98	0.84
460	0.20	0.39	−6.5	0.98	0.83

Table 4. Catch scenarios for SPA 1A to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.50	0.2	0.98	0.85
20	0.01	0.49	−0.8	0.98	0.85
40	0.02	0.47	−1.8	0.98	0.85
60	0.03	0.46	−2.8	0.98	0.84
80	0.04	0.44	−3.8	0.98	0.84
100	0.05	0.43	−4.8	0.98	0.84
120	0.06	0.41	−5.8	0.98	0.83
140	0.07	0.39	−6.8	0.98	0.83
160	0.08	0.38	−7.8	0.97	0.82
180	0.09	0.36	−8.8	0.97	0.82
200	0.10	0.35	−9.8	0.97	0.81
220	0.11	0.33	−10.8	0.97	0.81
240	0.12	0.31	−11.8	0.97	0.81
260	0.13	0.30	−12.8	0.97	0.80
280	0.14	0.28	−13.8	0.97	0.80
300	0.15	0.27	−14.8	0.97	0.79
310	0.16	0.25	−15.8	0.97	0.79
330	0.17	0.23	−16.8	0.96	0.78
350	0.18	0.22	−17.8	0.96	0.78
370	0.19	0.20	−18.8	0.96	0.77
390	0.20	0.19	−19.8	0.96	0.76

Table 5. Catch scenarios for SPA 1B to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.49	−0.4	0.98	0.77
30	0.01	0.47	−1.4	0.98	0.77
50	0.02	0.46	−2.4	0.98	0.76
80	0.03	0.44	−3.4	0.97	0.76
110	0.04	0.42	−4.4	0.97	0.75
130	0.05	0.40	−5.4	0.97	0.75
160	0.06	0.38	−6.4	0.97	0.74
190	0.07	0.36	−7.4	0.97	0.73
220	0.08	0.34	−8.4	0.97	0.73
240	0.09	0.32	−9.4	0.97	0.72
270	0.10	0.30	−10.4	0.97	0.71
300	0.11	0.29	−11.4	0.96	0.71
320	0.12	0.27	−12.4	0.96	0.70
350	0.13	0.25	−13.4	0.96	0.69
380	0.14	0.23	−14.3	0.96	0.68
400	0.15	0.22	−15.3	0.96	0.68
430	0.16	0.20	−16.3	0.96	0.67
460	0.17	0.19	−17.3	0.96	0.66
490	0.18	0.17	−18.3	0.95	0.65
510	0.19	0.16	−19.3	0.95	0.64
540	0.20	0.15	−20.3	0.95	0.63

Table 6. Catch scenarios for SPA 1B to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.78	18.8	0.99	0.86
30	0.01	0.77	17.6	0.99	0.86
60	0.02	0.76	16.4	0.99	0.85
100	0.03	0.74	15.2	0.99	0.85
130	0.04	0.73	14.1	0.99	0.84
160	0.05	0.71	12.9	0.99	0.84
190	0.06	0.70	11.7	0.98	0.83
230	0.07	0.68	10.5	0.98	0.83
260	0.08	0.66	9.3	0.98	0.82
290	0.09	0.64	8.1	0.98	0.82
320	0.10	0.62	6.9	0.98	0.81
360	0.11	0.60	5.7	0.98	0.81
390	0.12	0.58	4.6	0.98	0.80
420	0.13	0.56	3.4	0.98	0.80
450	0.14	0.54	2.2	0.98	0.79
480	0.15	0.52	1.0	0.98	0.78
520	0.16	0.50	−0.2	0.98	0.78
550	0.17	0.47	−1.4	0.98	0.77
580	0.18	0.45	−2.6	0.98	0.76
610	0.19	0.43	−3.8	0.97	0.76
650	0.20	0.41	−5.0	0.97	0.75

Table 7. Catch scenarios for SPA 1B to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.49	−0.8	0.98	0.78
30	0.01	0.47	−1.8	0.98	0.77
50	0.02	0.45	−2.8	0.98	0.76
80	0.03	0.43	−3.8	0.98	0.76
110	0.04	0.41	−4.7	0.97	0.75
130	0.05	0.39	−5.7	0.97	0.75
160	0.06	0.37	−6.7	0.97	0.74
190	0.07	0.35	−7.7	0.97	0.73
210	0.08	0.33	−8.7	0.97	0.73
240	0.09	0.31	−9.7	0.97	0.72
270	0.10	0.29	−10.7	0.97	0.71
300	0.11	0.27	−11.7	0.97	0.70
320	0.12	0.26	−12.7	0.96	0.70
350	0.13	0.24	−13.7	0.96	0.69
380	0.14	0.22	−14.7	0.96	0.68
400	0.15	0.21	−15.7	0.96	0.67
430	0.16	0.19	−16.7	0.96	0.67
460	0.17	0.18	−17.6	0.96	0.66
480	0.18	0.16	−18.6	0.95	0.65
510	0.19	0.15	−19.6	0.95	0.64
540	0.20	0.14	−20.6	0.95	0.63

Table 8. Catch scenarios for SPA 3 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.48	−1.5	0.96	0.84
20	0.01	0.46	−2.5	0.96	0.83
40	0.02	0.44	−3.5	0.96	0.83
60	0.03	0.43	−4.5	0.96	0.83
70	0.04	0.41	−5.5	0.95	0.82
90	0.05	0.39	−6.5	0.95	0.82
110	0.06	0.38	−7.4	0.95	0.81
130	0.07	0.36	−8.4	0.95	0.81
150	0.08	0.34	−9.4	0.95	0.80
170	0.09	0.33	−10.4	0.95	0.80
180	0.10	0.31	−11.4	0.94	0.80
200	0.11	0.29	−12.4	0.94	0.79
220	0.12	0.28	−13.3	0.94	0.78
240	0.13	0.26	−14.3	0.94	0.78
260	0.14	0.25	−15.3	0.94	0.77
280	0.15	0.23	−16.3	0.94	0.77
290	0.16	0.22	−17.3	0.93	0.76
310	0.17	0.20	−18.3	0.93	0.76
330	0.18	0.19	−19.3	0.93	0.75
350	0.19	0.18	−20.2	0.92	0.74
370	0.20	0.16	−21.2	0.92	0.74

Table 9. Catch scenarios for SPA 3 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.72	15.5	0.98	0.90
20	0.01	0.70	14.3	0.97	0.89
40	0.02	0.69	13.2	0.97	0.89
60	0.03	0.67	12.0	0.97	0.89
90	0.04	0.66	10.9	0.97	0.88
110	0.05	0.64	9.7	0.97	0.88
130	0.06	0.63	8.6	0.97	0.88
150	0.07	0.61	7.4	0.97	0.87
170	0.08	0.60	6.3	0.97	0.87
190	0.09	0.58	5.1	0.97	0.86
220	0.10	0.56	4.0	0.97	0.86
240	0.11	0.55	2.8	0.96	0.86
260	0.12	0.53	1.6	0.96	0.85
280	0.13	0.51	0.5	0.96	0.85
300	0.14	0.49	−0.7	0.96	0.85
320	0.15	0.47	−1.8	0.96	0.84
350	0.16	0.45	−3.0	0.96	0.84
370	0.17	0.43	−4.1	0.96	0.83
390	0.18	0.41	−5.3	0.96	0.83
410	0.19	0.39	−6.4	0.95	0.82
430	0.20	0.37	−7.6	0.95	0.82

Table 10. Catch scenarios for SPA 3 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.41	−5.4	0.96	0.82
20	0.01	0.39	−6.3	0.95	0.82
40	0.02	0.38	−7.3	0.95	0.82
50	0.03	0.36	−8.2	0.95	0.81
70	0.04	0.35	−9.2	0.95	0.81
90	0.05	0.33	−10.1	0.95	0.80
110	0.06	0.31	−11.1	0.95	0.80
120	0.07	0.30	−12.0	0.94	0.79
140	0.08	0.28	−13.0	0.94	0.79
160	0.09	0.27	−13.9	0.94	0.78
180	0.10	0.25	−14.9	0.94	0.78
190	0.11	0.24	−15.8	0.94	0.77
210	0.12	0.22	−16.7	0.94	0.77
230	0.13	0.21	−17.7	0.93	0.76
250	0.14	0.20	−18.6	0.93	0.76
260	0.15	0.18	−19.6	0.93	0.75
280	0.16	0.17	−20.5	0.93	0.74
300	0.17	0.16	−21.5	0.92	0.74
320	0.18	0.14	−22.4	0.92	0.73
330	0.19	0.13	−23.4	0.92	0.72
350	0.20	0.12	−24.3	0.92	0.72

Table 11. Catch scenarios for SPA 4 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.49	−0.6	0.85	0.71
10	0.01	0.48	−1.6	0.84	0.70
20	0.02	0.47	−2.6	0.84	0.70
30	0.03	0.46	−3.6	0.84	0.69
40	0.04	0.45	−4.6	0.83	0.69
60	0.05	0.43	−5.6	0.83	0.68
70	0.06	0.42	−6.6	0.83	0.68
80	0.07	0.41	−7.6	0.82	0.67
90	0.08	0.40	−8.6	0.82	0.66
100	0.09	0.38	−9.5	0.81	0.66
110	0.10	0.37	−10.5	0.81	0.65
120	0.11	0.36	−11.5	0.81	0.65
130	0.12	0.35	−12.5	0.80	0.64
140	0.13	0.33	−13.5	0.80	0.64
160	0.14	0.32	−14.5	0.79	0.63
170	0.15	0.31	−15.5	0.79	0.63
180	0.16	0.30	−16.5	0.78	0.62
190	0.17	0.28	−17.5	0.78	0.61
200	0.18	0.27	−18.5	0.78	0.61
210	0.19	0.26	−19.5	0.77	0.60
220	0.20	0.25	−20.5	0.76	0.59

Table 12. Catch scenarios for SPA 4 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.64	12.9	0.88	0.77
10	0.01	0.63	11.7	0.88	0.76
30	0.02	0.62	10.6	0.88	0.76
40	0.03	0.60	9.5	0.88	0.75
50	0.04	0.59	8.4	0.87	0.75
60	0.05	0.58	7.2	0.87	0.74
80	0.06	0.57	6.1	0.87	0.74
90	0.07	0.56	5.0	0.86	0.74
100	0.08	0.54	3.8	0.86	0.73
110	0.09	0.53	2.7	0.86	0.72
130	0.10	0.52	1.6	0.85	0.72
140	0.11	0.51	0.5	0.85	0.72
150	0.12	0.49	−0.7	0.85	0.71
160	0.13	0.48	−1.8	0.84	0.70
180	0.14	0.47	−2.9	0.84	0.70
190	0.15	0.45	−4.1	0.84	0.69
200	0.16	0.44	−5.2	0.83	0.69
210	0.17	0.42	−6.3	0.83	0.68
230	0.18	0.41	−7.4	0.82	0.67
240	0.19	0.40	−8.6	0.82	0.67
250	0.20	0.38	−9.7	0.81	0.66

Table 13. Catch scenarios for SPA 4 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt)	e	Pr Increase	% Change	Pr > LRP	Pr > USR
0	0.00	0.47	−2.2	0.84	0.70
10	0.01	0.46	−3.2	0.84	0.70
20	0.02	0.45	−4.2	0.84	0.69
30	0.03	0.44	−5.2	0.83	0.69
40	0.04	0.43	−6.1	0.83	0.68
50	0.05	0.41	−7.1	0.82	0.68
70	0.06	0.40	−8.1	0.82	0.67
80	0.07	0.39	−9.1	0.82	0.66
90	0.08	0.38	−10.1	0.81	0.66
100	0.09	0.36	−11.0	0.81	0.65
110	0.10	0.35	−12.0	0.81	0.65
120	0.11	0.34	−13.0	0.80	0.64
130	0.12	0.33	−14.0	0.80	0.64
140	0.13	0.32	−14.9	0.79	0.63
150	0.14	0.30	−15.9	0.79	0.62
160	0.15	0.29	−16.9	0.78	0.62
170	0.16	0.28	−17.9	0.78	0.61
190	0.17	0.27	−18.9	0.78	0.60
200	0.18	0.25	−19.8	0.77	0.60
210	0.19	0.24	−20.8	0.76	0.59
220	0.20	0.23	−21.8	0.76	0.58

Table 14. Catch scenarios for SPA 6 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase. These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change
0	0.00	0.44	−5.0
10	0.01	0.43	−5.9
20	0.02	0.42	−6.9
30	0.03	0.40	−7.8
40	0.04	0.39	−8.8
40	0.05	0.38	−9.7
50	0.06	0.37	−10.7
60	0.07	0.36	−11.6
70	0.08	0.34	−12.6
80	0.09	0.33	−13.5
90	0.10	0.32	−14.5
100	0.11	0.30	−15.4
110	0.12	0.29	−16.4
110	0.13	0.28	−17.3
120	0.14	0.27	−18.3
130	0.15	0.25	−19.2
140	0.16	0.24	−20.2
150	0.17	0.23	−21.1
160	0.18	0.22	−22.1
170	0.19	0.21	−23.0
180	0.20	0.20	−24.0
180	0.21	0.18	−24.9
190	0.22	0.17	−25.9
200	0.23	0.16	−26.8
210	0.24	0.15	−27.8
220	0.25	0.14	−28.7
230	0.26	0.13	−29.7
240	0.27	0.12	−30.6
250	0.28	0.11	−31.6
250	0.29	0.10	−32.5
260	0.30	0.09	−33.5

Table 15. Catch scenarios for SPA 6 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase. These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt)	e	Pr Increase	% Change
0	0.00	0.62	11.3
10	0.01	0.61	10.2
20	0.02	0.60	9.1
30	0.03	0.59	7.9
40	0.04	0.58	6.8
50	0.05	0.57	5.7
60	0.06	0.55	4.6
70	0.07	0.54	3.5
80	0.08	0.53	2.4
90	0.09	0.52	1.3
100	0.10	0.50	0.2
110	0.11	0.49	−1.0
120	0.12	0.47	−2.1
130	0.13	0.46	−3.2
140	0.14	0.45	−4.3
160	0.15	0.43	−5.4
170	0.16	0.42	−6.5
180	0.17	0.40	−7.6
190	0.18	0.39	−8.7
200	0.19	0.37	−9.9
210	0.20	0.36	−11.0
220	0.21	0.34	−12.1
230	0.22	0.33	−13.2
240	0.23	0.31	−14.3
250	0.24	0.30	−15.4
260	0.25	0.28	−16.5
270	0.26	0.26	−17.7
280	0.27	0.25	−18.8
290	0.28	0.23	−19.9
300	0.29	0.22	−21.0
310	0.30	0.20	−22.1

Table 16. Catch scenarios for SPA 6 to evaluate 2020/21 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase. These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt)	e	Pr Increase	% Change
0	0.00	0.51	0.4
10	0.01	0.49	−0.6
20	0.02	0.48	−1.6
30	0.03	0.47	−2.6
40	0.04	0.46	−3.6
50	0.05	0.44	−4.6
60	0.06	0.43	−5.6
60	0.07	0.42	−6.6
70	0.08	0.40	−7.6
80	0.09	0.39	−8.6
90	0.10	0.38	−9.6
100	0.11	0.37	−10.6
110	0.12	0.35	−11.6
120	0.13	0.34	−12.6
130	0.14	0.33	−13.6
140	0.15	0.31	−14.6
150	0.16	0.30	−15.6
160	0.17	0.29	−16.6
170	0.18	0.27	−17.6
180	0.19	0.26	−18.7
190	0.20	0.25	−19.7
190	0.21	0.23	−20.7
200	0.22	0.22	−21.7
210	0.23	0.21	−22.7
220	0.24	0.19	−23.7
230	0.25	0.18	−24.7
240	0.26	0.17	−25.7
250	0.27	0.16	−26.7
260	0.28	0.15	−27.7
270	0.29	0.14	−28.7
280	0.30	0.13	−29.7

Table 17. Catch scenarios for SFA 29 West Subarea A to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase. These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt) Subarea A	e Medium	% Change Medium	Pr Increase Medium	% Change Subarea A	Pr Increase Subarea A
0	0.00	−7.5	0.44	−6.1	0.45
5	0.03	−10.3	0.42	−8.9	0.43
9	0.05	−12.1	0.40	−10.7	0.41
10	0.06	−13.0	0.40	−11.7	0.41
15	0.09	−15.8	0.37	−14.4	0.38
21	0.12	−18.6	0.35	−17.3	0.36
26	0.15	−21.4	0.32	−20.1	0.33
31	0.18	−24.2	0.30	−23.0	0.31

Table 18. Catch scenarios for SFA 29 West Subarea A to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), and probability (Pr) of commercial biomass increase. These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt) Subarea A	e Medium	% Change Medium	Pr Increase Medium	% Change Subarea A	Pr Increase Subarea A
0	0.00	−2.5	0.48	−0.9	0.49
5	0.03	−5.5	0.46	−3.9	0.47
9	0.05	−7.4	0.44	−5.8	0.45
11	0.06	−8.4	0.43	−6.8	0.45
16	0.09	−11.3	0.41	−9.8	0.42
22	0.12	−14.2	0.38	−12.8	0.39
27	0.15	−17.2	0.36	−15.7	0.37
33	0.18	−20.1	0.33	−18.7	0.34

Table 19. Catch scenarios for SFA 29 West Subarea A to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), and probability (Pr) of commercial biomass increase. These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt) Subarea A	e Medium	% Change Medium	Pr Increase Medium	% Change Subarea A	Pr Increase Subarea A
0	0.00	−29.7	0.26	−29.6	0.27
4	0.03	−31.8	0.25	−31.7	0.25
6	0.05	−33.1	0.23	−33.0	0.24
7	0.06	−33.9	0.23	−33.7	0.23
11	0.09	−35.9	0.21	−35.9	0.21
15	0.12	−38.1	0.19	−38.0	0.20
18	0.15	−40.2	0.18	−40.1	0.18
22	0.18	−42.3	0.16	−42.2	0.16

Table 20. Catch scenarios for SFA 29 West Subarea B to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt) Subarea B	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea B	Pr Increase Subarea B
0	0.00	−4.8	0.46	0.91	0.74	−3.6	0.47
15	0.03	−7.7	0.44	0.91	0.72	−6.5	0.44
26	0.05	−9.6	0.42	0.91	0.72	−8.4	0.42
31	0.06	−10.5	0.41	0.90	0.71	−9.4	0.41
46	0.09	−13.4	0.39	0.90	0.70	−12.3	0.38
62	0.12	−16.3	0.36	0.89	0.69	−15.2	0.35
77	0.15	−19.1	0.34	0.88	0.67	−18.1	0.32
93	0.18	−22.0	0.31	0.88	0.66	−21.0	0.29

Table 21. Catch scenarios for SFA 29 West Subarea B to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt) Subarea B	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea B	Pr Increase Subarea B
0	0.00	8.8	0.57	0.93	0.79	9.8	0.59
18	0.03	5.5	0.54	0.93	0.78	6.6	0.56
30	0.05	3.4	0.53	0.93	0.77	4.3	0.54
36	0.06	2.3	0.52	0.93	0.77	3.1	0.53
54	0.09	−0.9	0.49	0.92	0.75	0.0	0.50
73	0.12	−4.2	0.46	0.92	0.74	−3.4	0.47
91	0.15	−7.5	0.44	0.91	0.73	−6.8	0.43
109	0.18	−10.7	0.41	0.91	0.72	−9.9	0.40

Table 22. Catch scenarios for SFA 29 West Subarea B to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt) Subarea B	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea B	Pr Increase Subarea B
0	0.00	−9.5	0.42	0.91	0.72	−11.9	0.39
14	0.03	−12.2	0.40	0.90	0.70	−14.6	0.36
23	0.05	−14.1	0.38	0.90	0.70	−16.4	0.35
28	0.06	−14.9	0.38	0.90	0.69	−17.2	0.34
42	0.09	−17.6	0.35	0.89	0.68	−19.9	0.31
56	0.12	−20.4	0.33	0.89	0.66	−22.6	0.29
70	0.15	−23.1	0.30	0.88	0.65	−25.2	0.26
84	0.18	−25.8	0.28	0.87	0.63	−27.8	0.23

Table 23. Catch scenarios for SFA 29 West Subarea C to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt) Subarea C	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea C	Pr Increase Subarea C
0	0.00	−3.8	0.48	0.71	0.48	−3.9	0.47
7	0.03	−6.6	0.46	0.70	0.47	−6.8	0.45
12	0.05	−8.6	0.45	0.70	0.46	−8.7	0.44
15	0.06	−9.5	0.45	0.69	0.46	−9.7	0.43
22	0.09	−12.4	0.43	0.68	0.45	−12.6	0.41
30	0.12	−15.3	0.41	0.67	0.44	−15.4	0.38
37	0.15	−18.2	0.40	0.66	0.42	−18.3	0.36
44	0.18	−21.1	0.38	0.65	0.41	−21.2	0.34

Table 24. Catch scenarios for SFA 29 West Subarea C to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt) Subarea C	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea C	Pr Increase Subarea C
0	0.00	−2.0	0.49	0.71	0.49	−1.9	0.49
8	0.03	−4.8	0.47	0.71	0.48	−4.9	0.46
13	0.05	−6.8	0.46	0.70	0.47	−6.8	0.45
15	0.06	−7.8	0.46	0.70	0.47	−7.8	0.44
23	0.09	−10.8	0.44	0.69	0.45	−10.7	0.42
30	0.12	−13.6	0.42	0.68	0.44	−13.8	0.40
38	0.15	−16.6	0.40	0.66	0.43	−16.6	0.37
45	0.18	−19.6	0.39	0.66	0.42	−19.6	0.35

Table 25. Catch scenarios for SFA 29 West Subarea C to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt) Subarea C	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea C	Pr Increase Subarea C
0	0.00	−14.4	0.42	0.67	0.43	−14.6	0.40
6	0.03	−16.8	0.41	0.66	0.42	−17.1	0.38
11	0.05	−18.6	0.40	0.66	0.41	−18.7	0.37
13	0.06	−19.5	0.39	0.65	0.41	−19.6	0.36
19	0.09	−22.0	0.37	0.64	0.40	−22.2	0.34
26	0.12	−24.6	0.36	0.63	0.38	−24.7	0.32
32	0.15	−27.2	0.34	0.62	0.37	−27.3	0.30
39	0.18	−29.7	0.32	0.61	0.36	−29.9	0.28

Table 26. Catch scenarios for SFA 29 West Subarea D to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming zero surplus production from 2020 to 2021.

Catch (mt) Subarea D	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea D	Pr Increase Subarea D
0	0.00	−0.7	0.49	0.64	0.31	−7.6	0.43
8	0.03	−3.7	0.47	0.63	0.30	−10.4	0.41
13	0.05	−5.7	0.45	0.62	0.29	−12.2	0.39
16	0.06	−6.7	0.44	0.62	0.29	−13.1	0.38
24	0.09	−9.7	0.41	0.60	0.27	−15.9	0.36
32	0.12	−12.7	0.38	0.59	0.26	−18.7	0.33
40	0.15	−15.6	0.36	0.57	0.24	−21.4	0.30
47	0.18	−18.6	0.33	0.55	0.23	−24.2	0.28
55	0.21	−21.6	0.30	0.54	0.22	−27.0	0.25
63	0.24	−24.6	0.27	0.52	0.20	−29.8	0.23
71	0.27	−27.5	0.24	0.50	0.19	−32.5	0.20
79	0.30	−30.5	0.22	0.48	0.17	−35.3	0.18

Table 27. Catch scenarios for SFA 29 West Subarea D to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming median surplus production from 2020 to 2021.

Catch (mt) Subarea D	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea D	Pr Increase Subarea D
0	0.00	13.6	0.61	0.70	0.38	3.3	0.53
9	0.03	10.1	0.58	0.69	0.36	0.3	0.50
15	0.05	7.9	0.57	0.68	0.35	−1.7	0.48
18	0.06	6.7	0.56	0.68	0.35	−2.9	0.47
27	0.09	3.3	0.53	0.66	0.33	−6.0	0.45
36	0.12	−0.1	0.50	0.65	0.32	−9.0	0.42
45	0.15	−3.5	0.47	0.63	0.30	−12.1	0.39
54	0.18	−6.9	0.44	0.62	0.29	−15.2	0.36
64	0.21	−10.3	0.41	0.60	0.27	−18.3	0.33
73	0.24	−13.7	0.37	0.58	0.25	−21.4	0.30
82	0.27	−17.1	0.34	0.56	0.24	−24.5	0.27
91	0.30	−20.5	0.31	0.54	0.22	−27.6	0.24

Table 28. Catch scenarios for SFA 29 West Subarea D to evaluate 2021 catch levels in terms of resulting exploitation (e), expected changes in commercial biomass (%), probability (Pr) of commercial biomass increase, probability that after removal the stock will be above the upper stock reference (USR), and above the limit reference point (LRP). These probabilities account for uncertainty in the biomass forecasts and are presented assuming the status quo assumption (same recruitment, mortality, and growth as for the 2020 projection).

Catch (mt) Subarea D	e High	% Change High	Pr Increase High	Pr > LRP	Pr > USR	% Change Subarea D	Pr Increase Subarea D
0	0.00	−11.1	0.40	0.59	0.26	−20.6	0.32
7	0.03	−13.8	0.38	0.58	0.24	−23.2	0.30
11	0.05	−15.6	0.36	0.57	0.23	−24.8	0.29
13	0.06	−16.5	0.35	0.56	0.23	−25.4	0.28
20	0.09	−19.1	0.33	0.55	0.22	−27.9	0.26
27	0.12	−21.8	0.30	0.53	0.20	−30.3	0.24
33	0.15	−24.5	0.28	0.51	0.19	−32.5	0.22
40	0.18	−27.1	0.25	0.50	0.18	−35.1	0.20
46	0.21	−29.8	0.23	0.48	0.17	−37.5	0.18
53	0.24	−32.5	0.21	0.46	0.16	−39.7	0.16
60	0.27	−35.1	0.18	0.44	0.14	−42.2	0.14
66	0.30	−37.8	0.16	0.41	0.13	−44.6	0.12

FIGURES

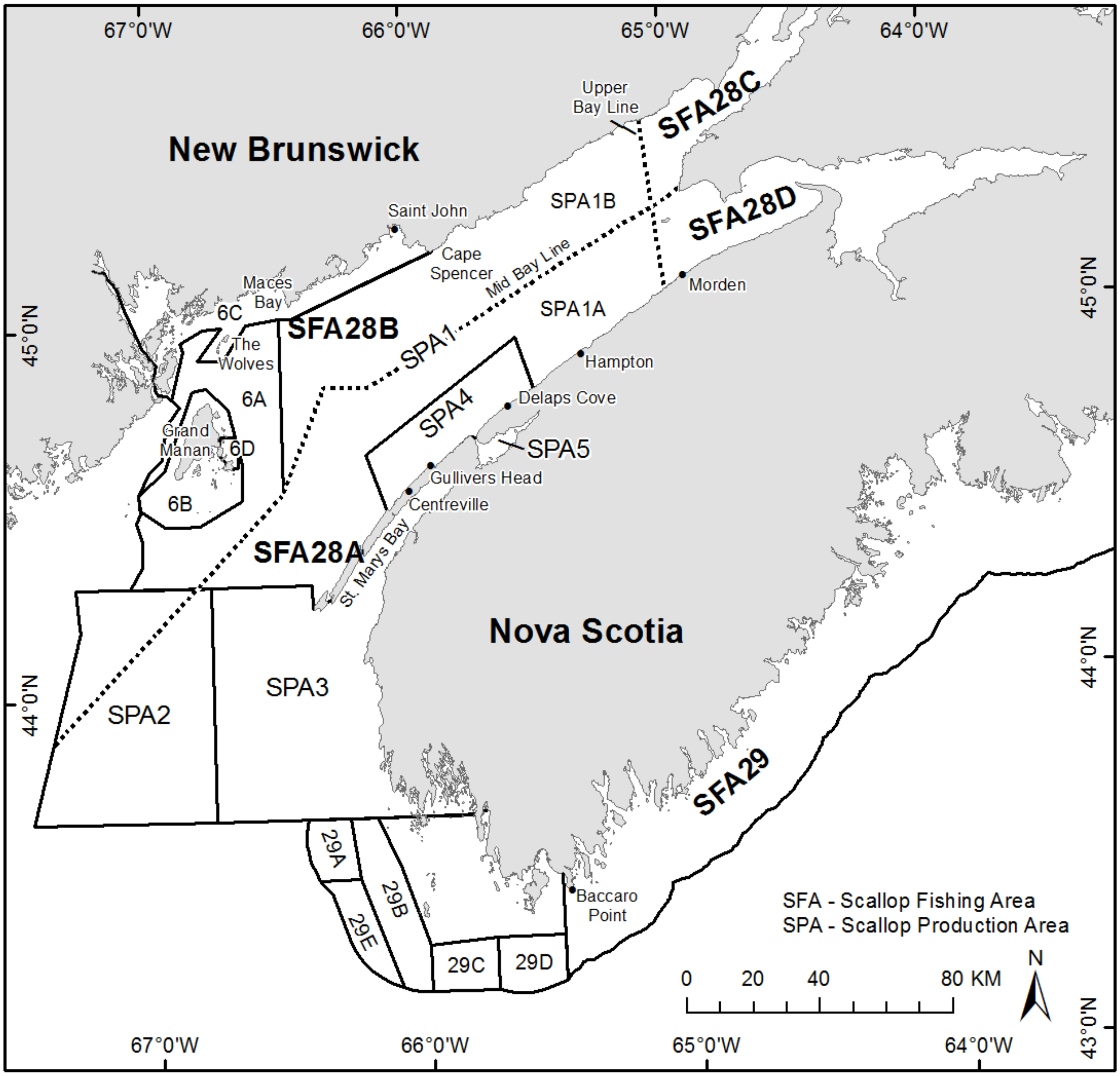

Figure 1. Map of Scallop Production Areas (SPAs) and Scallop Fishing Areas (SFAs) in the Bay of Fundy and approaches.

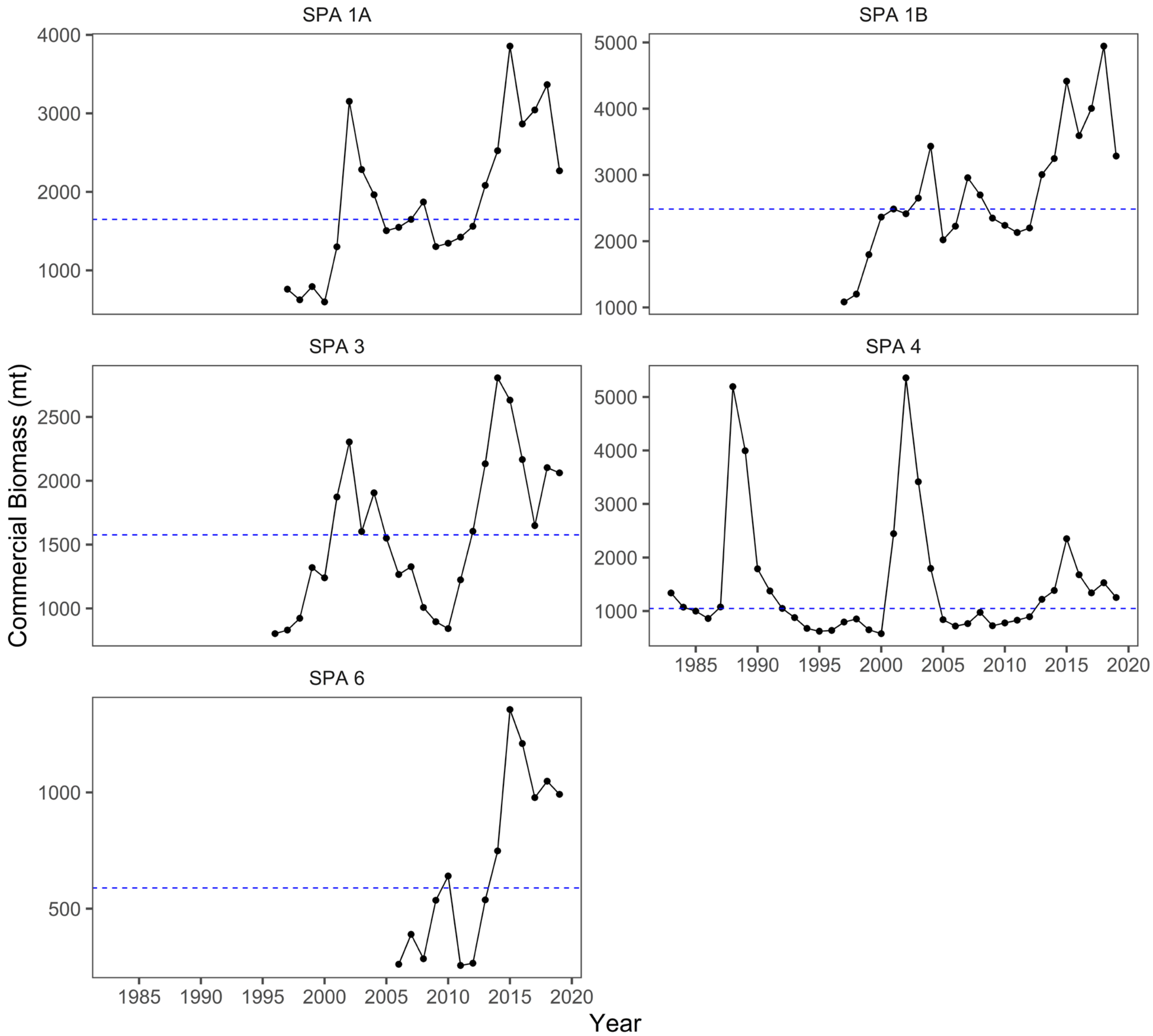

Figure 2. Time series of median biomass estimates (tonnes, mt) of commercial size scallops from the stock assessment model fit to SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the long−term medians.

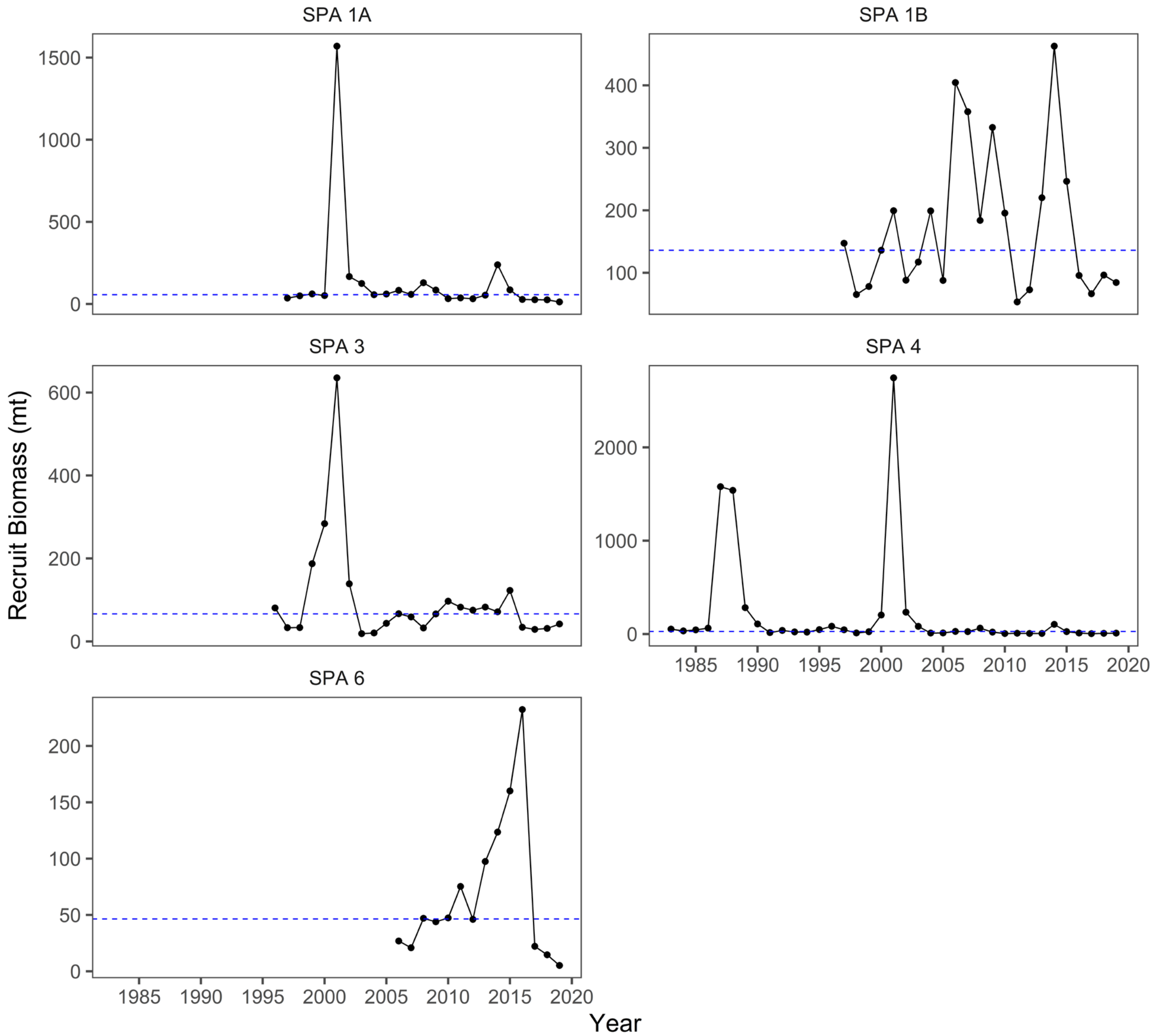

Figure 3. Time series of median biomass estimates (tonnes, mt) of recruit size scallops from the stock assessment model fit to SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the long−term medians.

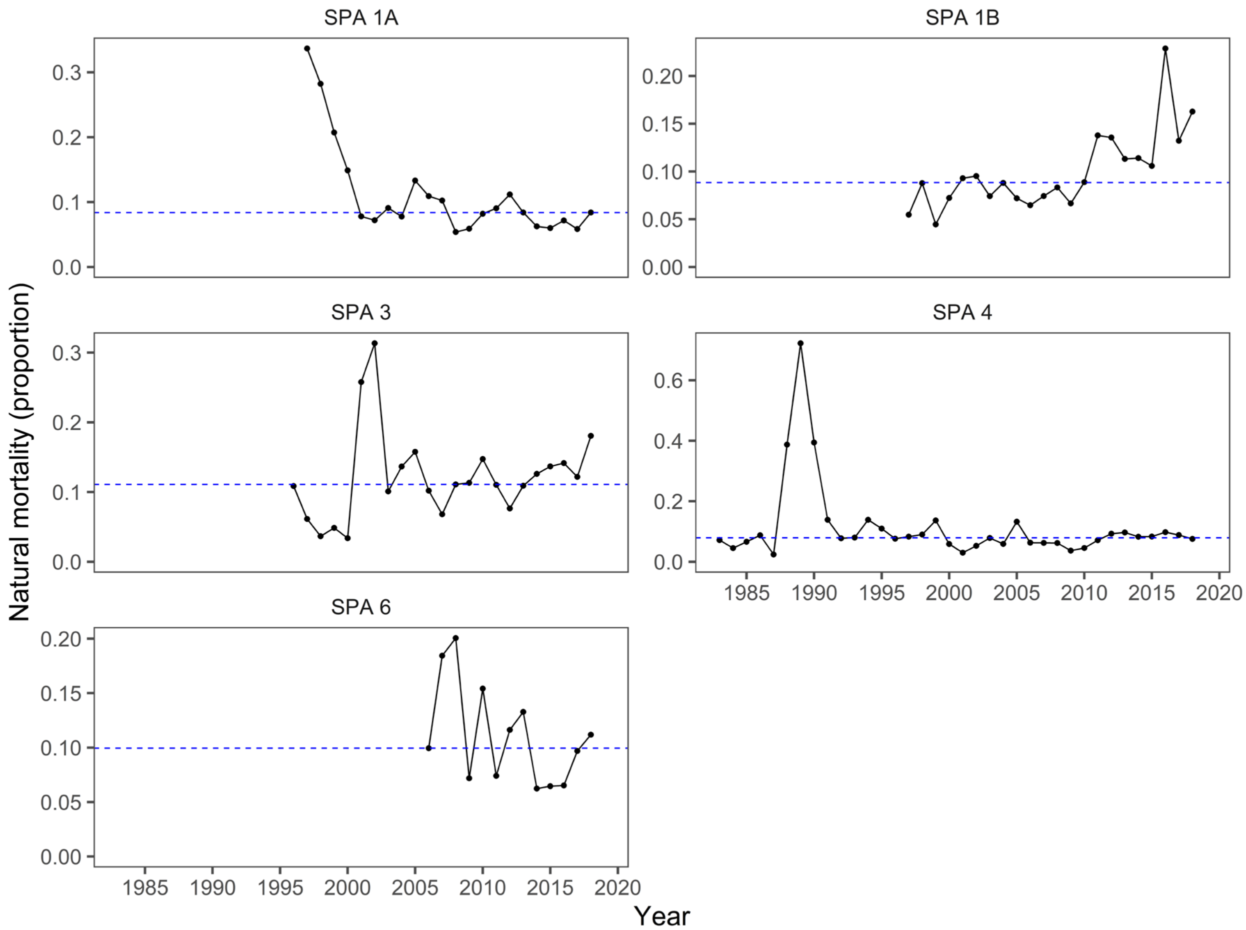

Figure 4. Time series of median natural mortality (proportion) estimates for commercial size scallop from the stock assessment model fit to SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the long−term medians.

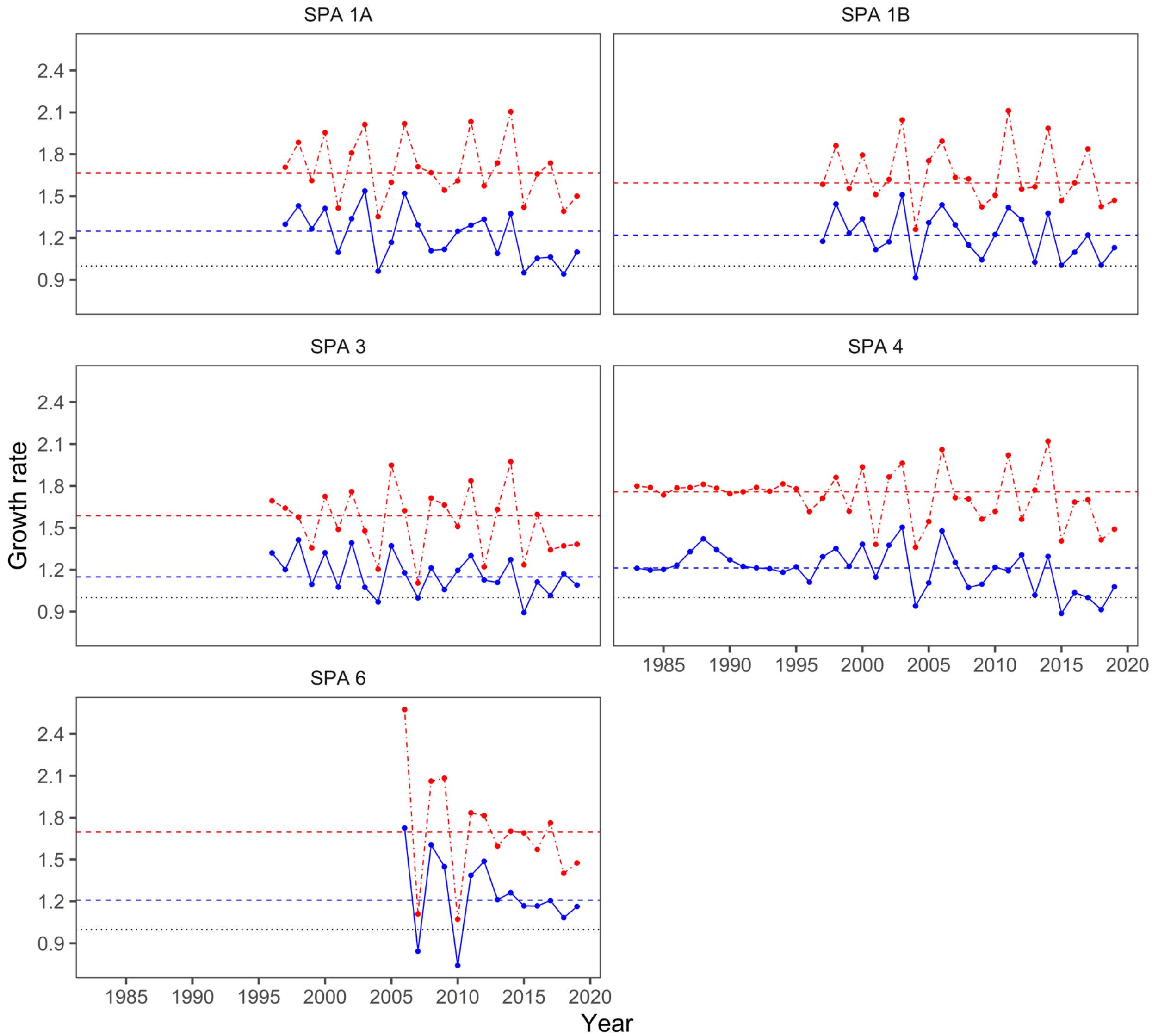

Figure 5. Time series of average commercial growth rate (blue) and recruit growth rate (red) for SPAs 1A, 1B, 3, 4, and 6. The blue and red dashed lines represent the long−term medians for commercial and recruit size scallops, respectively. Note that growth rates prior to 1996 are interpolated, whereas growth rates from 1996 are derived from yearly meat weight – shell height sampling.

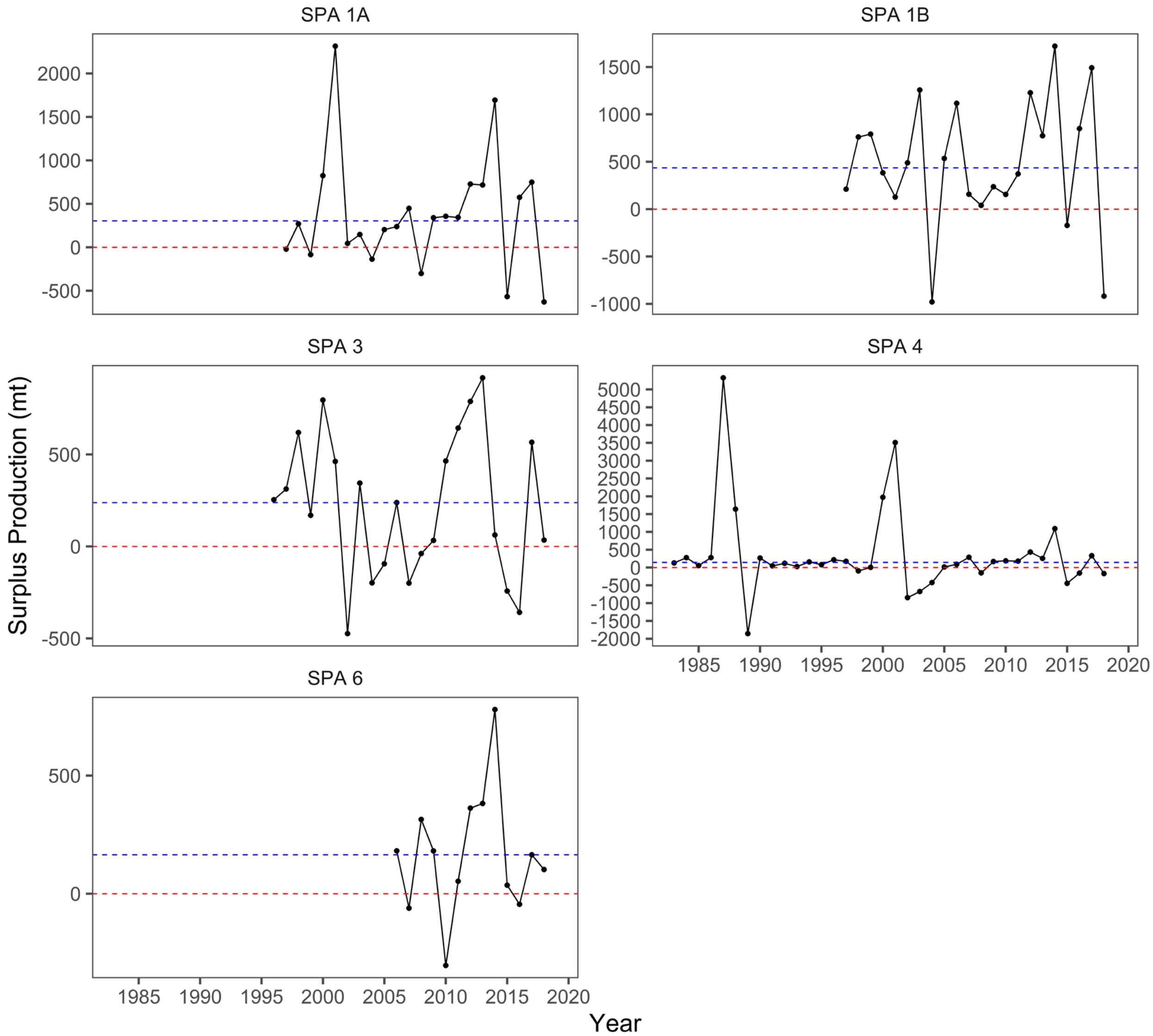

Figure 6. Time series of surplus production (meats, tonnes, mt) of commercial biomass for SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the long−term medians, and the red dashed lines represent zero surplus production.

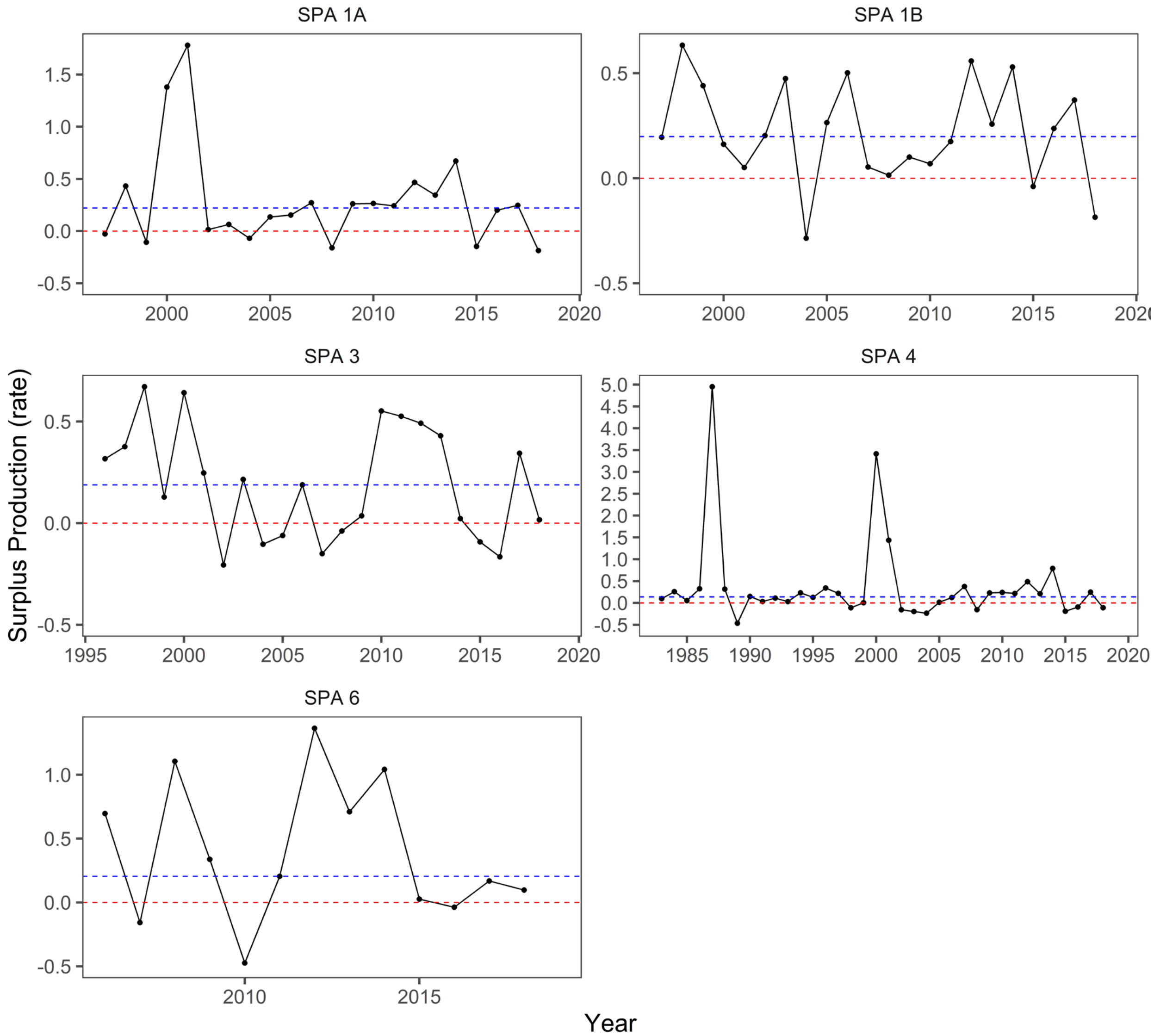

Figure 7. Time series of surplus production rate of commercial biomass for SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the long−term medians, and the red dashed lines represent zero surplus production.

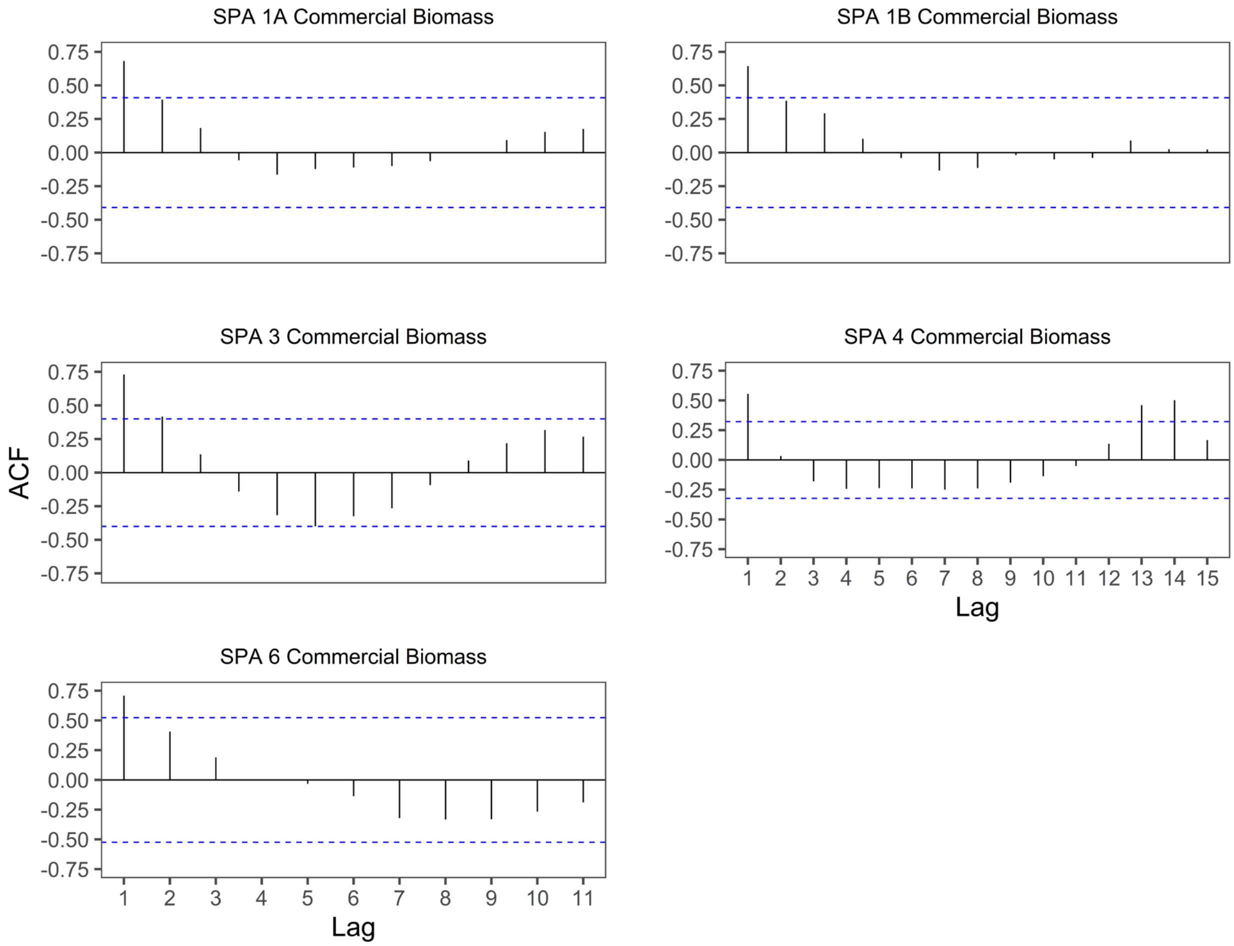

Figure 8. Autocorrelation (ACF) in commercial biomass time series for SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the 95% confidence intervals.

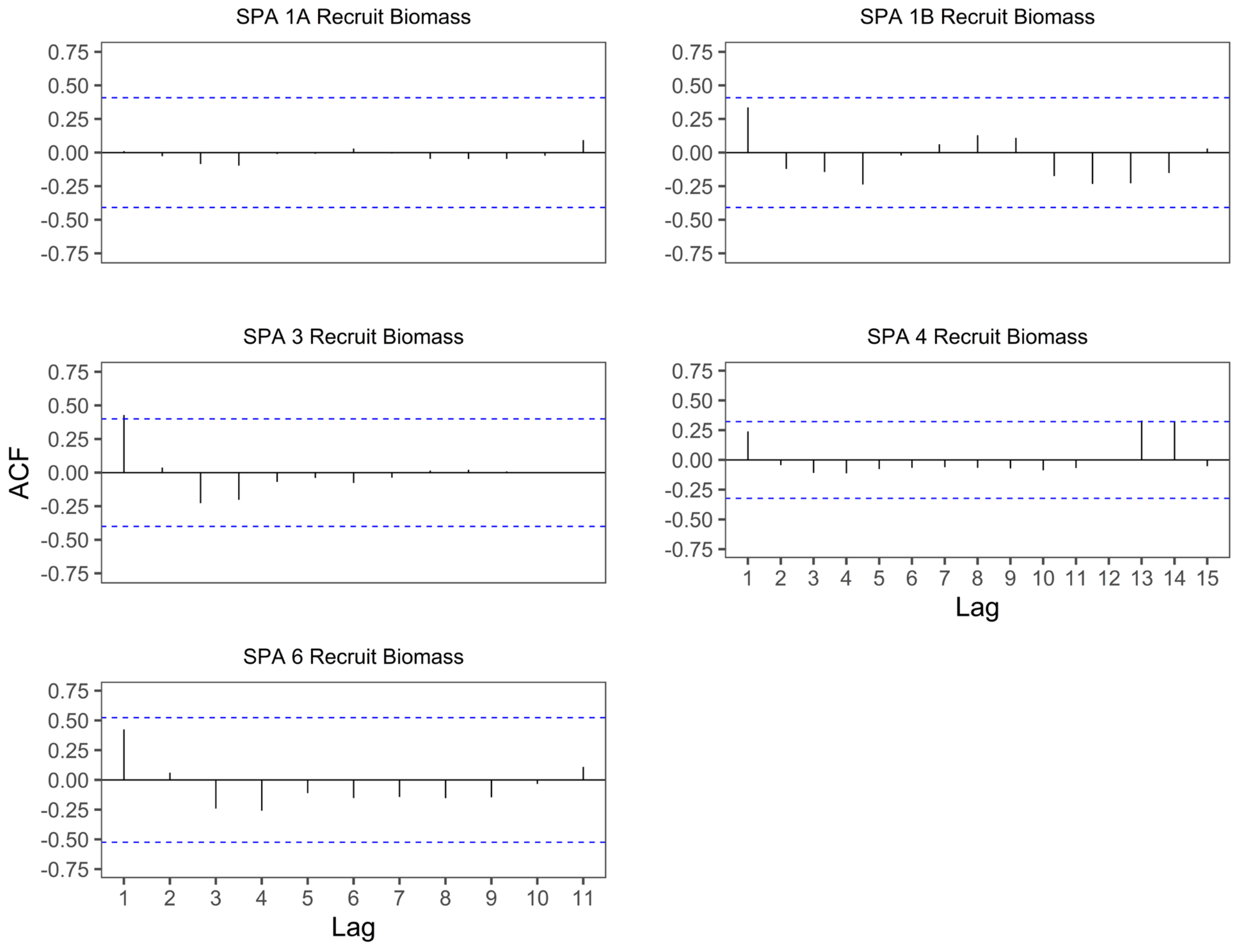

Figure 9. Autocorrelation (ACF) in recruit biomass time series for SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the 95% confidence intervals.

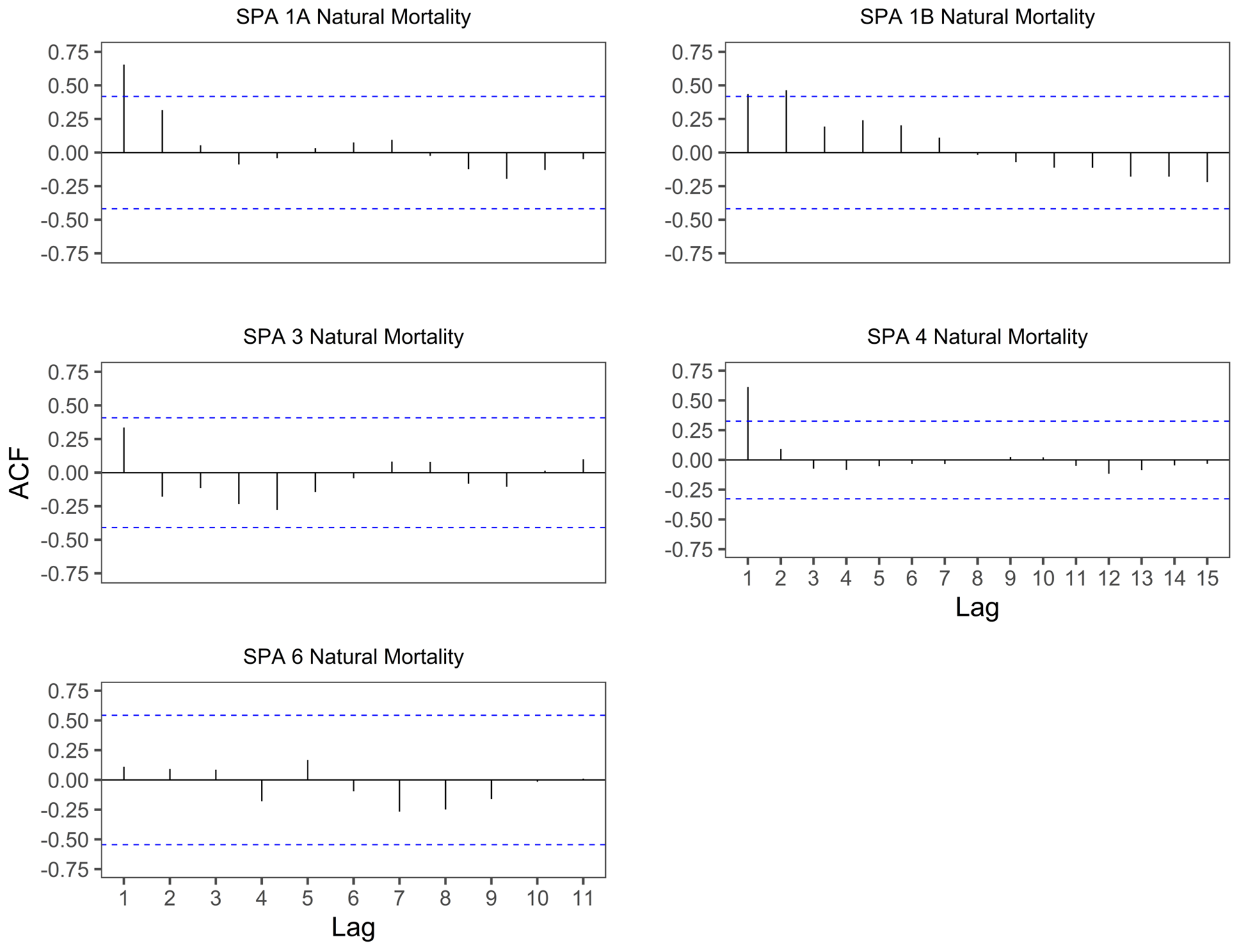

Figure 10. Autocorrelation (ACF) in natural mortality time series for SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the 95% confidence intervals.

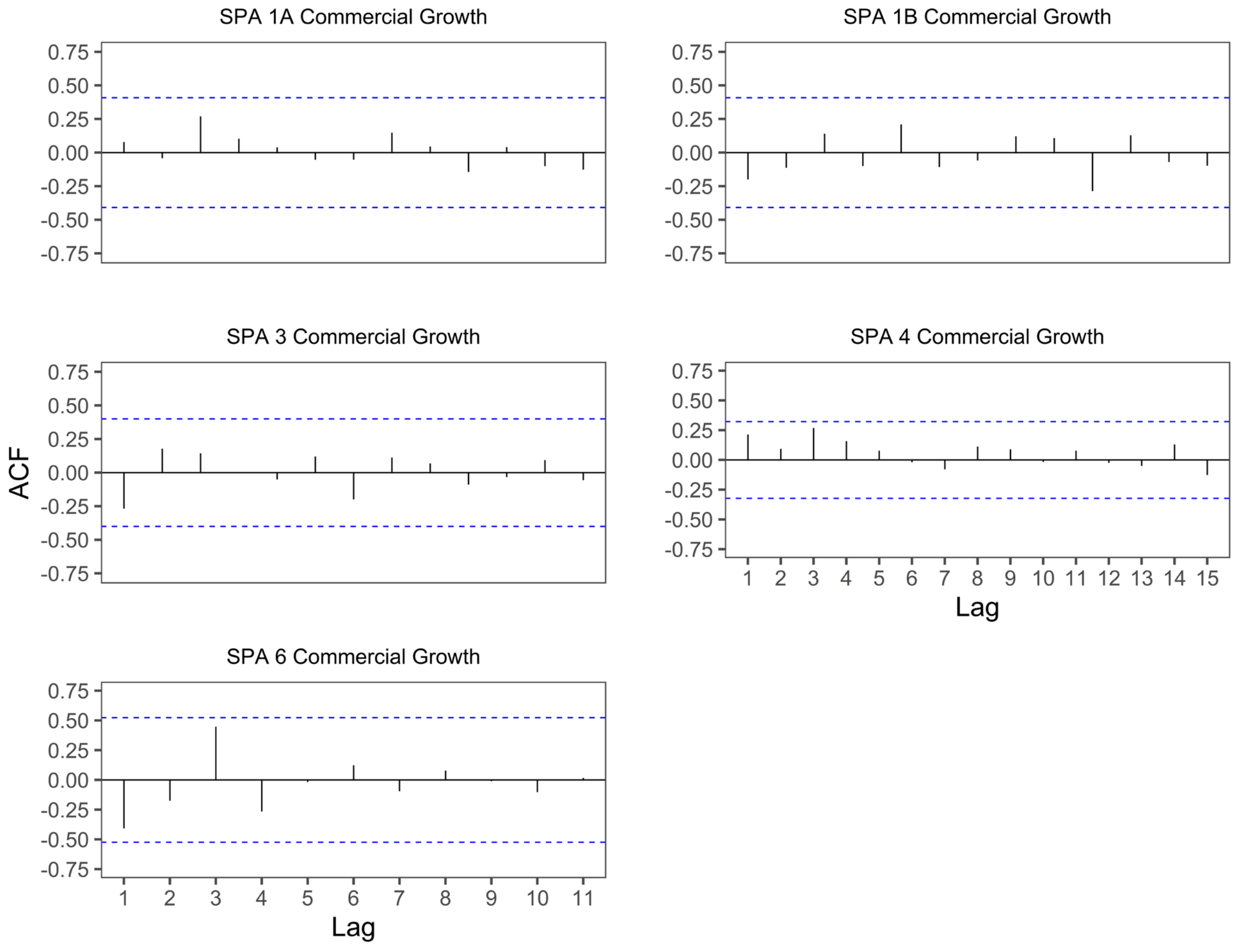

Figure 11. Autocorrelation (ACF) in commercial growth rate time series for SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the 95% confidence intervals.

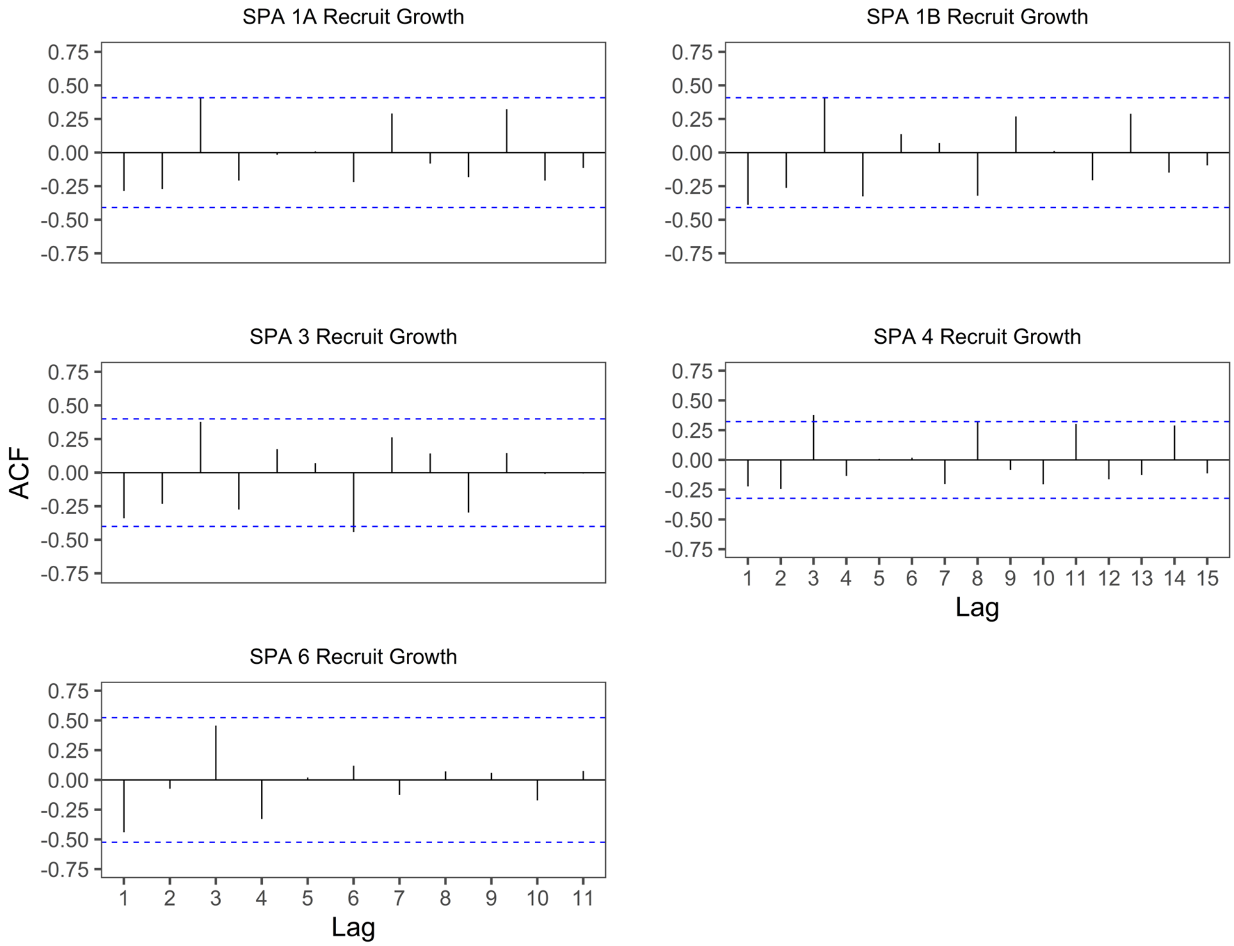

Figure 12. Autocorrelation (ACF) in recruit growth rate time series for SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the 95% confidence intervals.

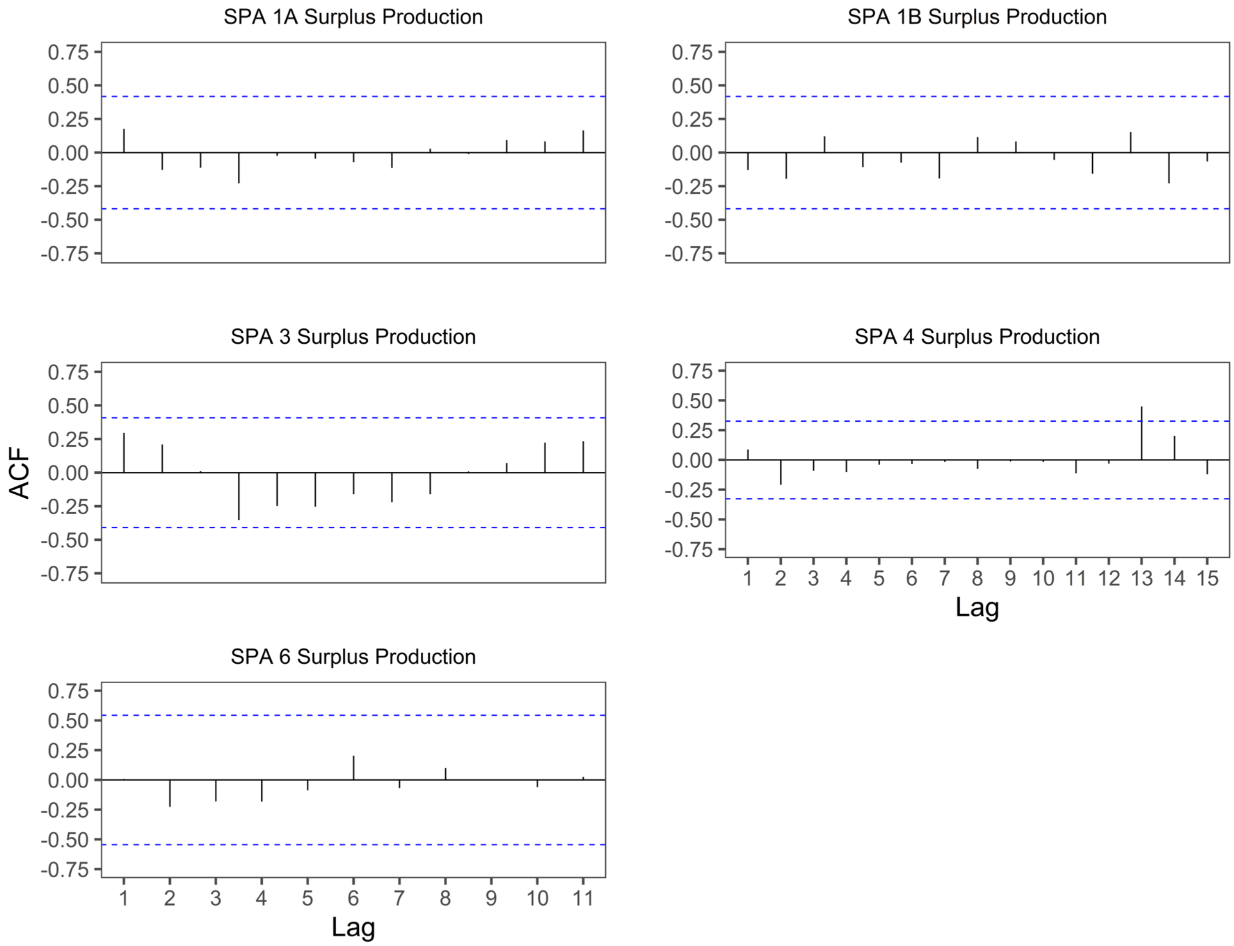

Figure 13. Autocorrelation (ACF) in surplus production rate time series for SPAs 1A, 1B, 3, 4, and 6. The blue dashed lines represent the 95% confidence intervals.

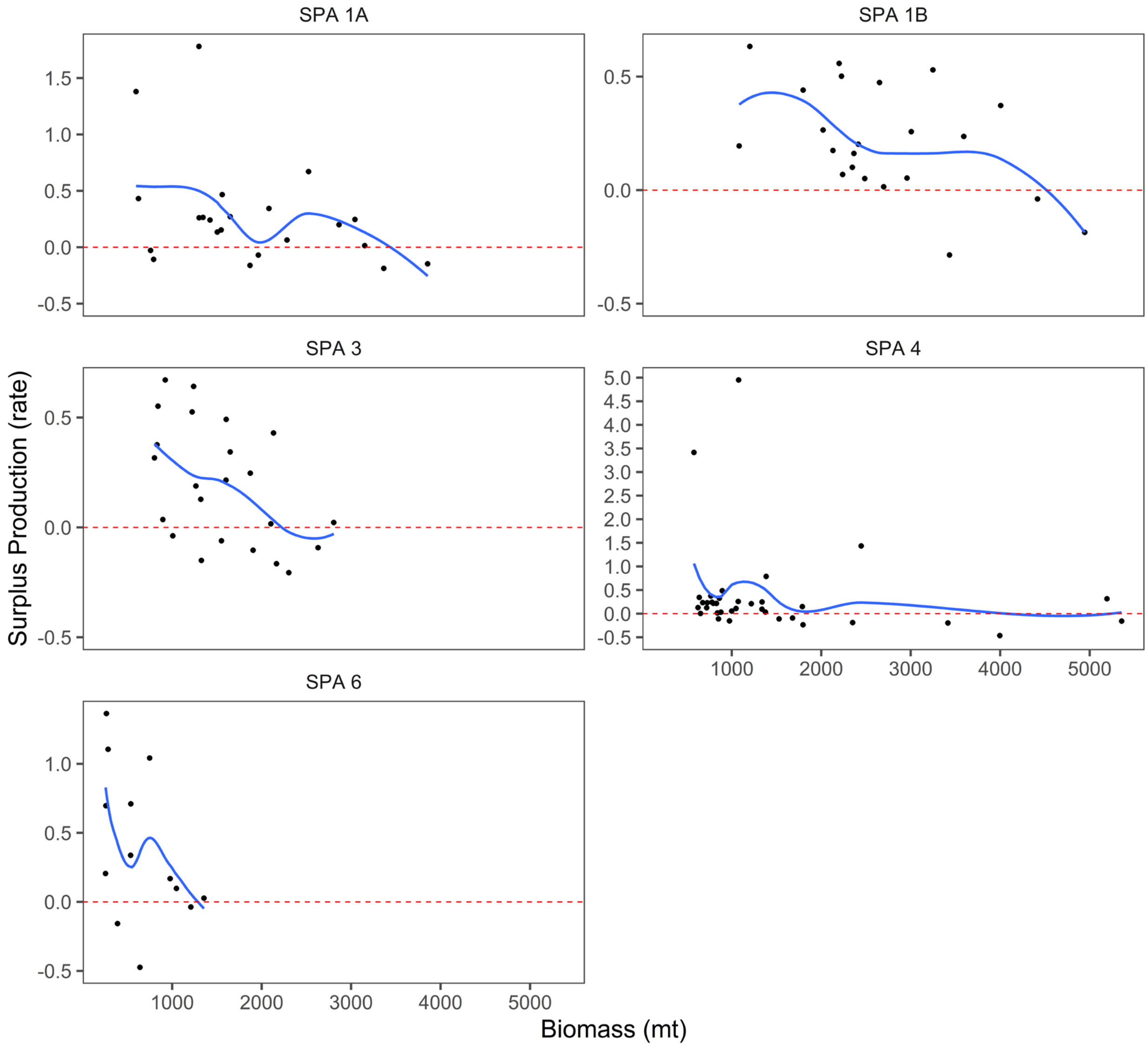

Figure 14. Surplus production (rate) of commercial biomass for SPAs 1A, 1B, 3, 4, and 6. The red dashed line represent zero surplus production. The blue line represents a loess curve added to detect trend.

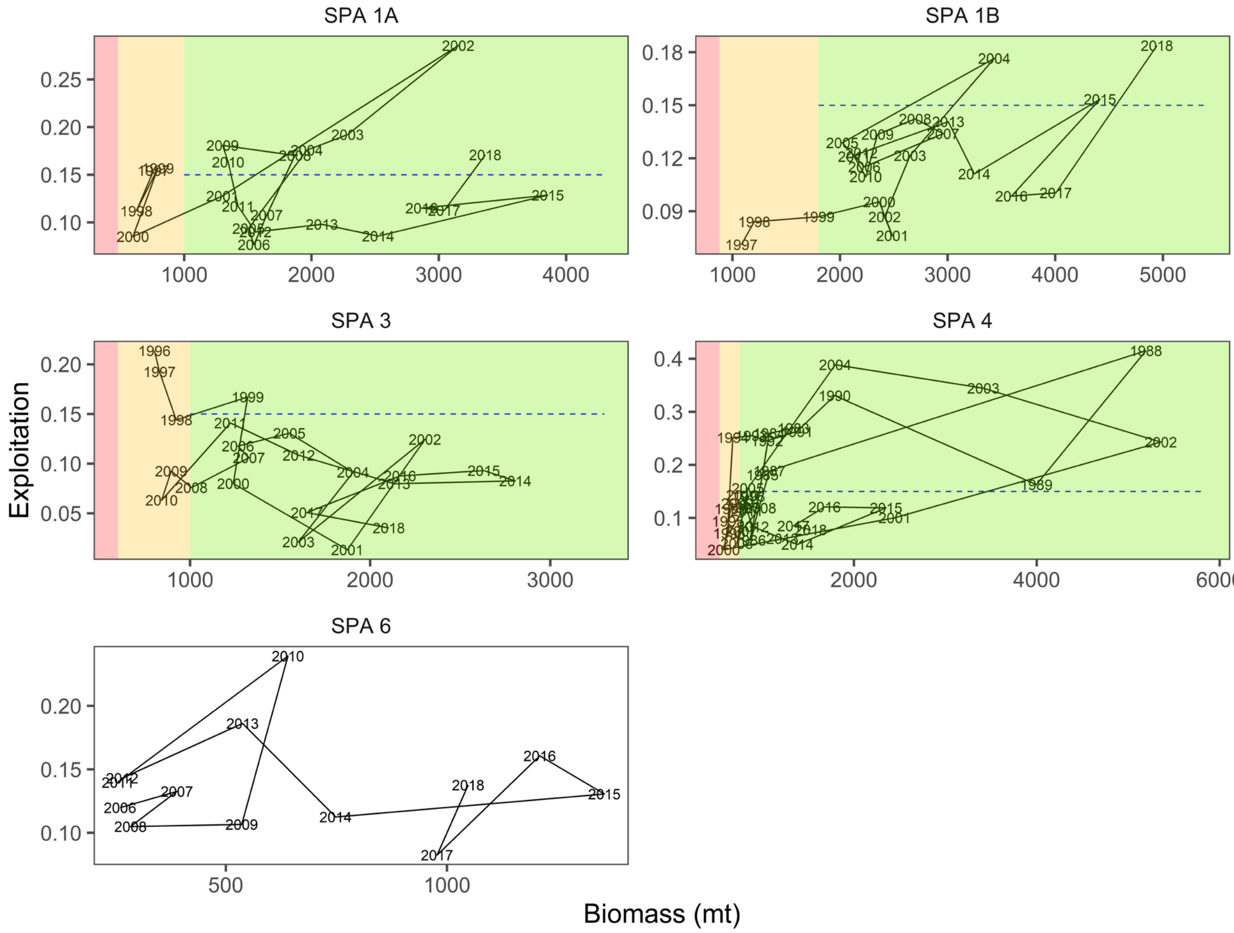

Figure 15. Phase plot of commercial biomass and exploitation for SPAs 1A, 1B, 3, 4, and 6. Labels refer to year of the survey. The green−shaded area represents the Healthy zone, the yellow−shaded area represents the Cautious zone, and the red−shading area represents the Critical zone. Biomass based reference points are not adopted for SPA 6.

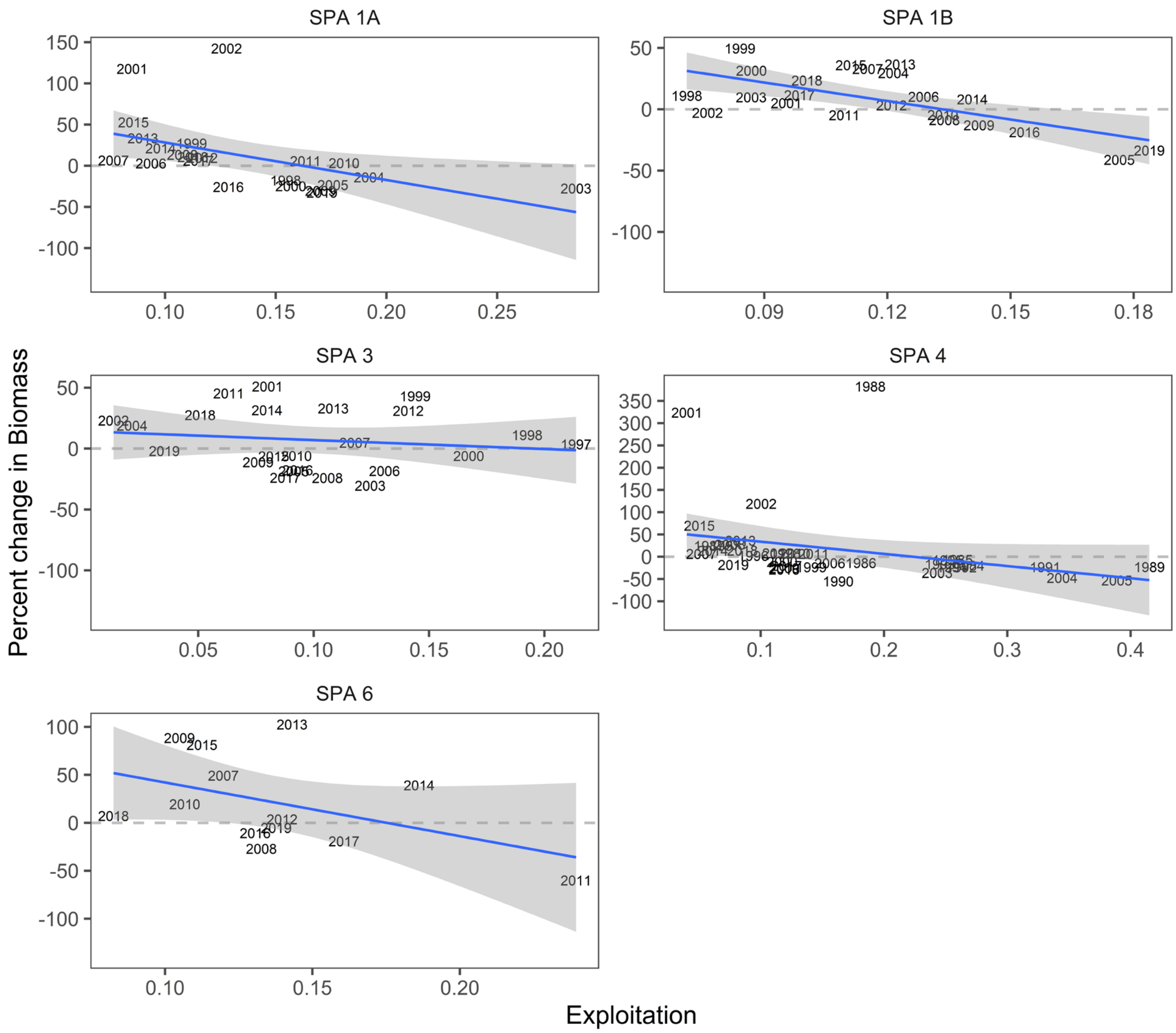

Figure 16. Change in commercial biomass with exploitation for SPAs 1A, 1B, 3, 4, and 6. Labels of year t represent change from year $t-1$ to t. For each SPA (panel), the exploitation rate at zero biomass change is based on a linear model (blue line) with a 95% confidence interval (gray ribbon).

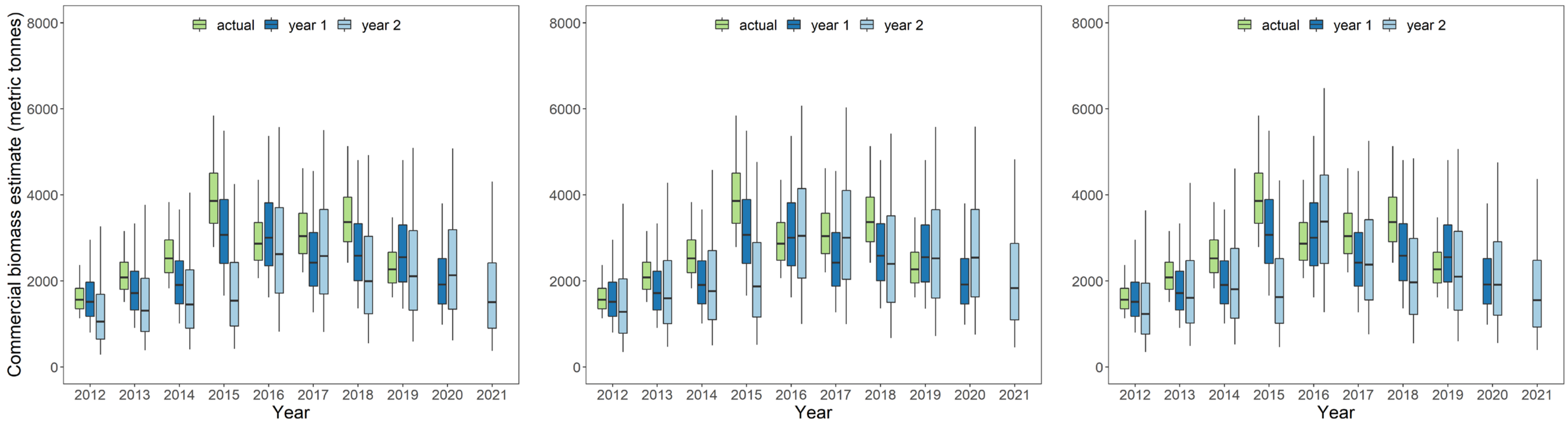

Figure 17. Evaluation of the model projection performance from 2012 to 2021 for SPA 1A. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 415 mt is caught, and for 2021 the total allowable catch of 270 mt is caught. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

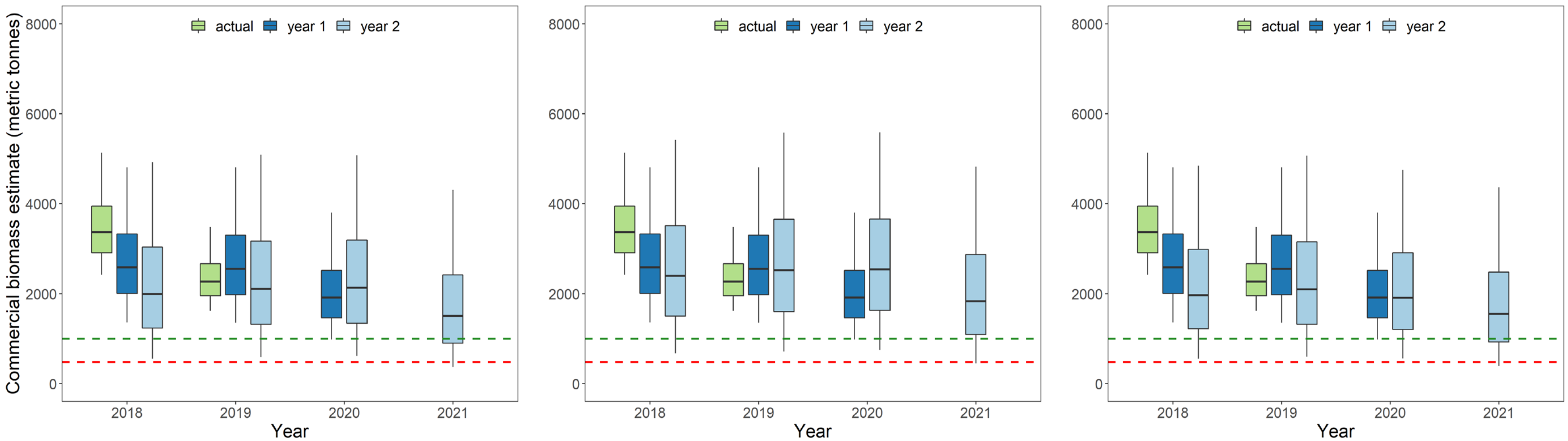

Figure 18. Evaluation of the model projection performance from 2018 to 2021 for SPA 1A relative to the upper stock reference (USR; green dashed line) and limit reference point (LRP; red dashed line). Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 415 mt is caught, and for 2021 the total allowable catch of 270 mt is caught. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

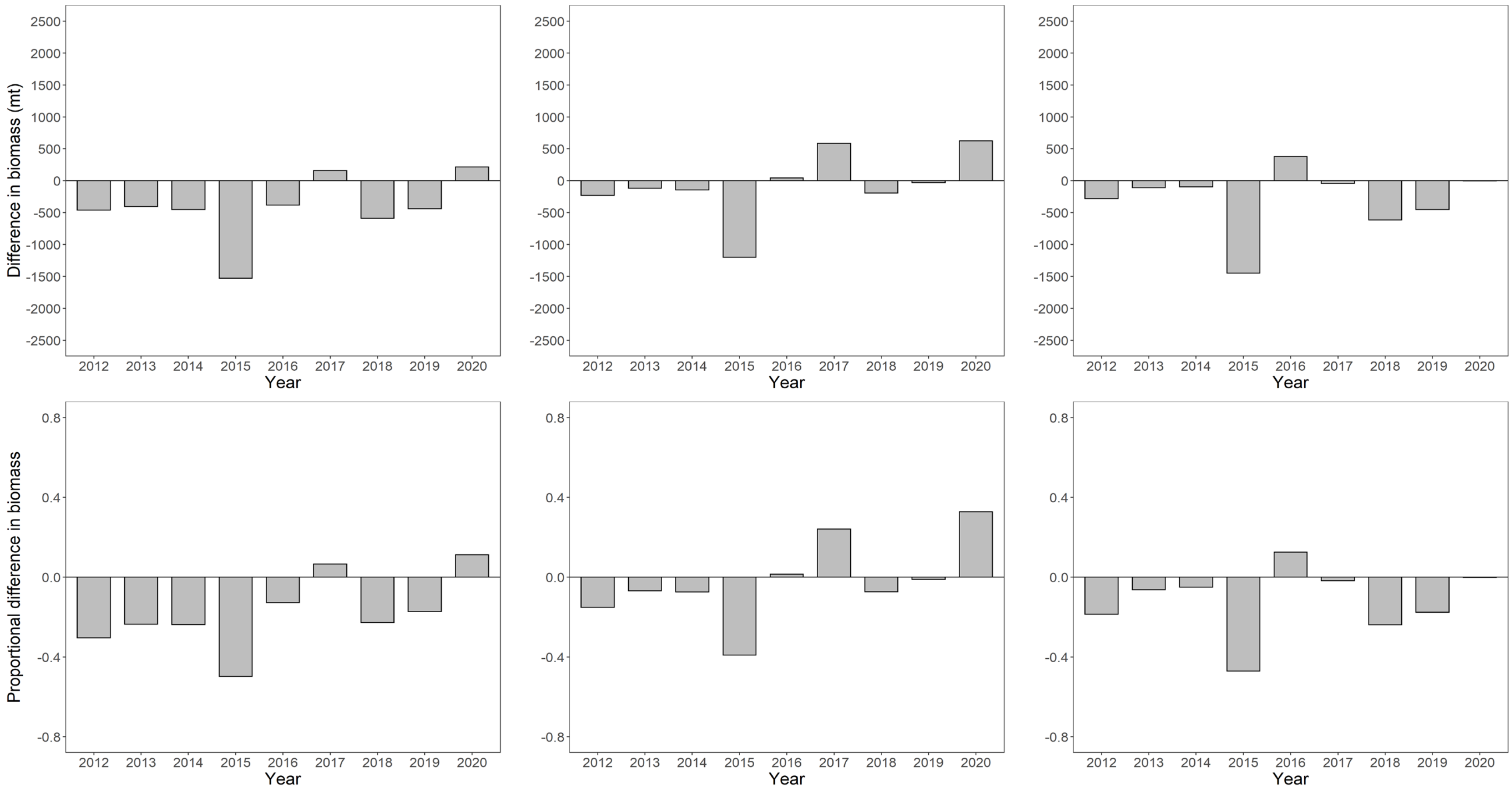

Figure 19. Difference in commercial biomass between two−year and one−year projections for each year (t) from 2012 to 2020 for SPA 1A. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

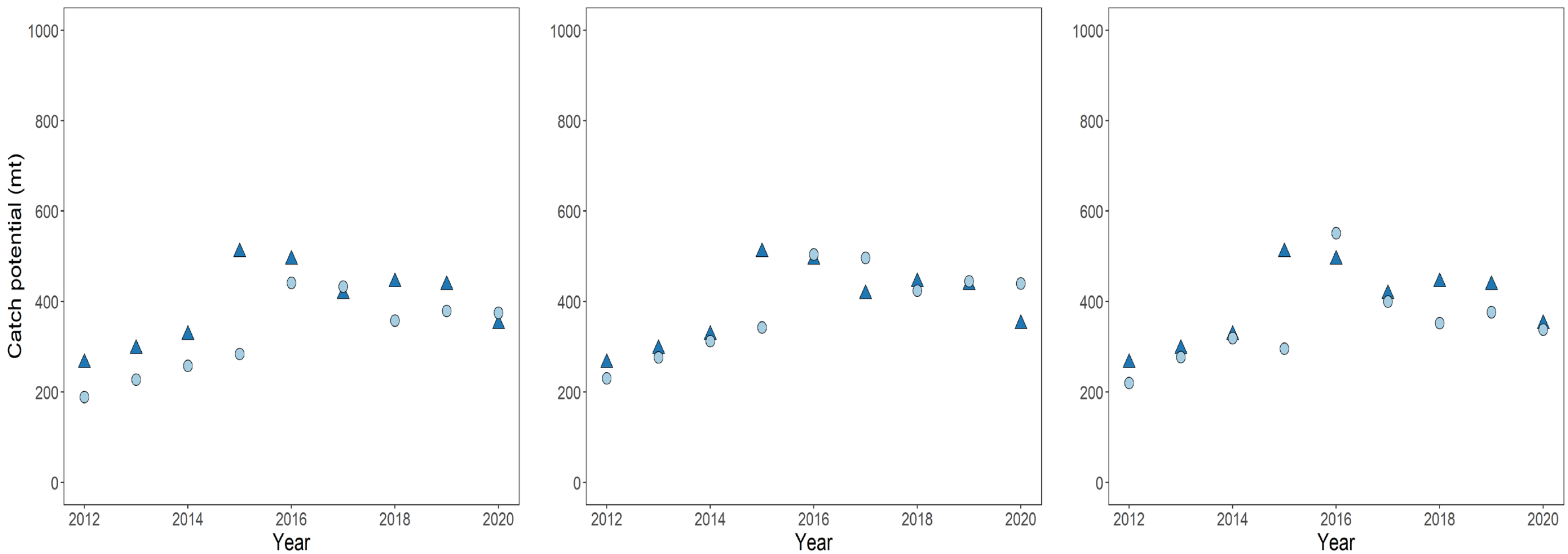

Figure 20. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.15 for SPA 1A for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

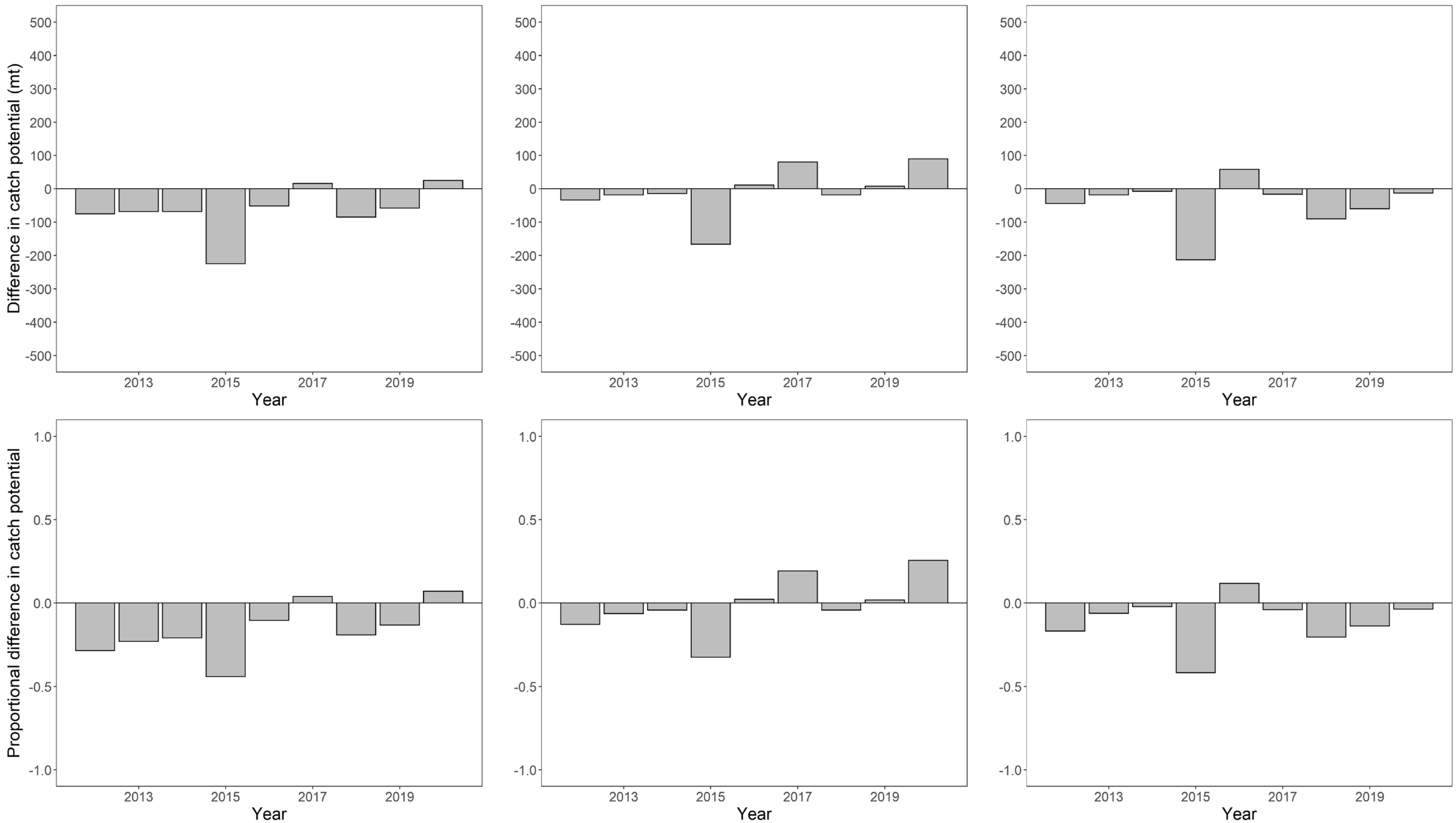

Figure 21. Difference in maximum catch between using a one−year projection for year t and a two−year projection for year t where exploitation is 0.15 for SPA 1A. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

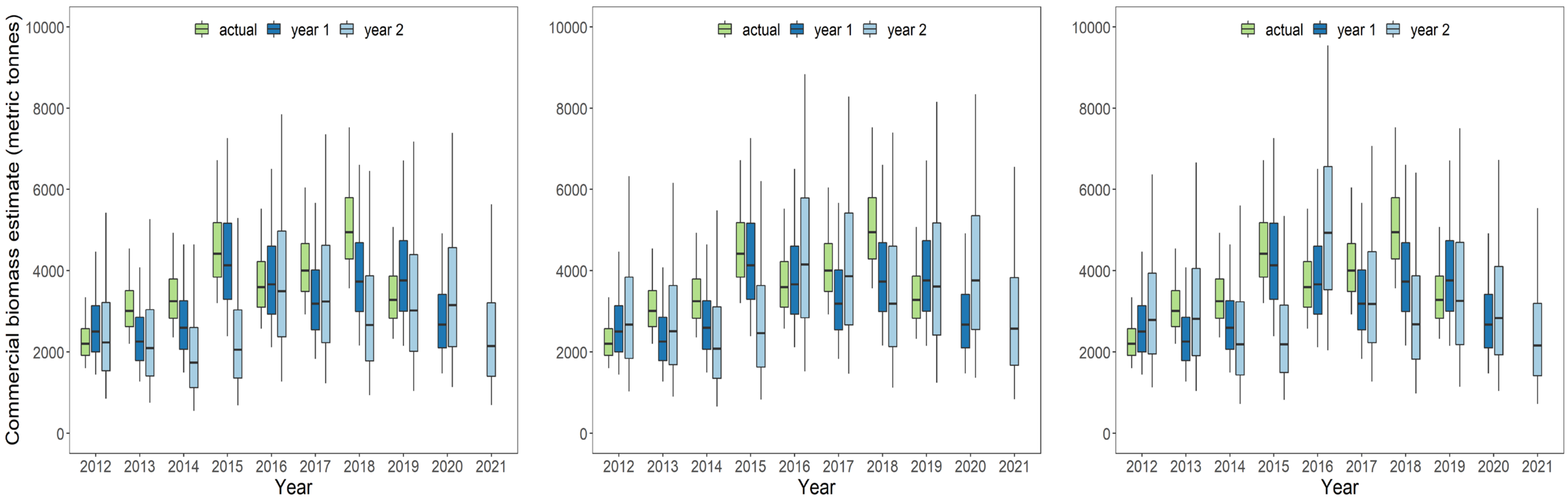

Figure 22. Evaluation of the model projection performance from 2012 to 2021 for SPA 1B. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 545 mt is caught, and for 2021 the total allowable catch of 400 mt is caught. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

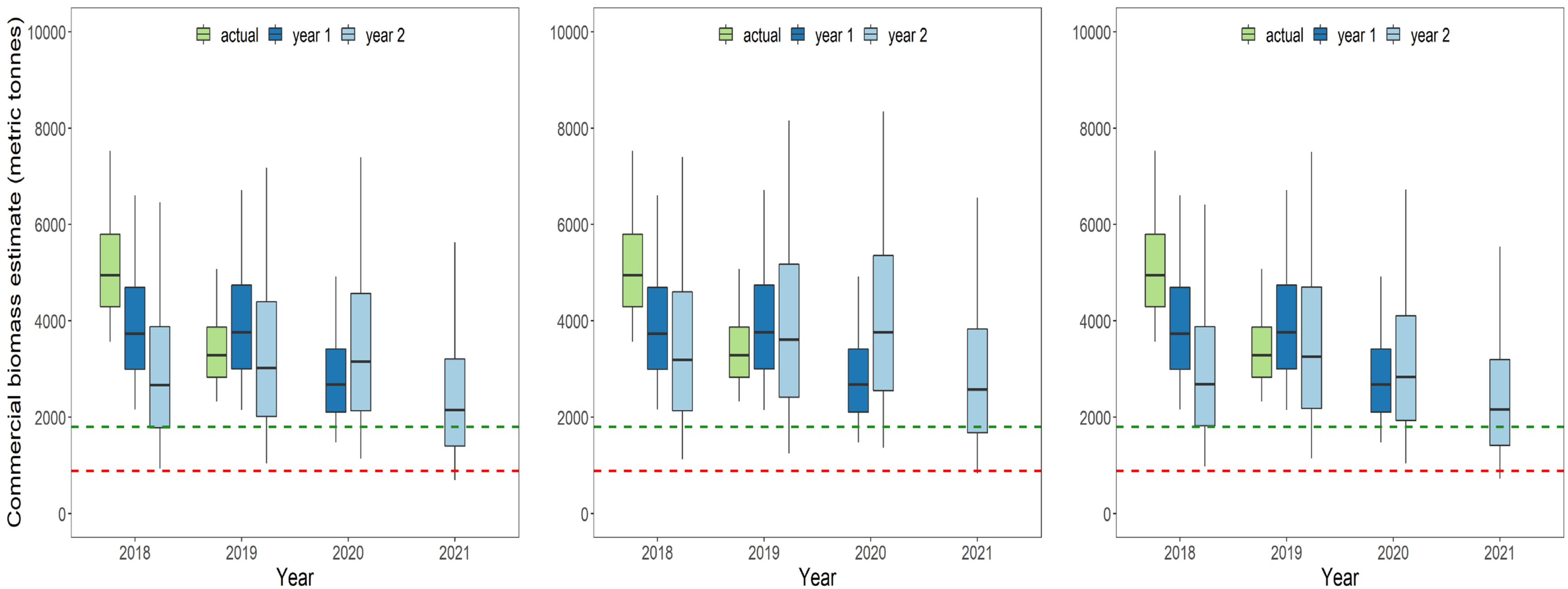

Figure 23. Evaluation of the model projection performance from 2018 to 2021 for SPA 1B relative to the upper stock reference (USR; green dashed line) and limit reference point (LRP; red dashed line). Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 545 mt is caught, and for 2021 the total allowable catch of 400 mt is caught. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

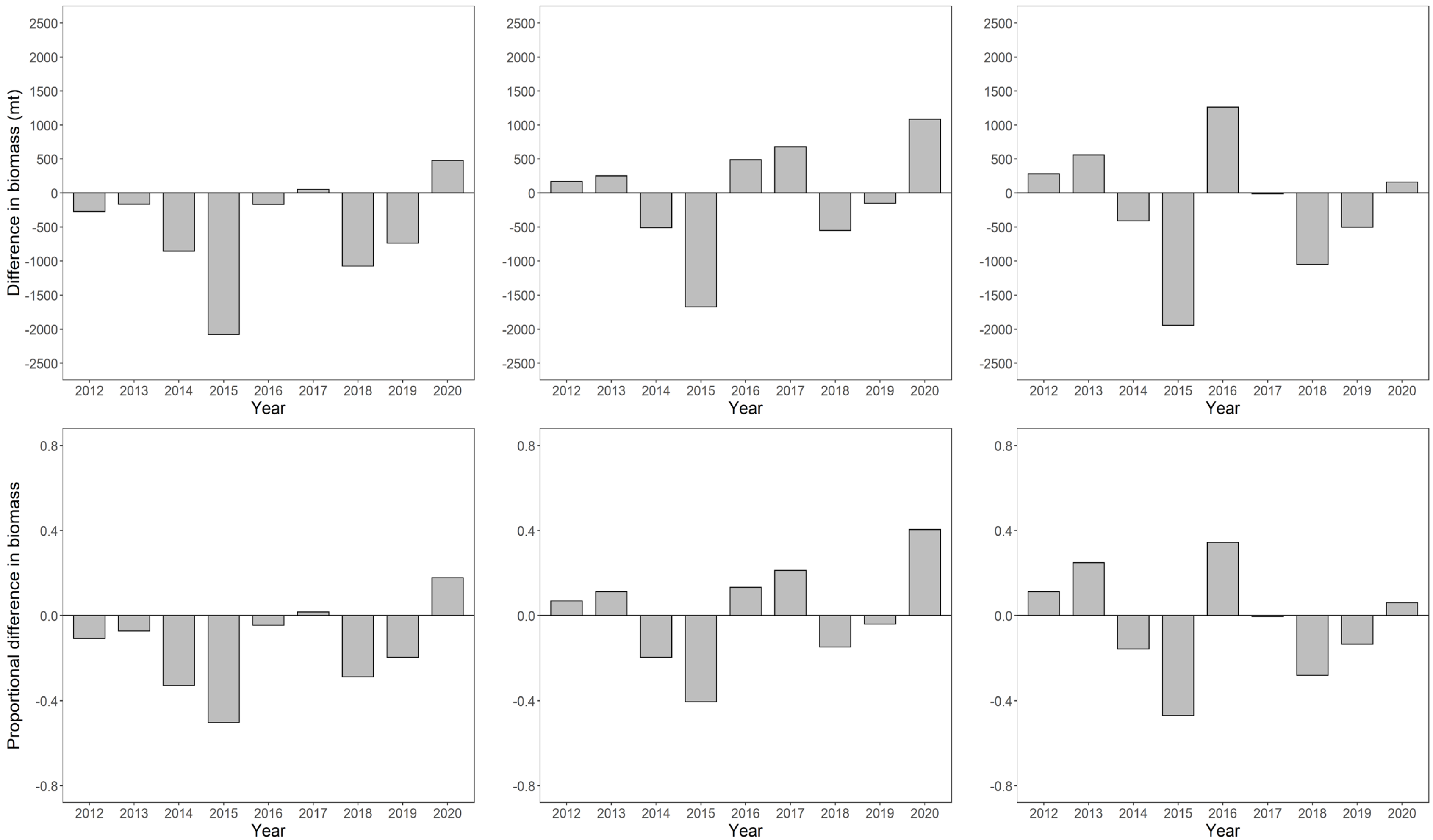

Figure 24. Difference in commercial biomass between two−year and one−year projections for each year t from 2012 to 2020 for SPA 1B. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

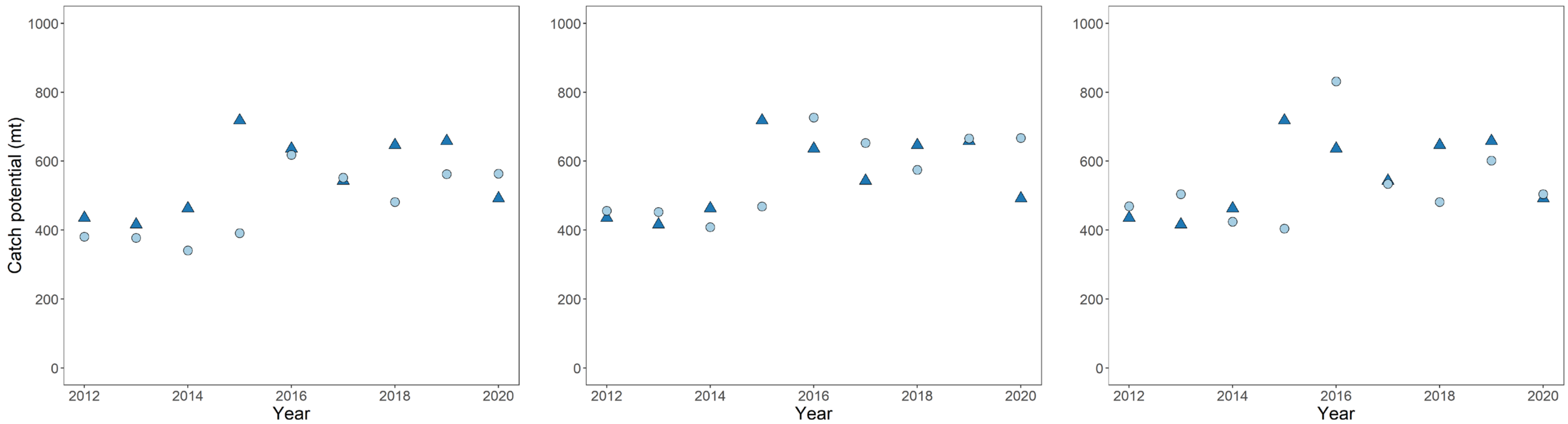

Figure 25. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.15 for SPA 1B for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

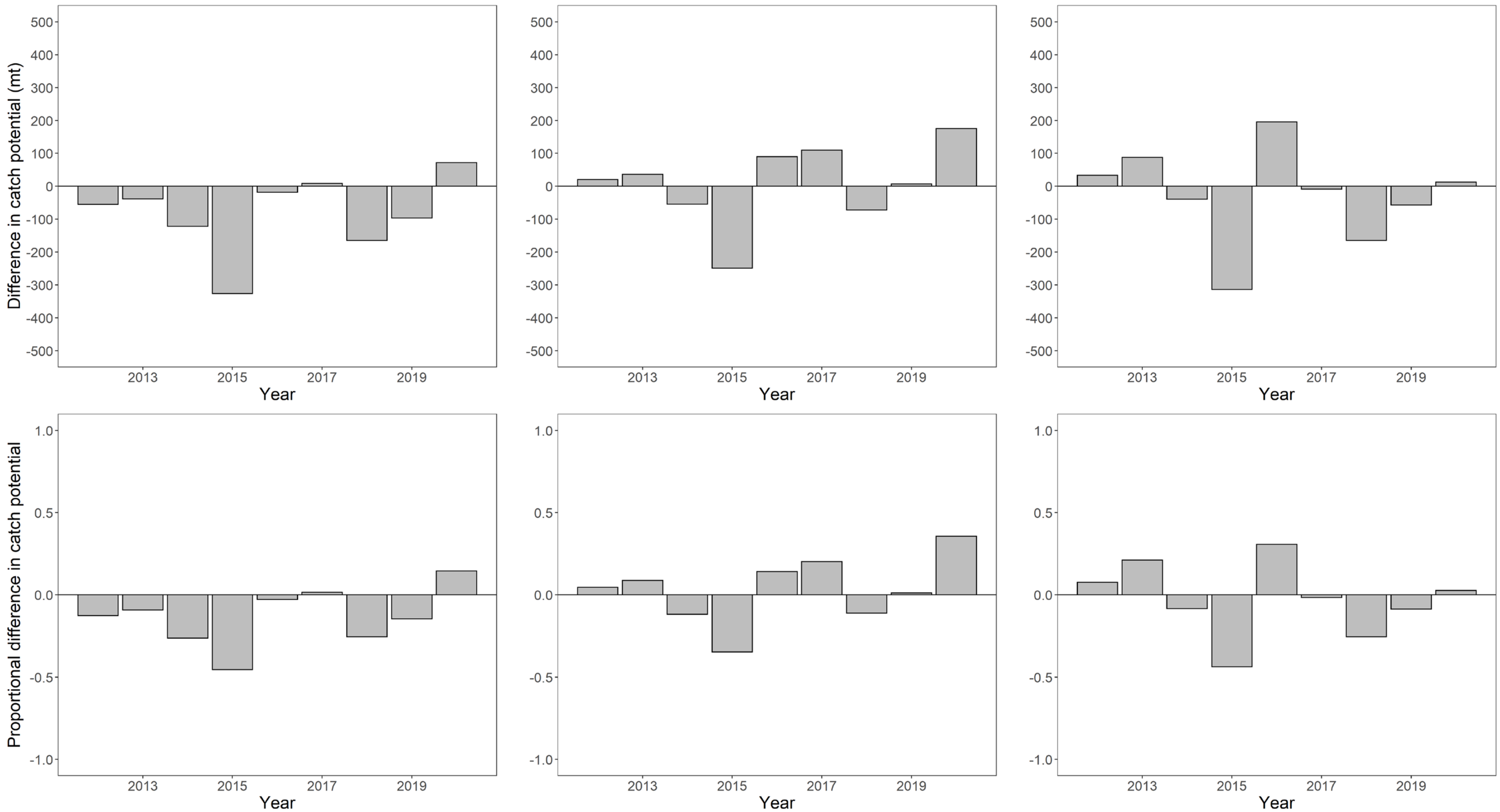

Figure 26. Difference in maximum catch between using a one−year projection for year t and a two−year projection for year t where exploitation is 0.15 for SPA 1B. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

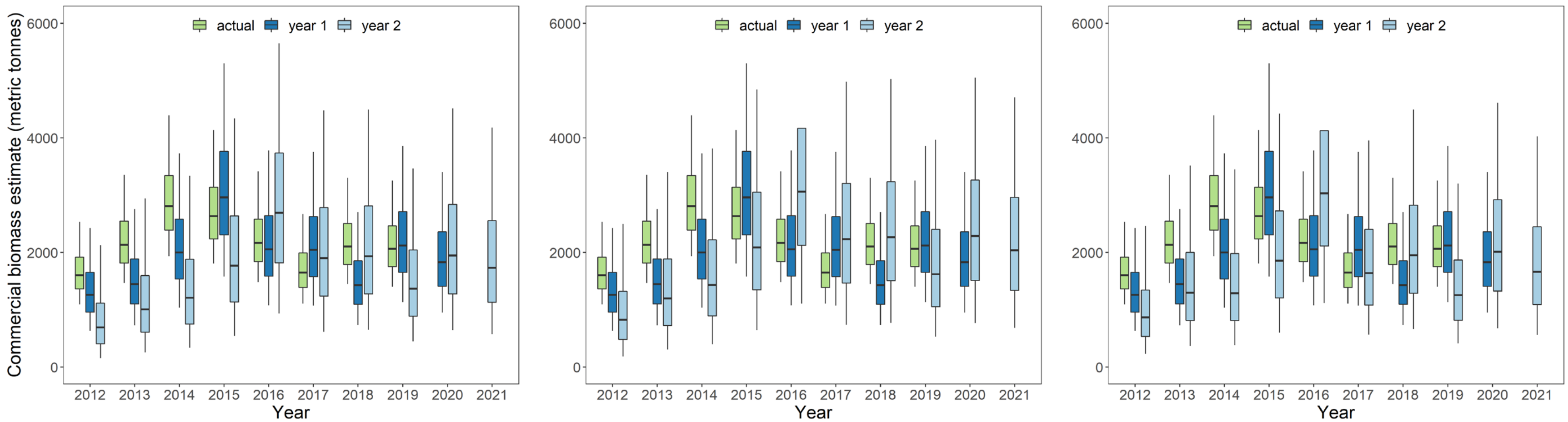

Figure 27. Evaluation of the model projection performance from 2012 to 2021 for SPA 3. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 108 mt is caught, and for 2021 the total allowable catch of 200 mt is caught. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

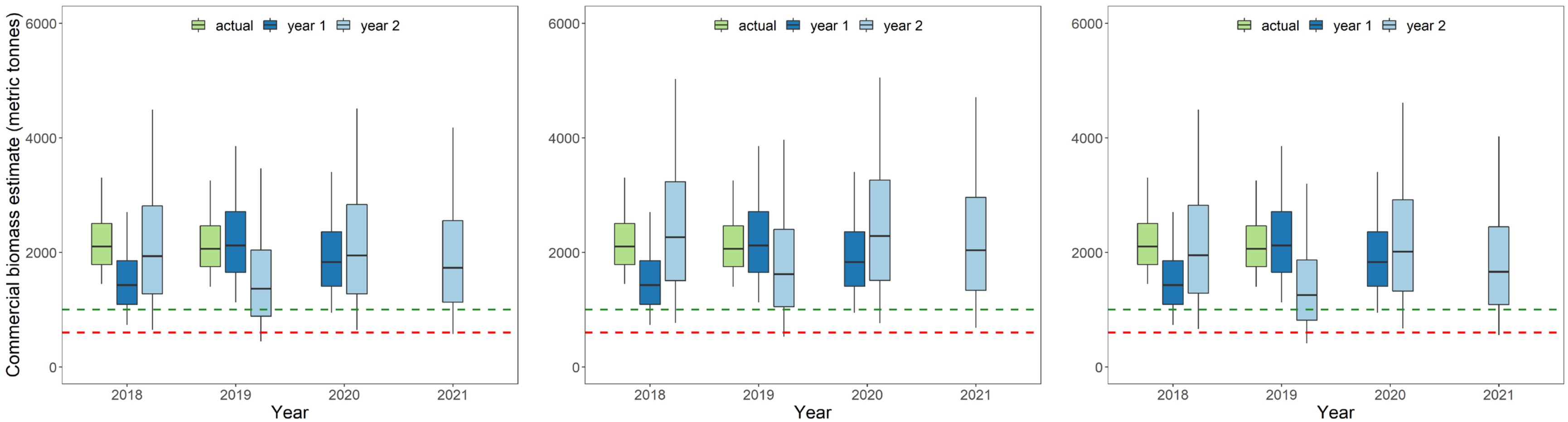

Figure 28. Evaluation of the model projection performance from 2018 to 2021 for SPA 3 relative to the upper stock reference (USR; green dashed line) and limit reference point (LRP; red dashed line). Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 108 mt is caught, and for 2021 the total allowable catch of 200 mt is caught. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

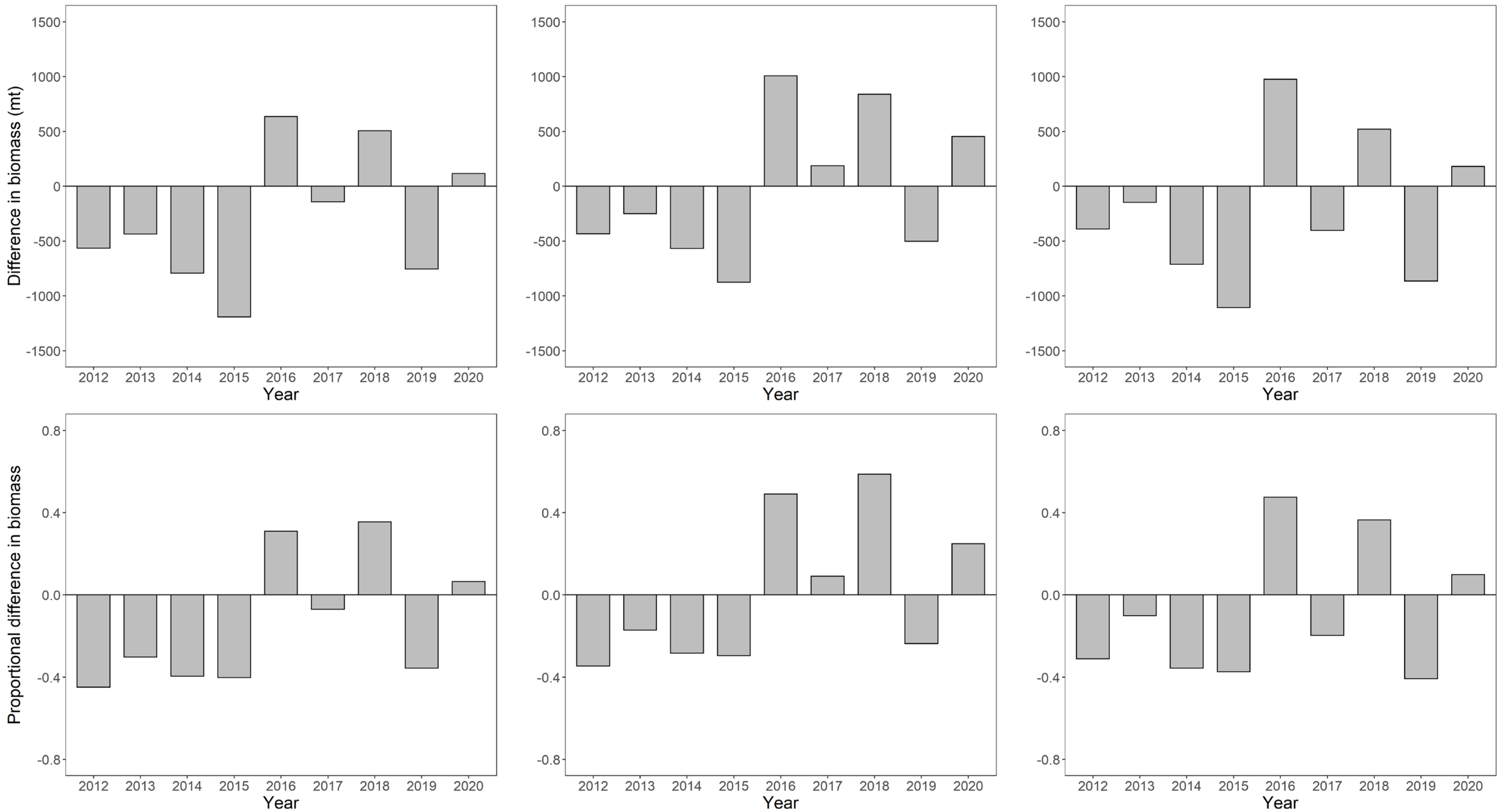

Figure 29. Difference in commercial biomass between two−year and one−year projections for each year (t) from 2012 to 2020 for SPA 3. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

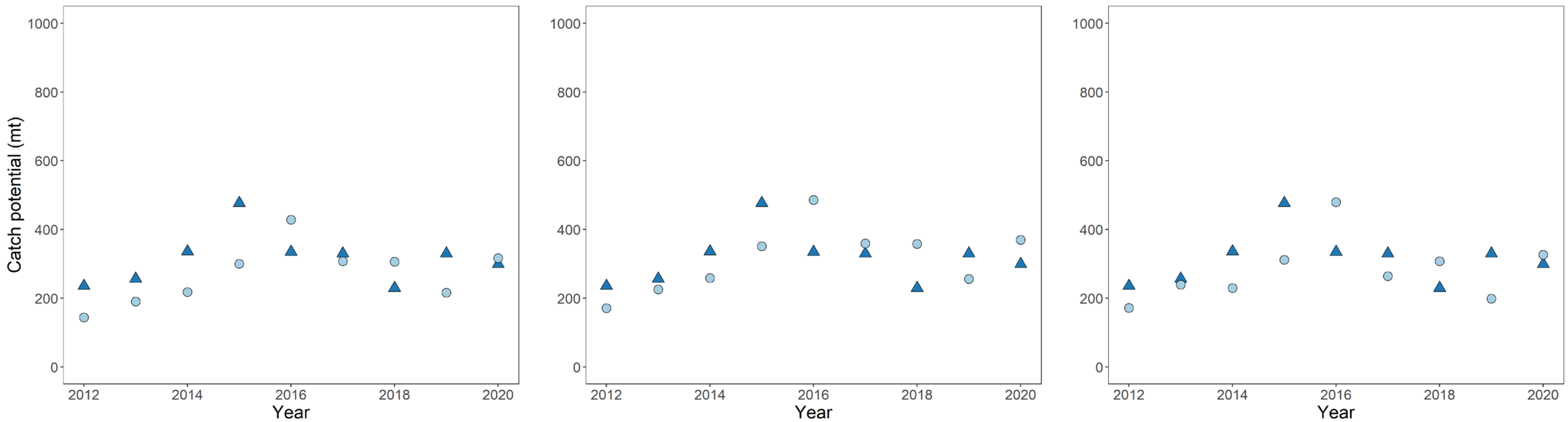

Figure 30. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.15 for SPA 3 for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

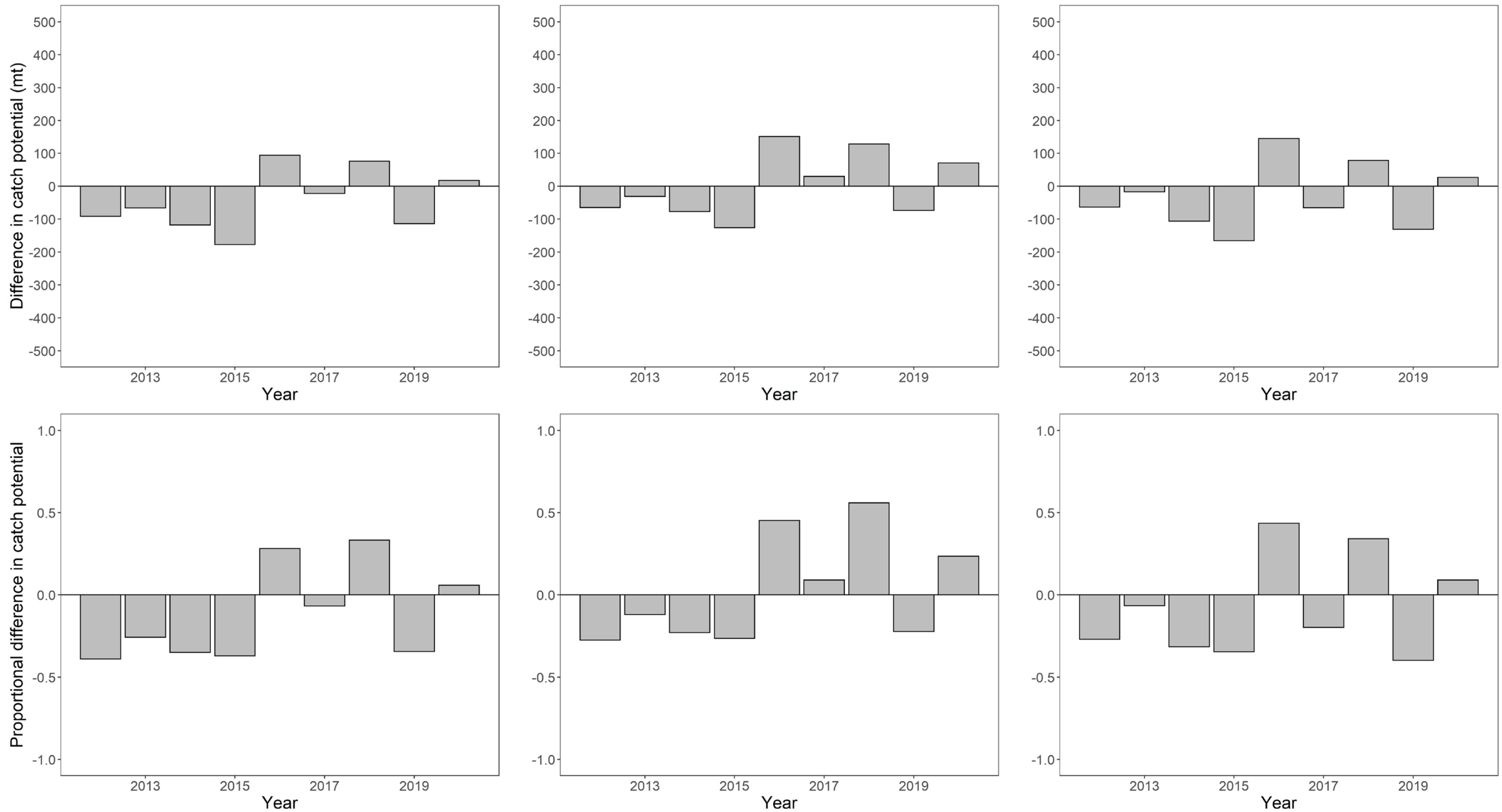

Figure 31. Difference in maximum catch between using a one−year projection for year t and a two−year projection for year t where exploitation is 0.15 for SPA 3. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

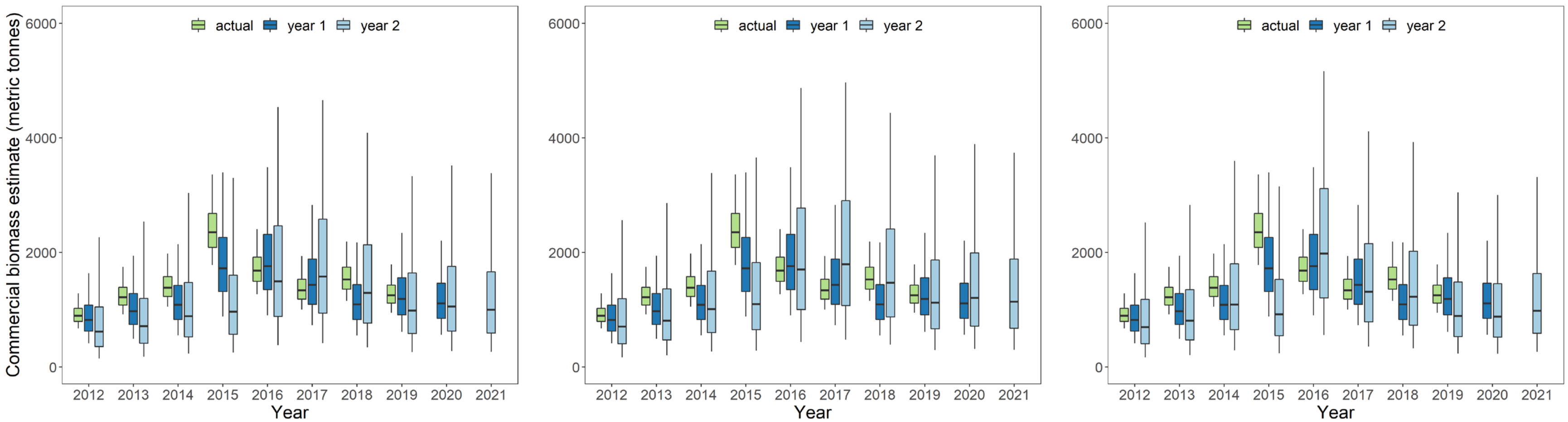

Figure 32. Evaluation of the model projection performance from 2012 to 2021 for SPA 4. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 113 mt is caught, and for 2021 the total allowable catch of 175 mt is caught. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

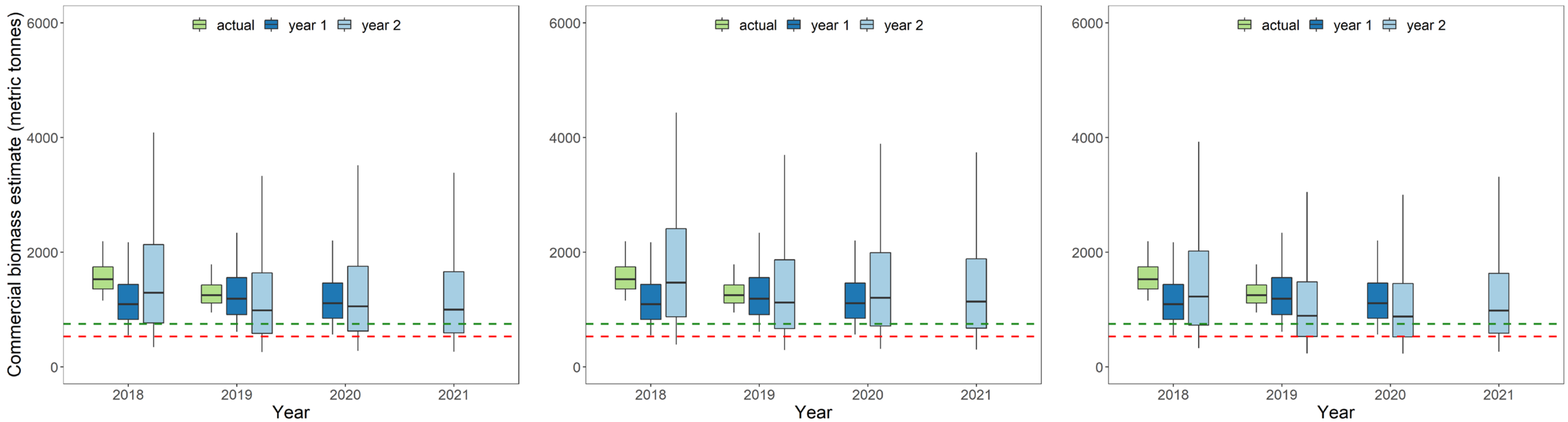

Figure 33. Evaluation of the model projection performance from 2018 to 2021 for SPA 4 relative to the upper stock reference (USR; green dashed line) and limit reference point (LRP; red dashed line). Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 113 mt is caught, and for 2021 the total allowable catch of 175 mt is caught. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

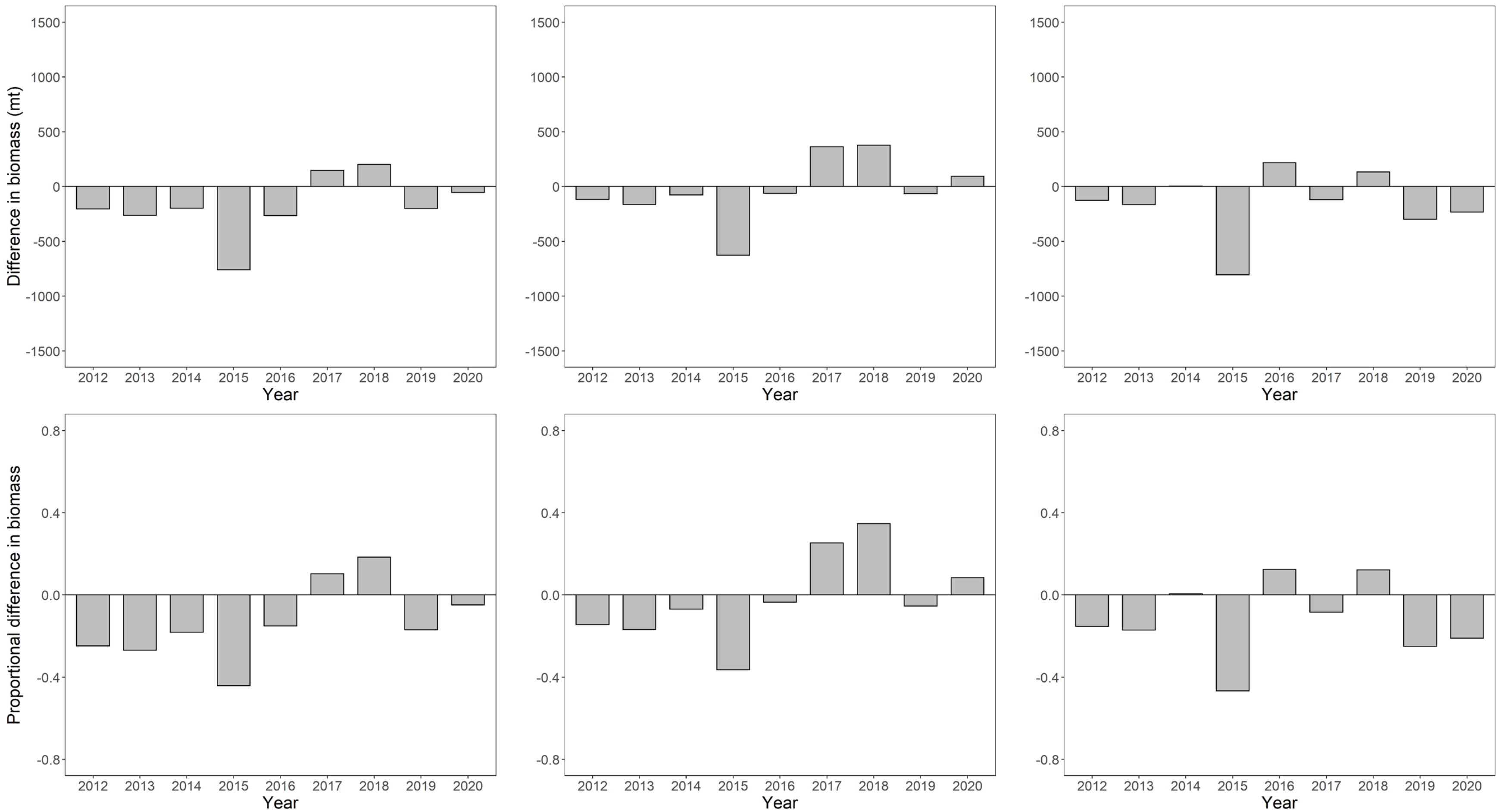

Figure 34. Difference in commercial biomass between two−year and one−year projections for each year (t) from 2012 to 2020 for SPA 4. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

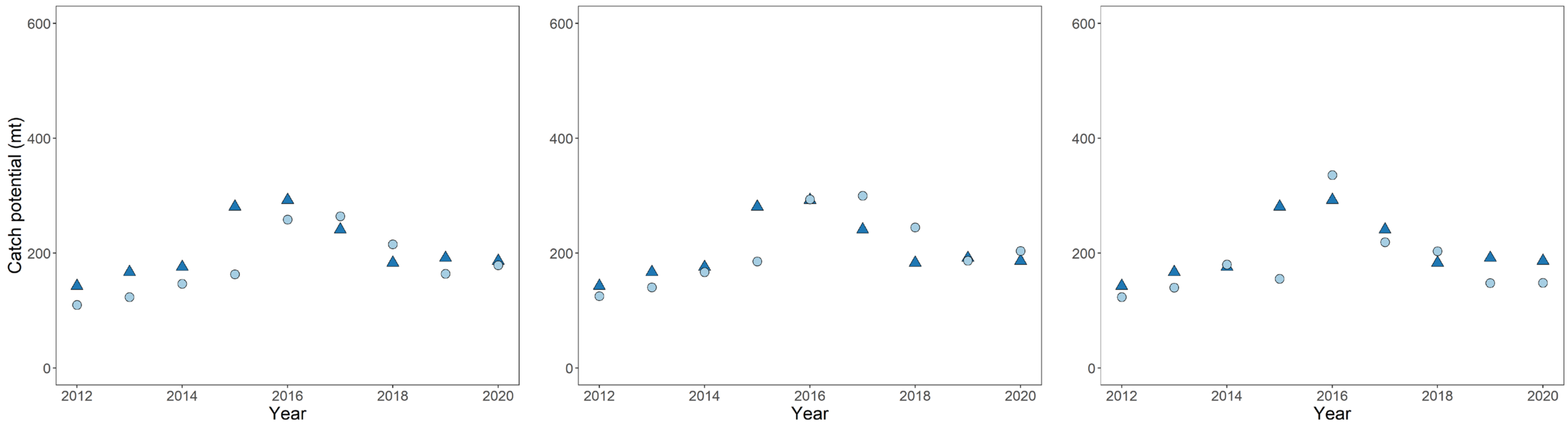

Figure 35. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.15 for SPA 4 for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

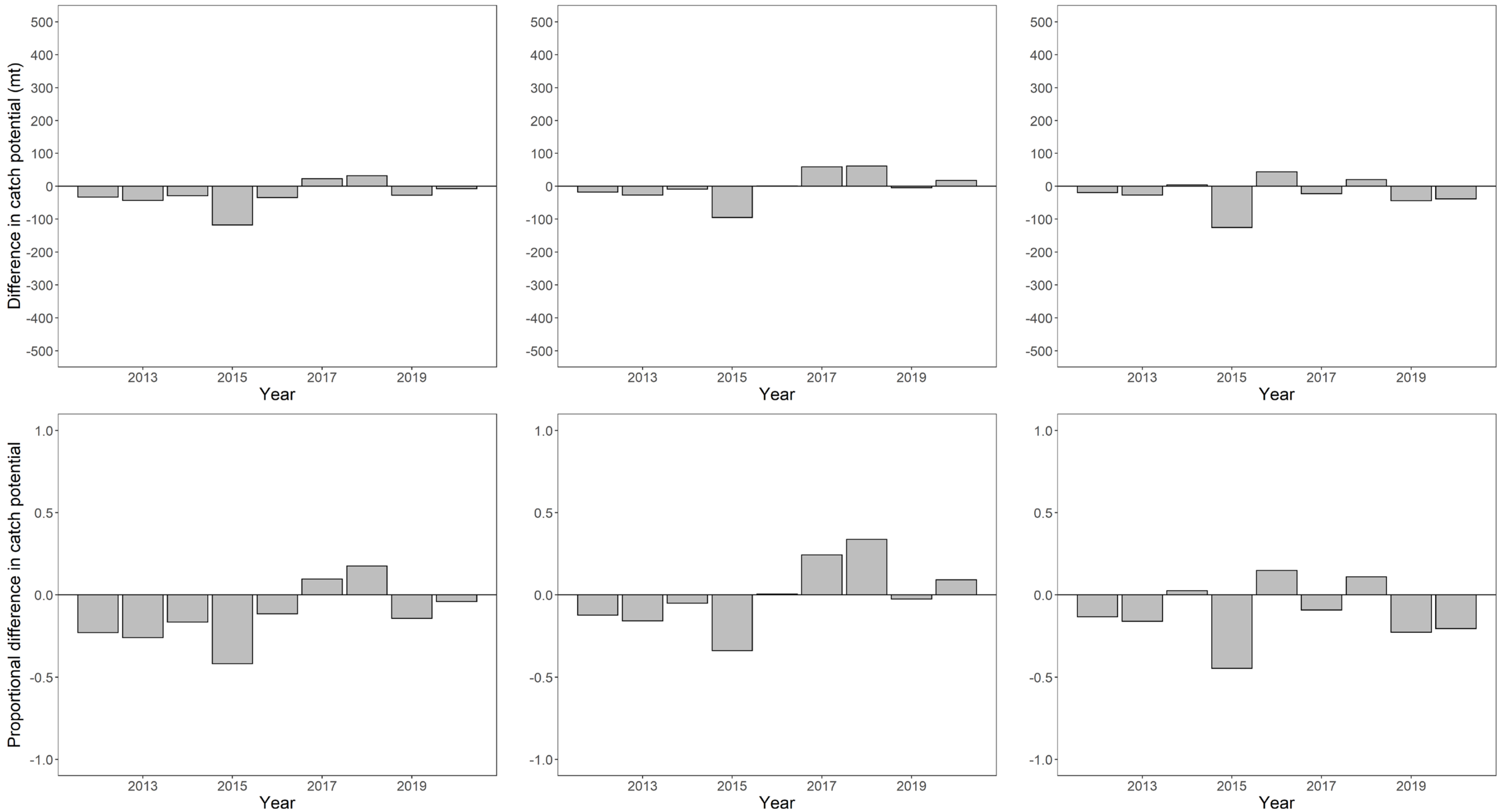

Figure 36. Difference in maximum catch between using a one−year projection for year t and a two−year projection for year t where exploitation is 0.15 for SPA 4. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

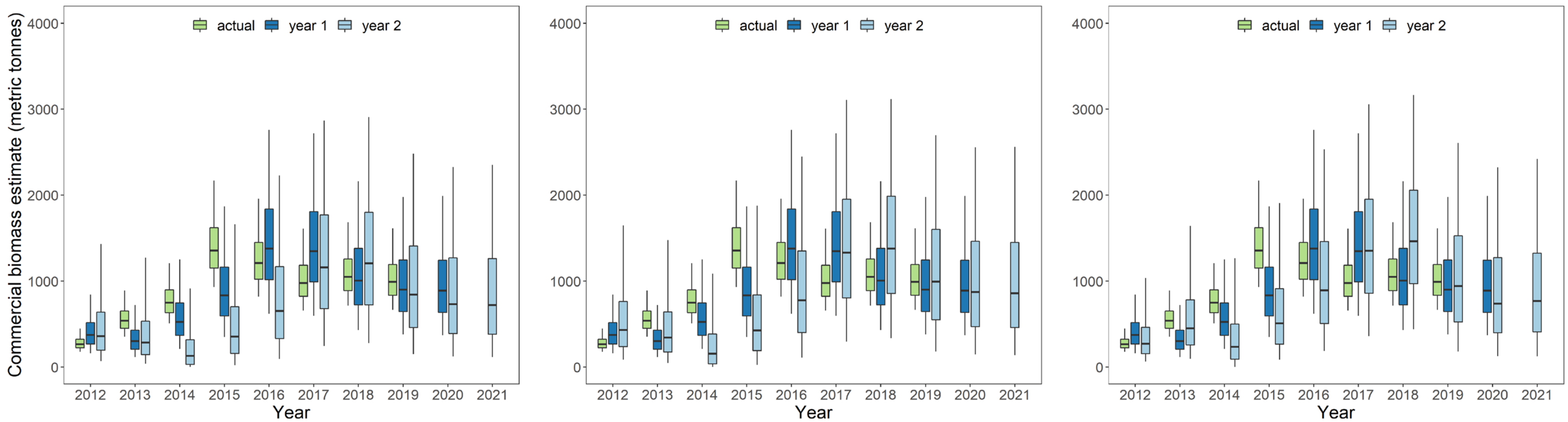

Figure 37. Evaluation of the model projection performance from 2012 to 2021 for SPA 6. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 164 mt is caught from the modeled area, and for 2021 the total allowable catch of 210 mt is caught from the modeled area. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

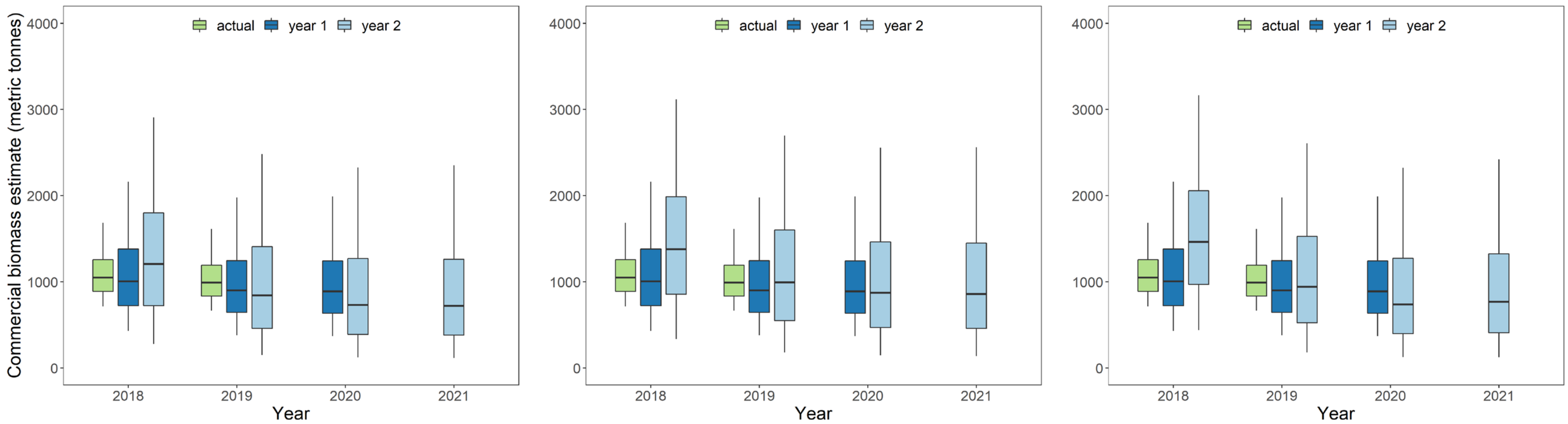

Figure 38. Evaluation of the model projection performance from 2018 to 2021 for SPA 6. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t - 1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t - 2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 assumes landings of 164 mt is caught from the modeled area, and for 2021 the total allowable catch of 210 mt is caught from the modeled area. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t - 1$; right panel).

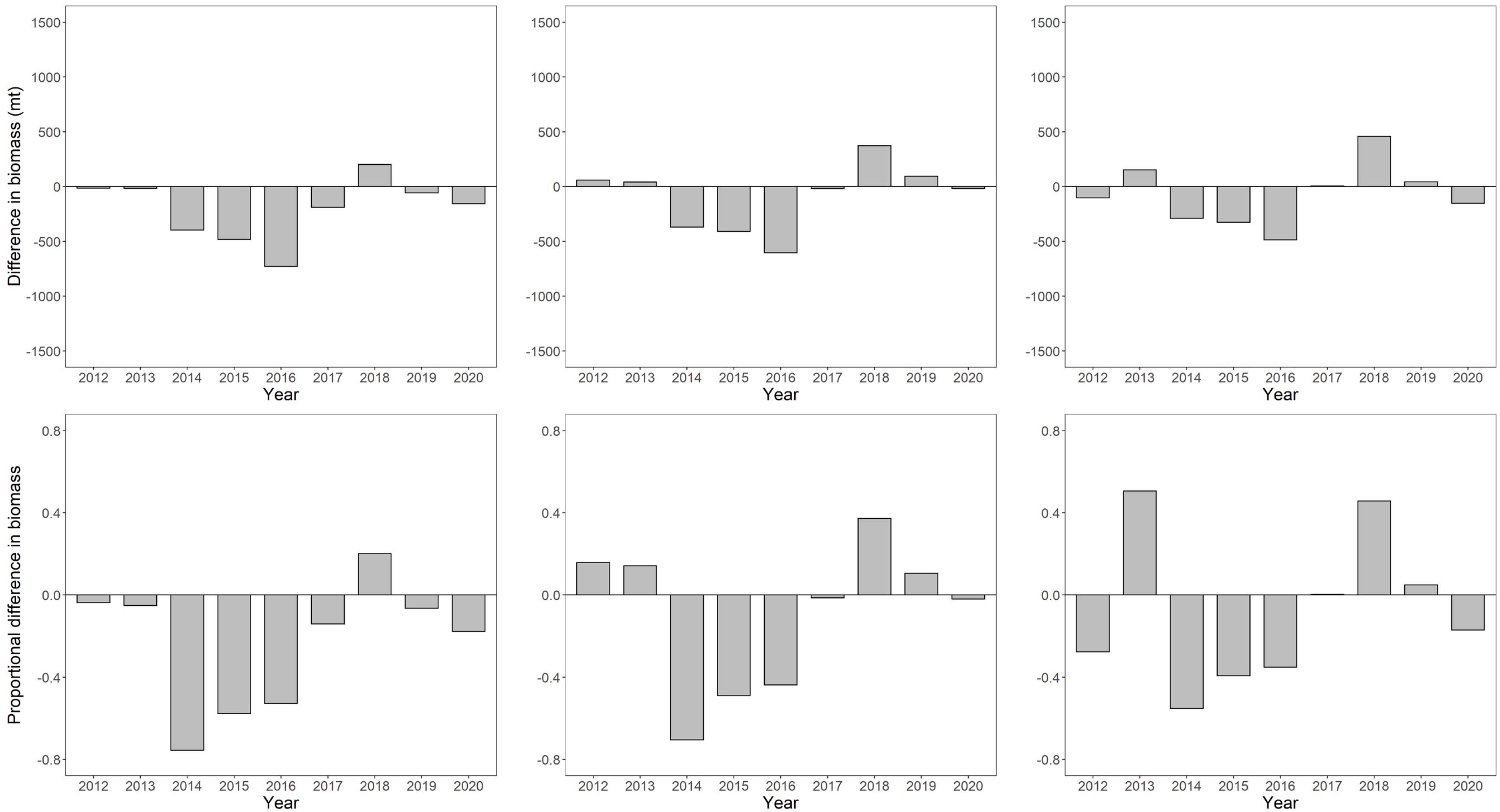

Figure 39. Difference in commercial biomass between two−year and one−year projections for each year (t) from 2012 to 2020 for SPA 6. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

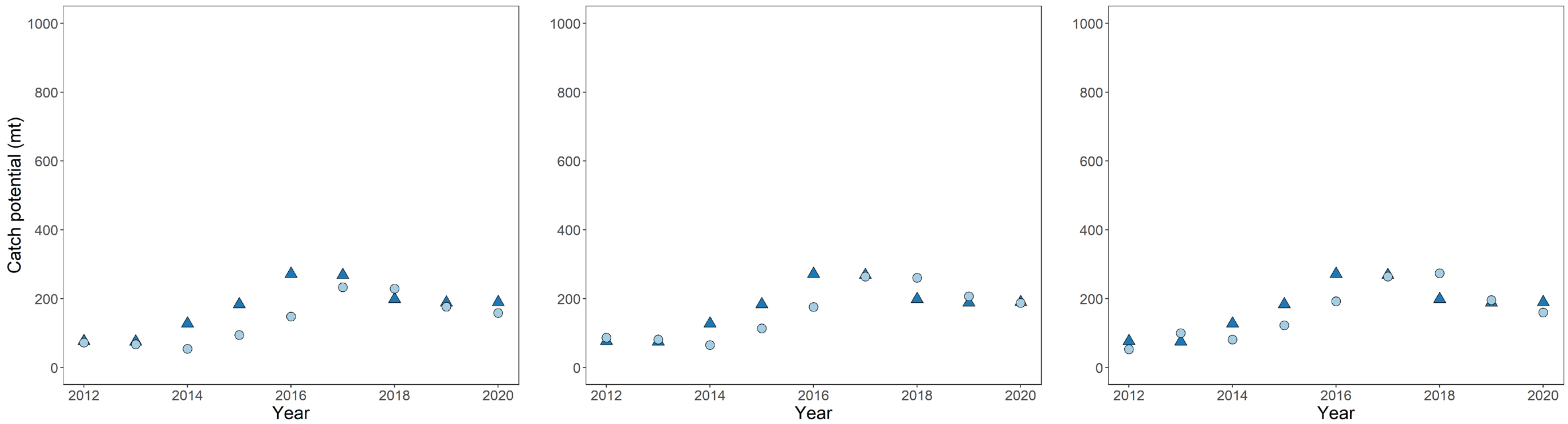

Figure 40. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.18 for SPA 6 for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t - 1$; right panel).

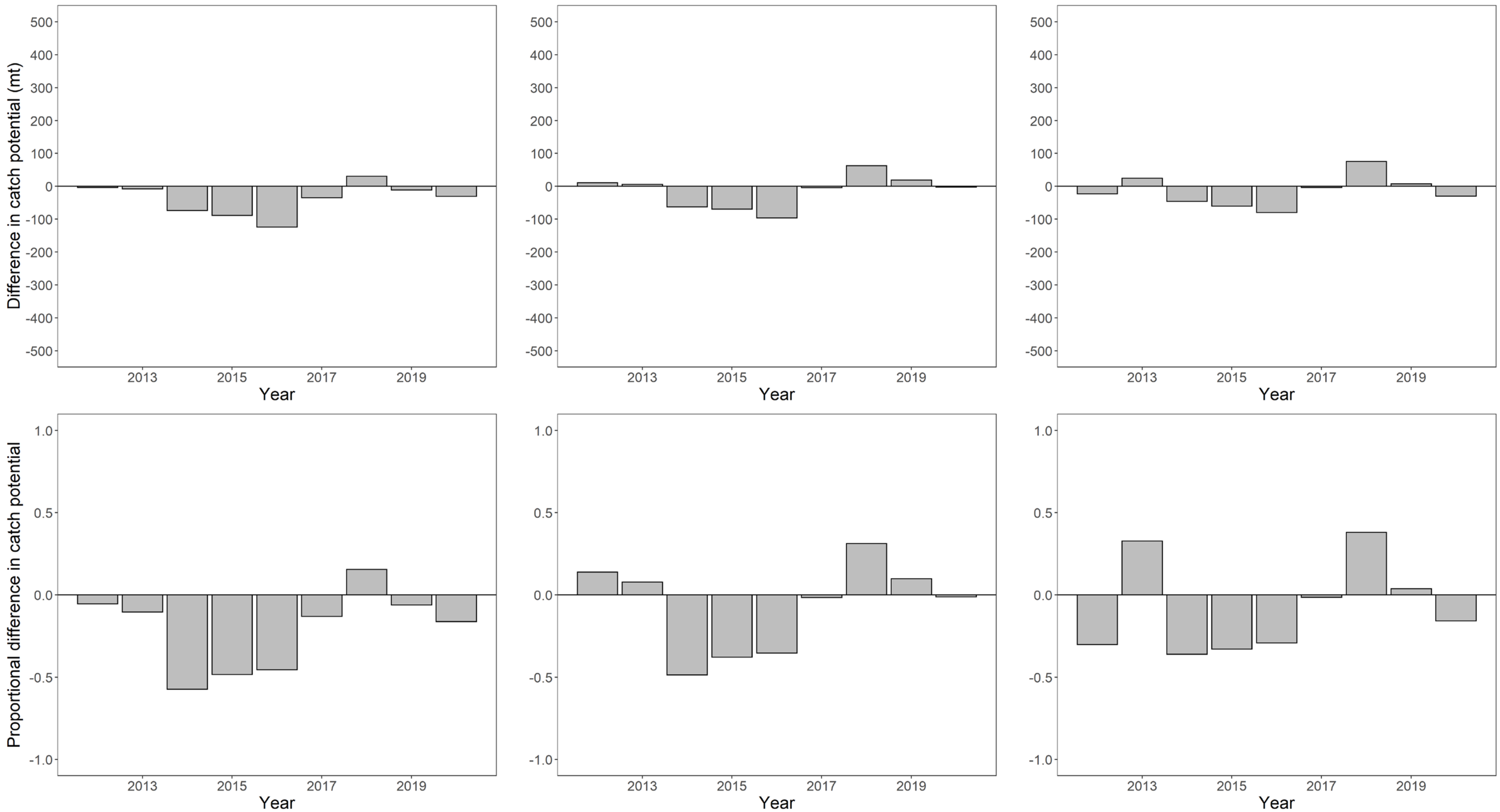

Figure 41. Difference in maximum allowable catch between using a one−year projection for year t and a two−year projection for year (t) where exploitation is 0.18 for SPA 6. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

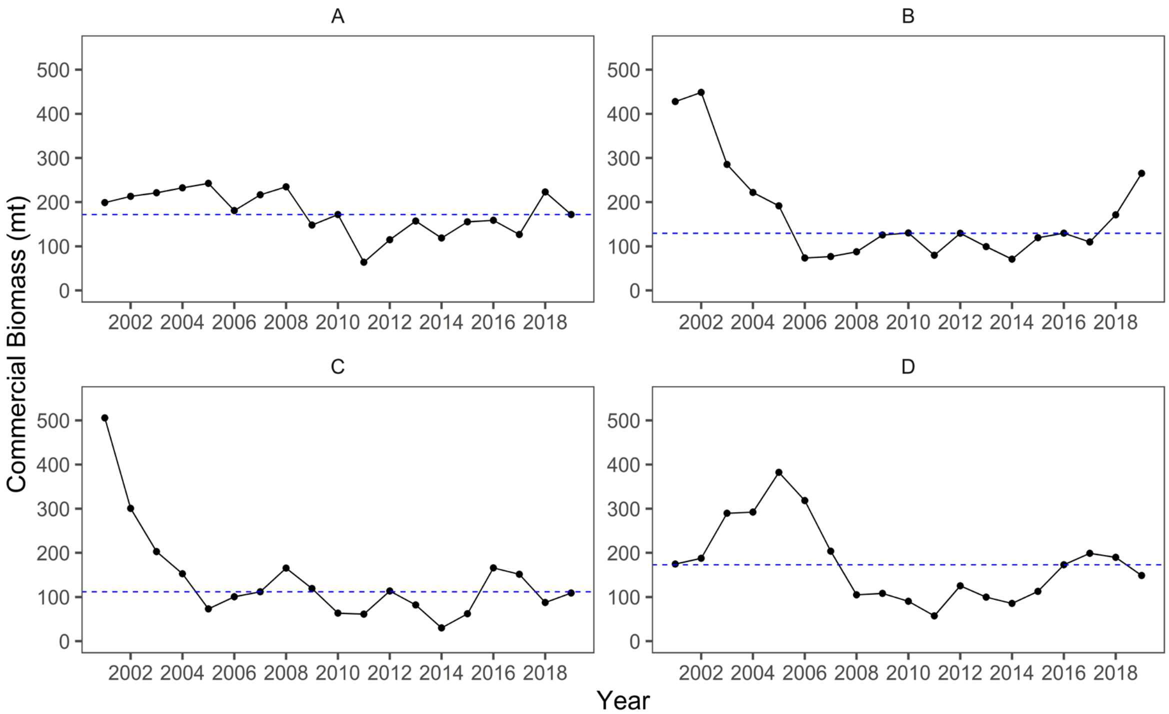

Figure 42. Time series of median biomass estimates (tonnes, mt) of commercial size scallops in the medium habitat category for SFA 29W Subarea A (A), and the high habitat categories for SFA 29W Subareas B, C, and D (B, C, D) from the stock assessment model. The blue dashed lines represent the long−term medians.

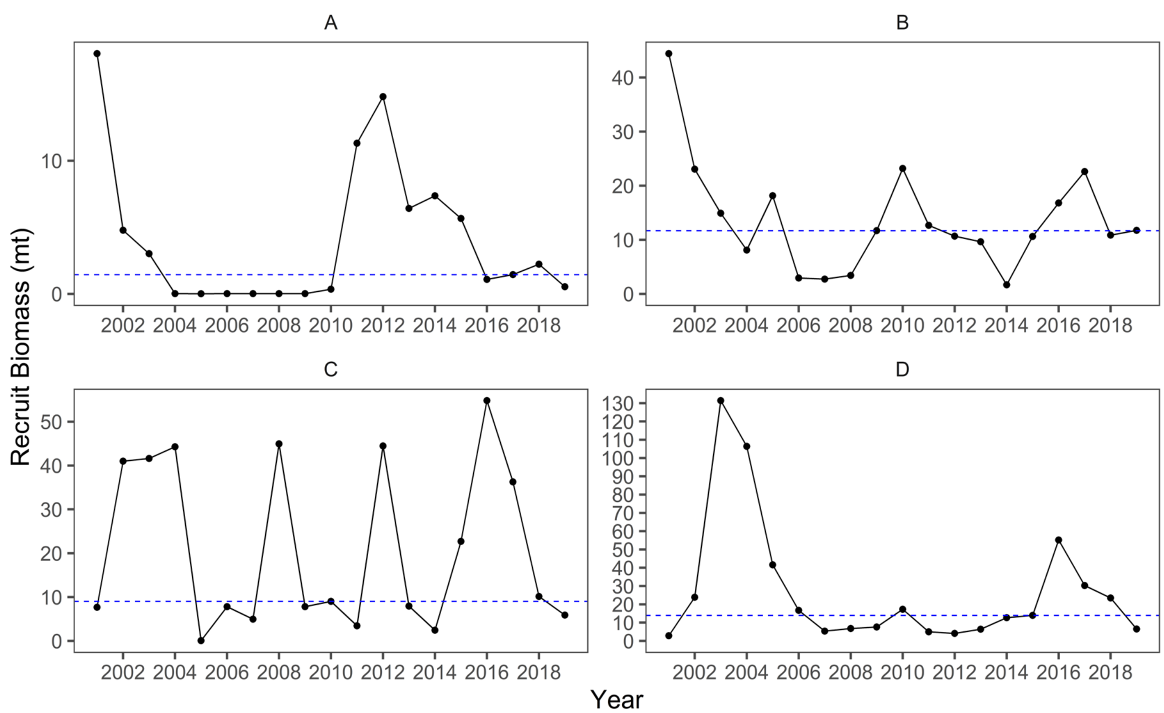

Figure 43. Time series of median biomass estimates (tonnes, mt) of recruit size scallops in the medium habitat category for SFA 29W Subarea A (A), and the high habitat categories for SFA 29W Subareas B, C, and D (B, C, D) from the stock assessment model. The blue dashed lines represent the long−term medians.

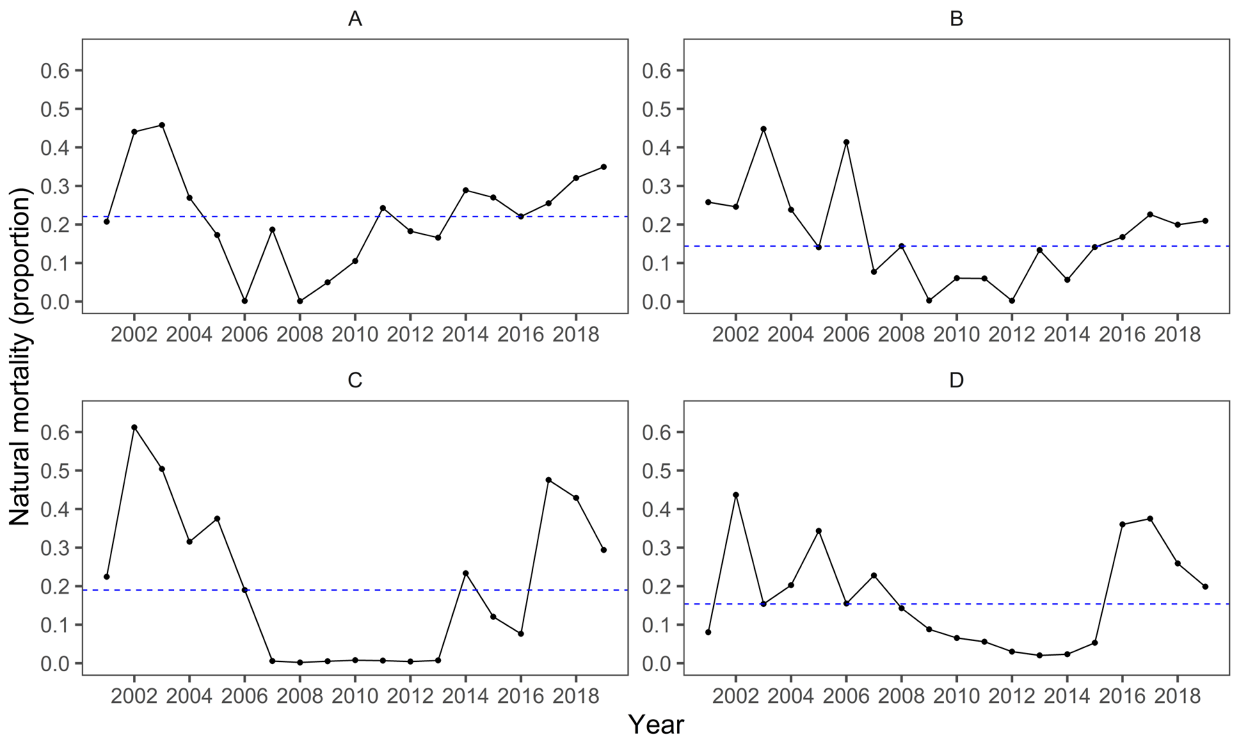

Figure 44. Time series of median natural mortality (proportion) estimates in the medium habitat category for SFA 29W Subarea A (A), and the high habitat categories for SFA 29W Subareas B, C, and D (B, C, D) from the stock assessment model. The blue dashed lines represent the long−term medians.

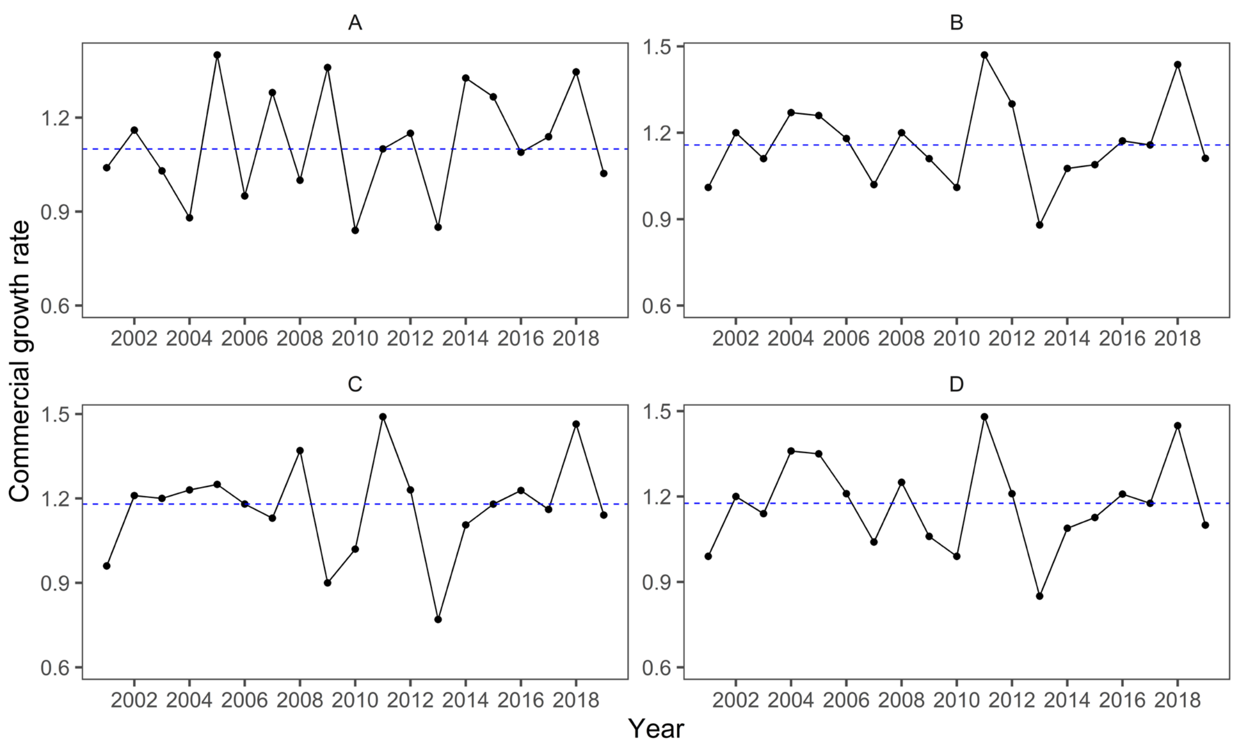

Figure 45. Time series of average commercial growth rate in SFA 29W Subareas A (A), B (B), C (C), and D (D). The blue dashed lines represent the long−term medians.

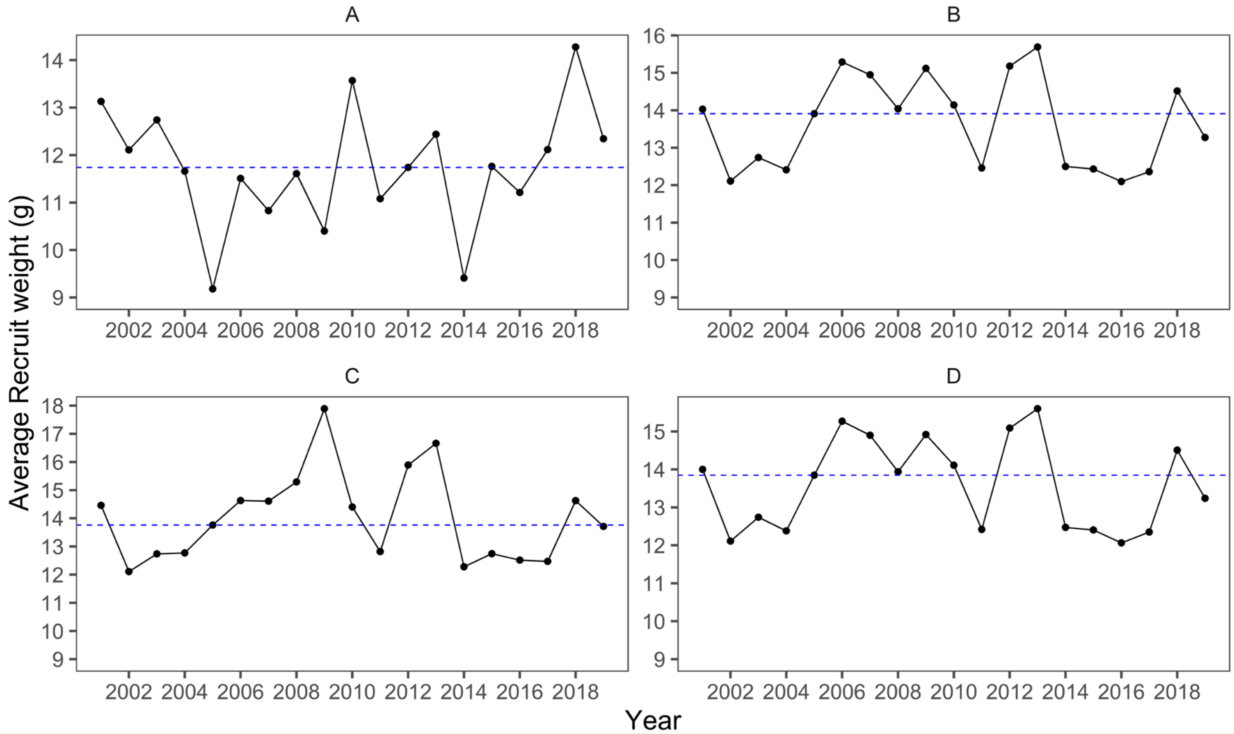

Figure 46. Time series of average recruit weight (grams, g) in SFA 29W Subareas A (A), B (B), C (C), and D (D). The blue dashed lines represent the long−term medians.

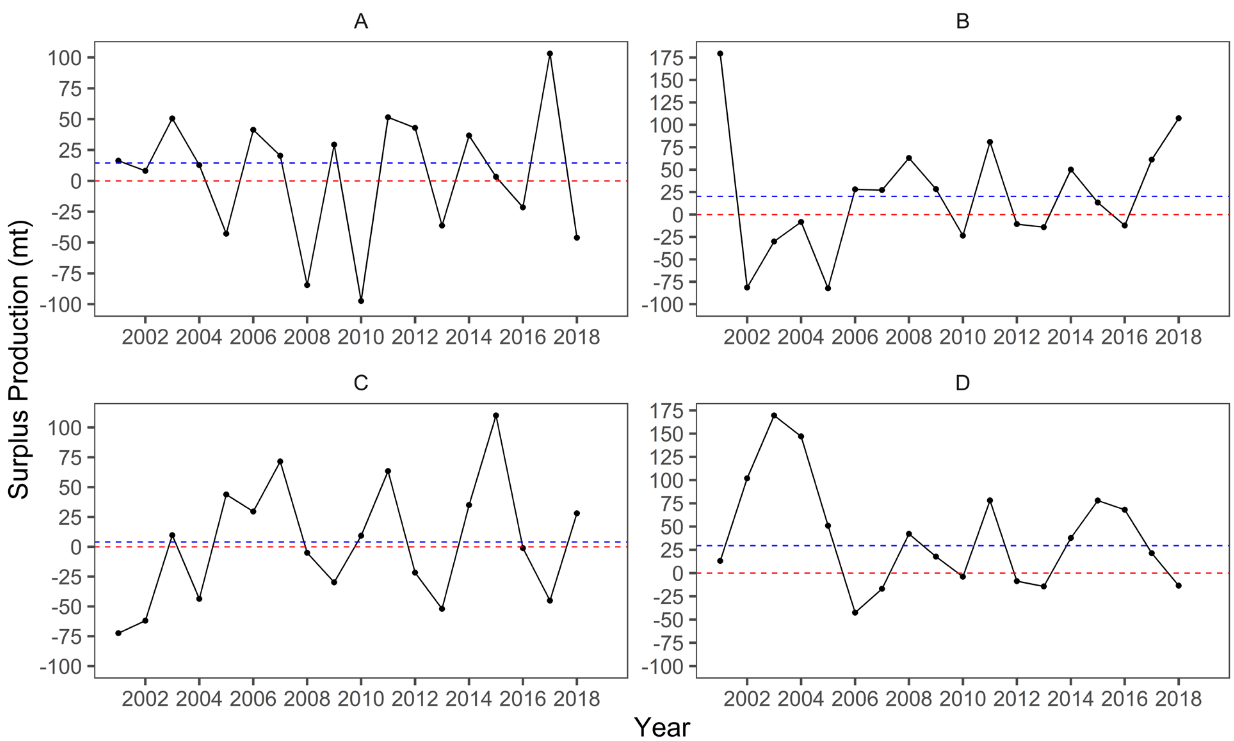

Figure 47. Time series of surplus production (meats, tonnes, mt) of commercial biomass for SFA 29W Subareas A (A), B (B), C (C), and D (D). The blue dashed lines represent the long−term medians, and the red dashed lines represent zero surplus production.

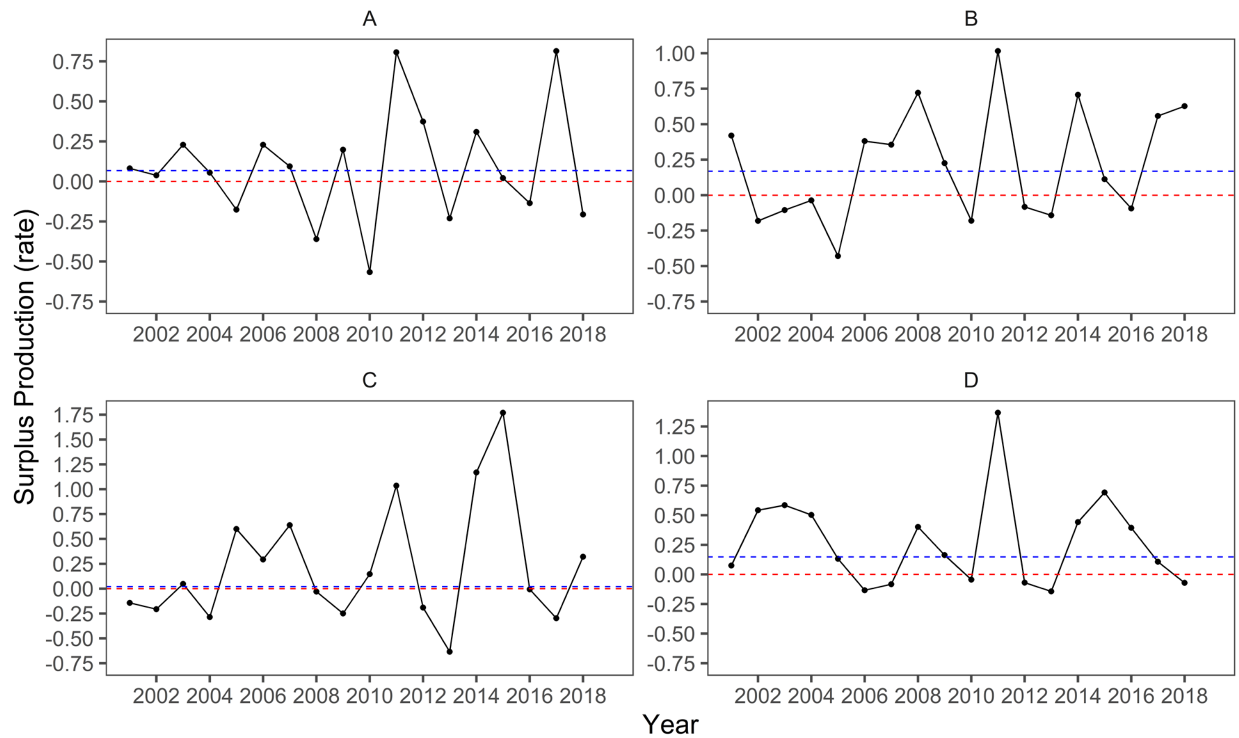

Figure 48. Time series of surplus production rate of commercial biomass for SFA 29W Subareas A (A), B (B), C (C), and D (D). The blue dashed lines represent the long−term medians, and the red dashed lines represent zero surplus production.

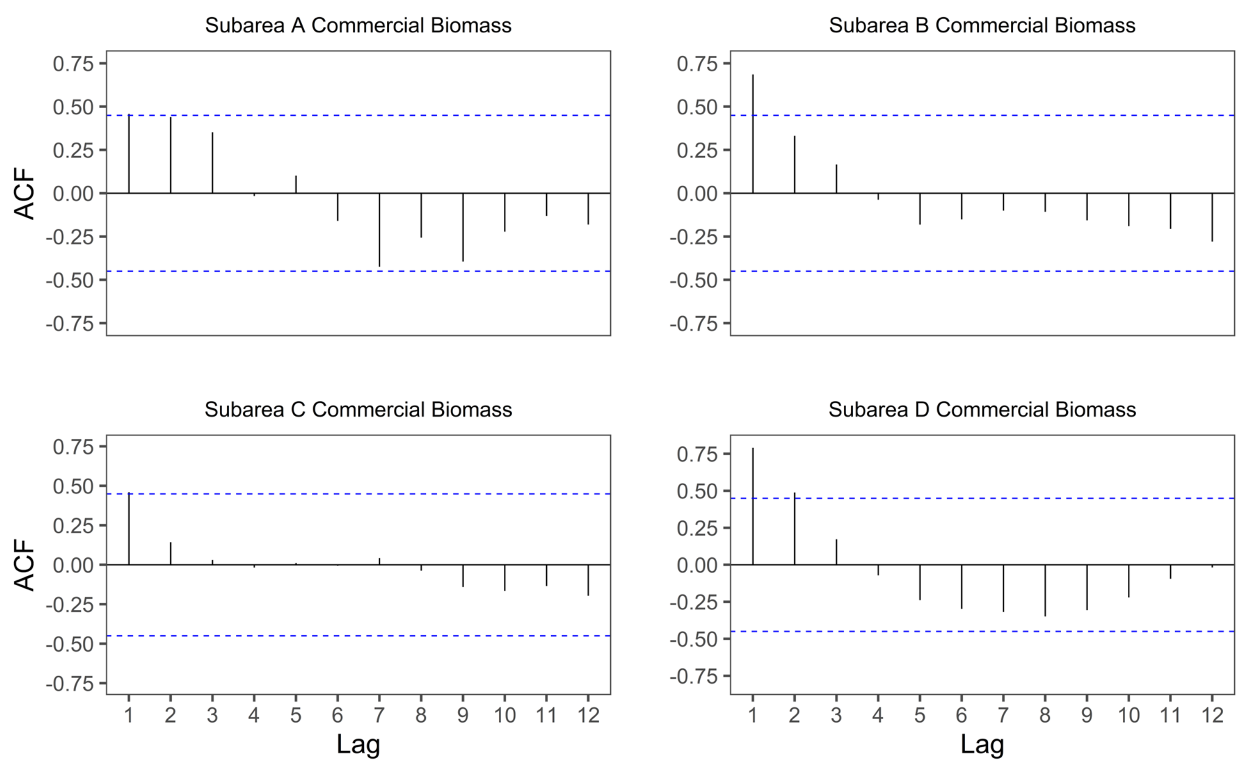

Figure 49. Autocorrelation (ACF) in commercial biomass time series for SFA 29W Subareas A, B, C, and D. The blue dashed lines represent the 95% confidence intervals.

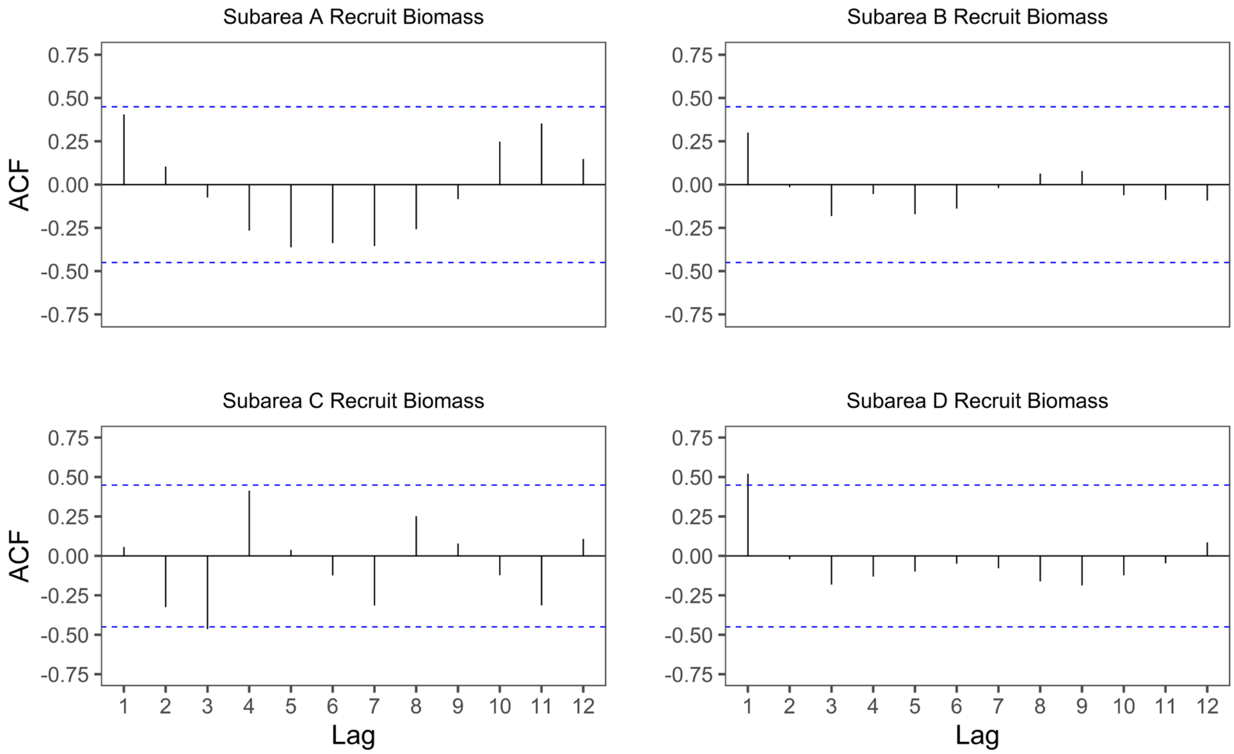

Figure 50. Autocorrelation (ACF) in recruit biomass time series for SFA 29W Subareas A, B, C, and D. The blue dashed lines represent the 95% confidence intervals.

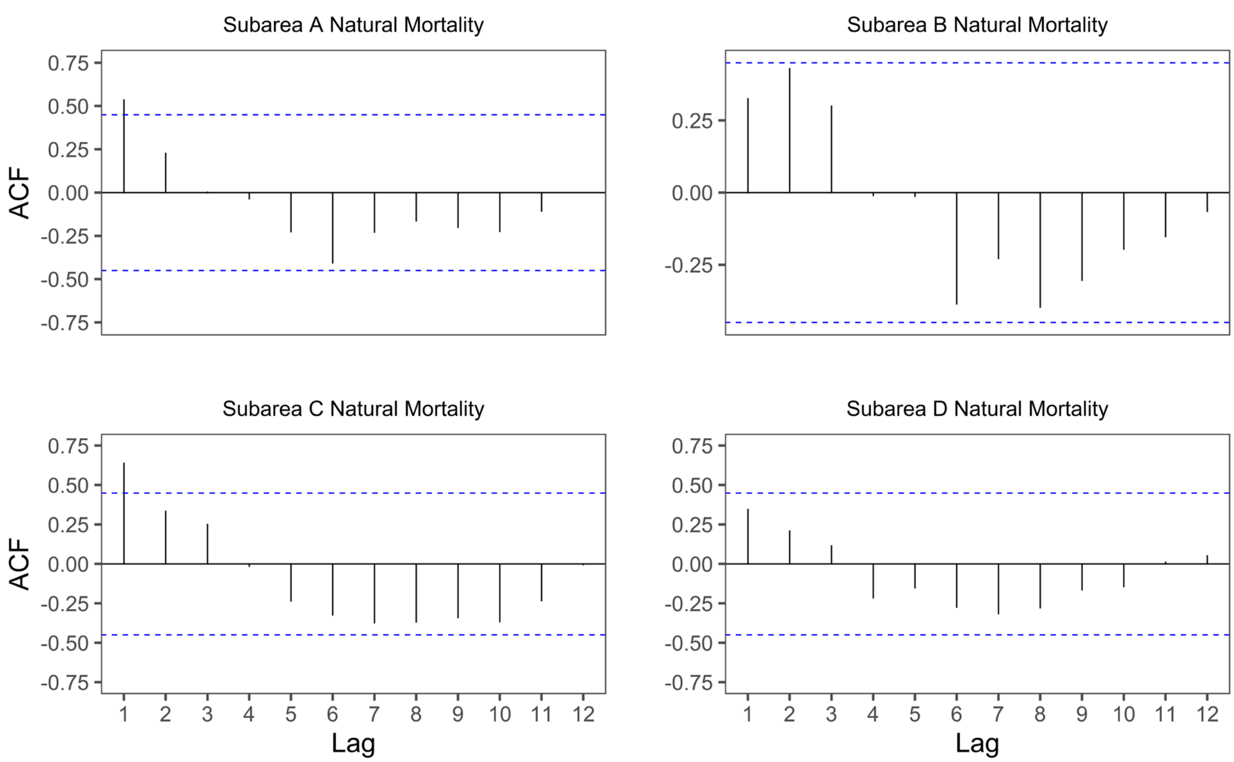

Figure 51. Autocorrelation (ACF) in natural mortality time series for SFA 29W Subareas A, B, C, and D. The blue dashed lines represent the 95% confidence intervals.

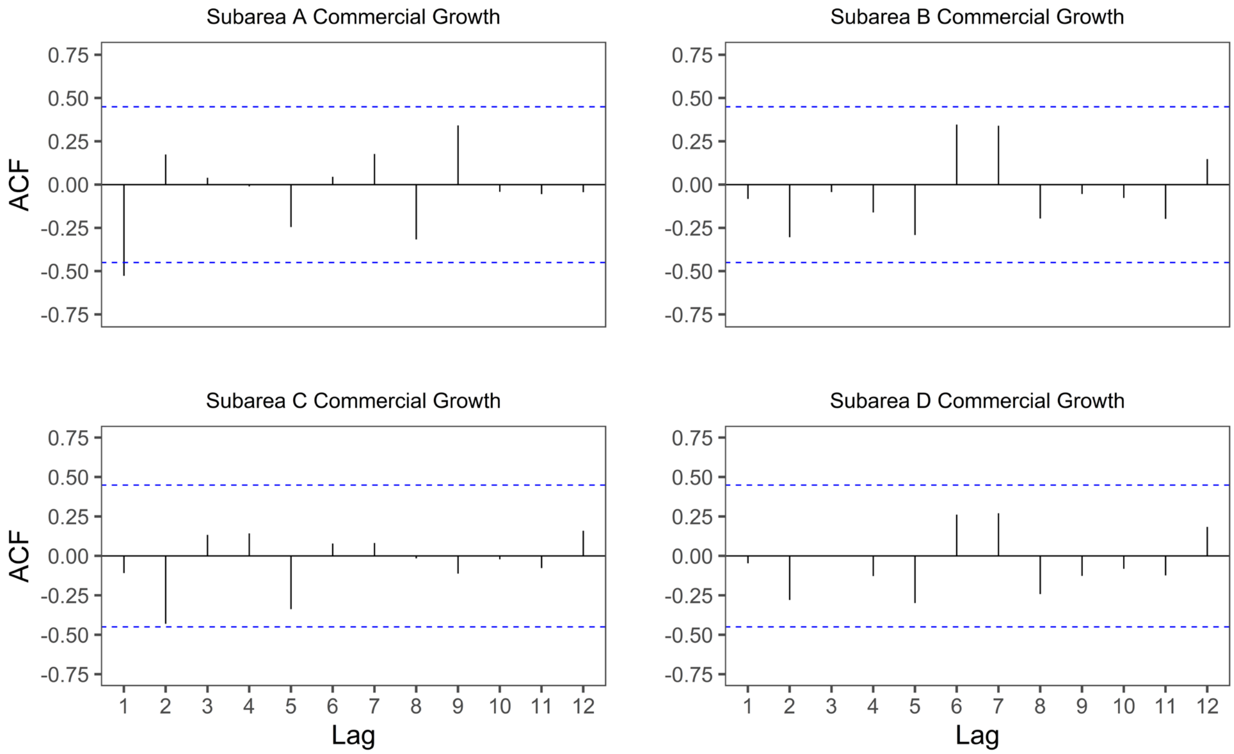

Figure 52. Autocorrelation (ACF) in commercial growth rate time series for SFA 29W Subareas A, B, C, and D. The blue dashed lines represent the 95% confidence intervals.

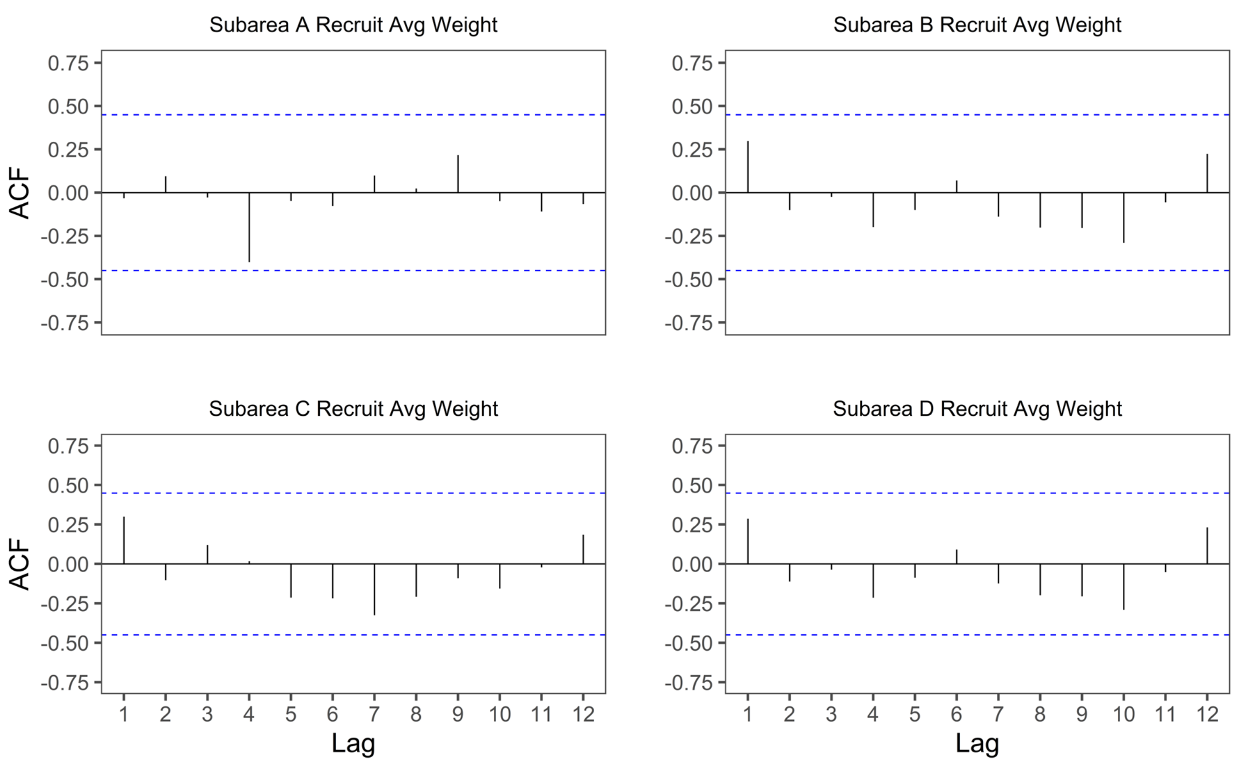

Figure 53. Autocorrelation (ACF) in average recruit weight time series for SFA 29W Subareas A, B, C, and D. The blue dashed lines represent the 95% confidence intervals.

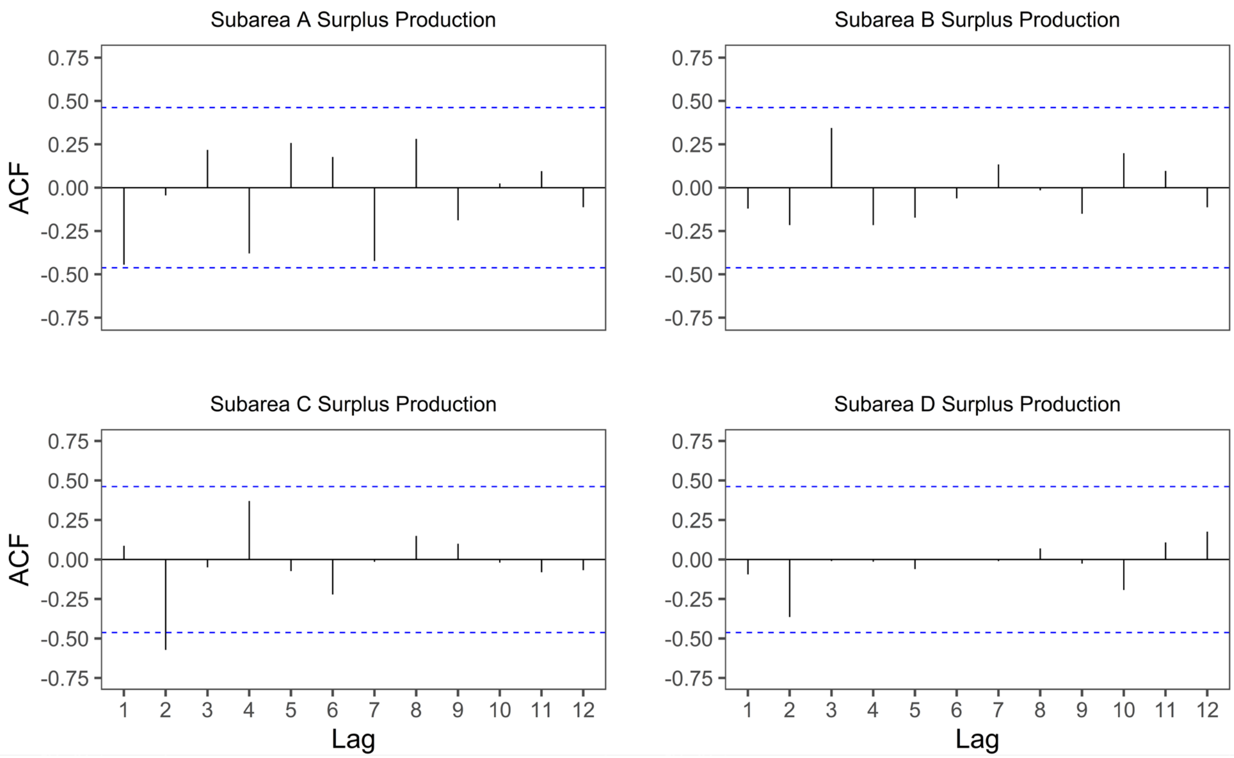

Figure 54. Autocorrelation (ACF) in surplus production rate time series for SFA 29W Subareas A, B, C, and D. The blue dashed lines represent the 95% confidence intervals.

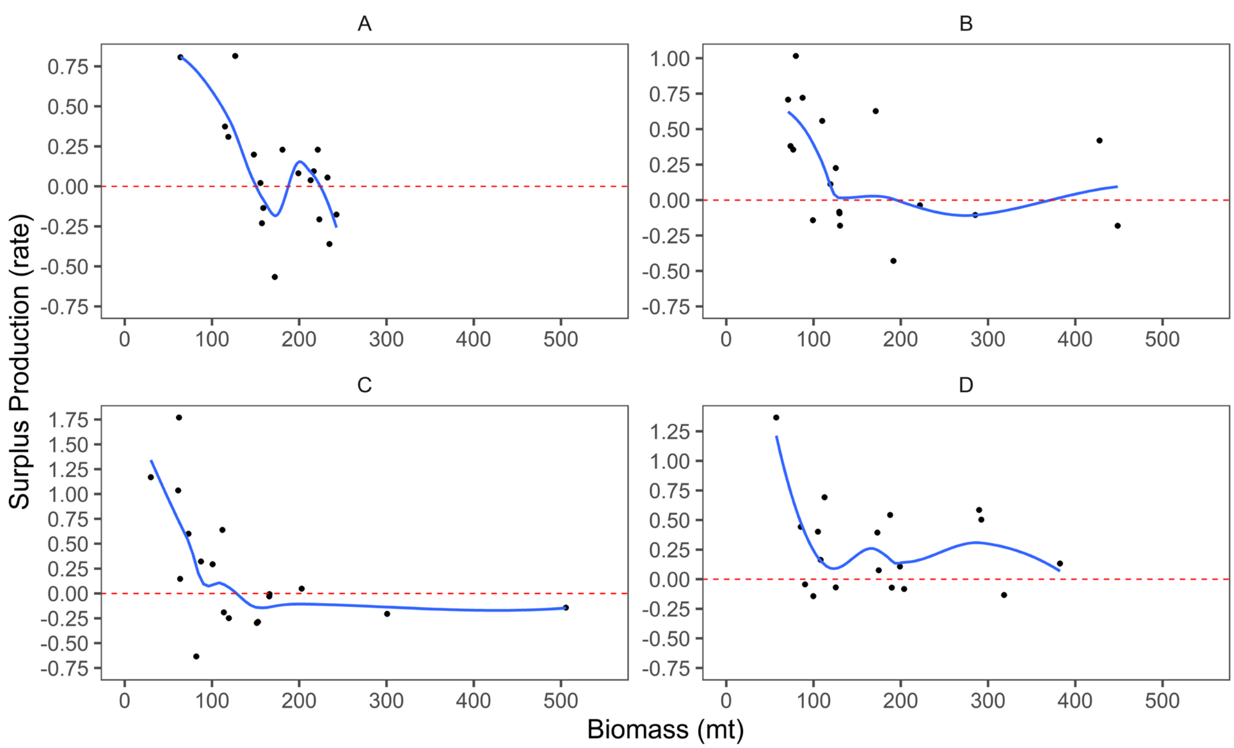

Figure 55. Surplus production (rate) of commercial biomass for SFA 29W Subareas A, B, C, and D. The red dashed line represents zero surplus production. The blue line represents a loess curve added to detect trend.

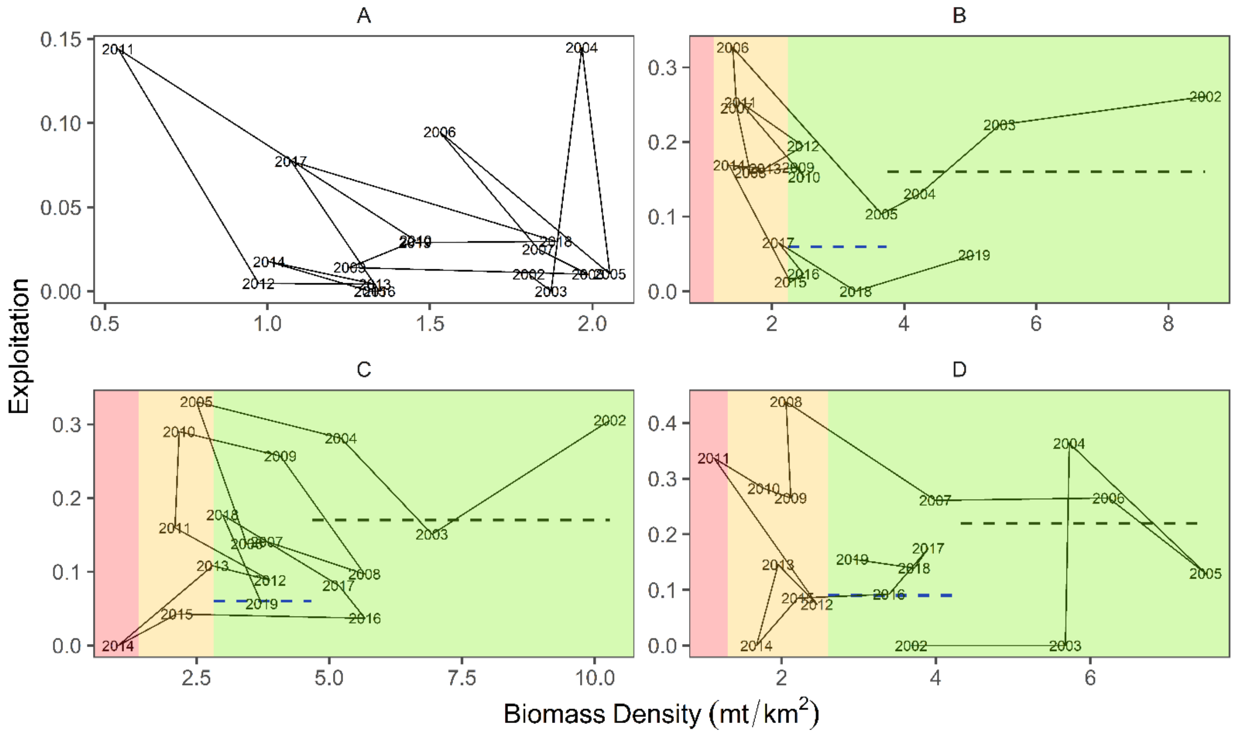

Figure 56. Phase plot of commercial biomass and exploitation for SFA 29W Subareas A, B, C, and D. Labels refer to year of the survey. The green−shaded area represents the Healthy zone, the yellow−shaded area represents the Cautious zone, and the red−shading area represents the Critical zone. reference points are not adopted for Subarea A. The removal rates (horizontal dashed lines) in the Healthy zone are a function of the Biomass Density.

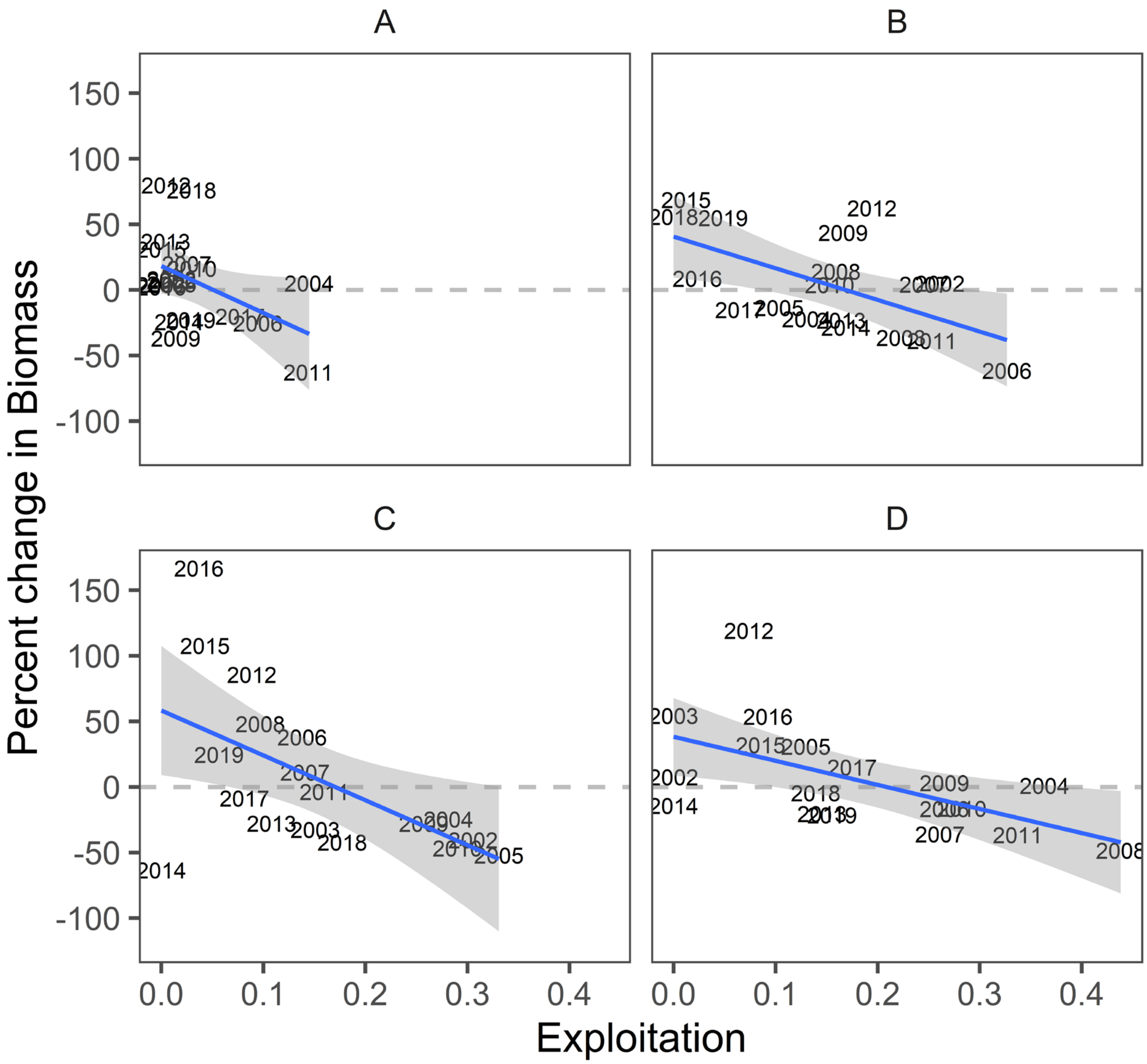

Figure 57. Change in commercial biomass with exploitation for SFA 29W Subareas A, B, C, and D. Labels of year t represent change from year $t-1$ to t. For each Subarea (panel), the exploitation rate at zero biomass change is based on a linear model (blue line) with a 95% confidence interval (gray ribbon).

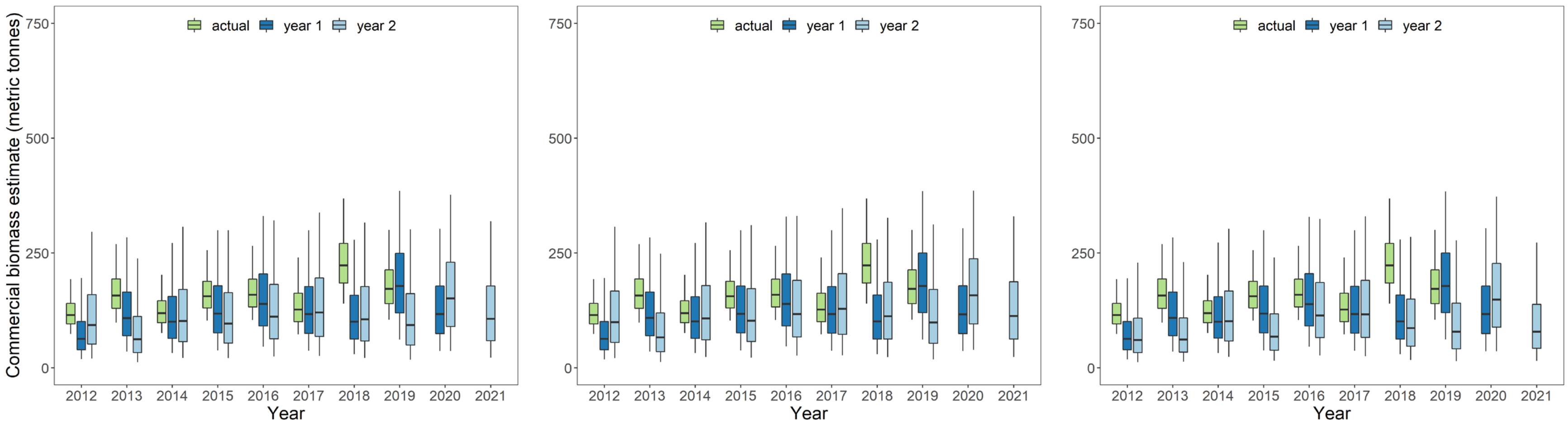

Figure 58. Evaluation of the model projection performance from 2012 to 2021 for SFA 29W Subarea A. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year t−1 (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g. 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 and 2021 assume landings of 6.5 mt in each respective year is caught from the subarea. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

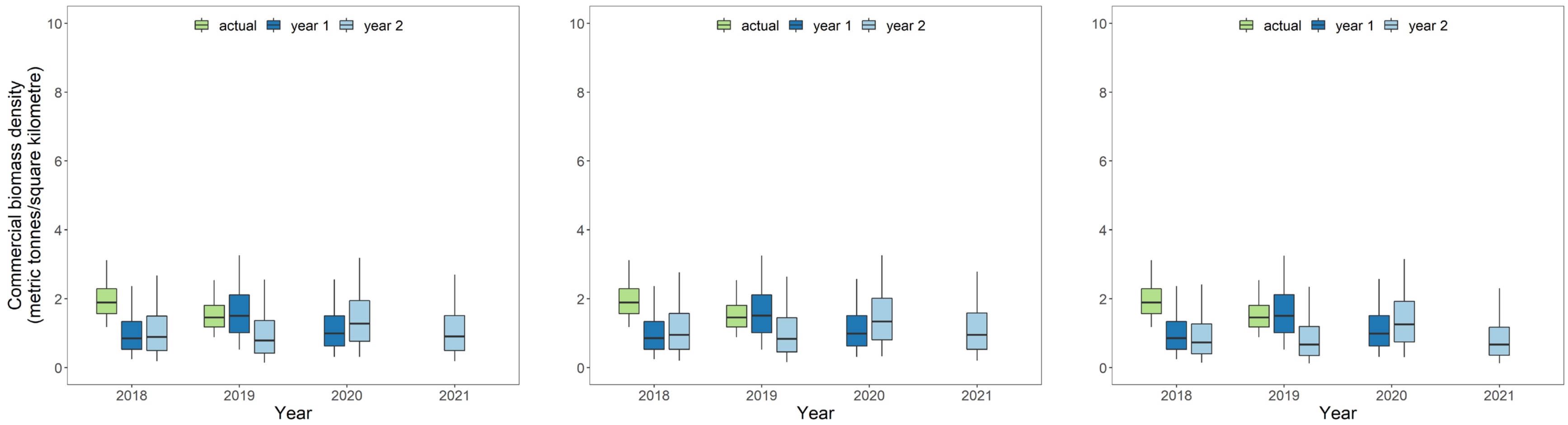

Figure 59. Evaluation of the model projection performance from 2018 to 2021 for SFA 29W Subarea A. Green box and whisker plots summarize the posterior distribution of the commercial biomass density in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass density in year t based on model fit to year $t-1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass density in year t based on model fit to year $t-2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 and 2021 assume landings of 6.5 mt in each respective year is caught from the subarea. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

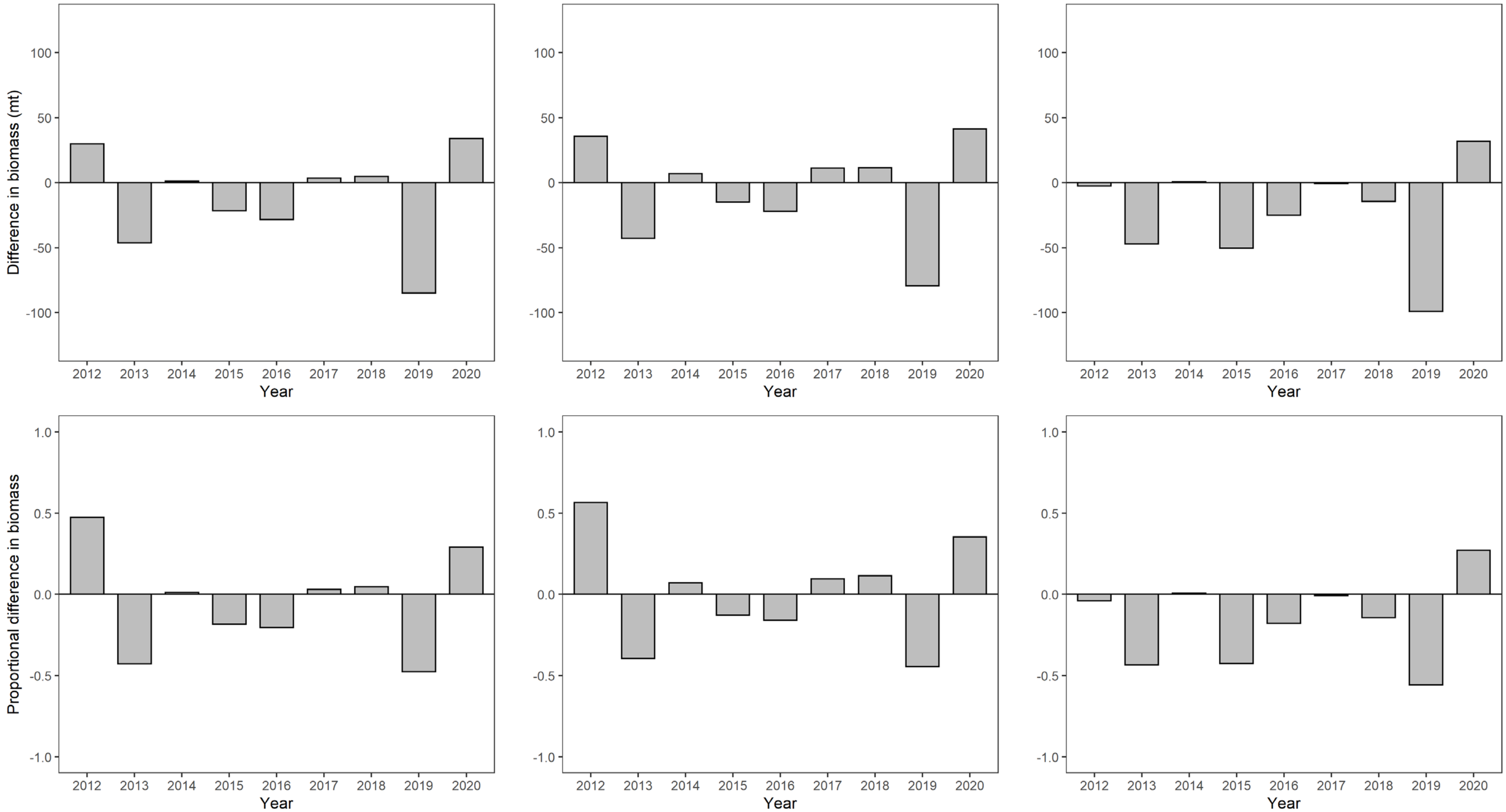

Figure 60. Difference in commercial biomass between two−year and one−year projections for each year t from 2012 to 2020 for SFA 29W Subarea A. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

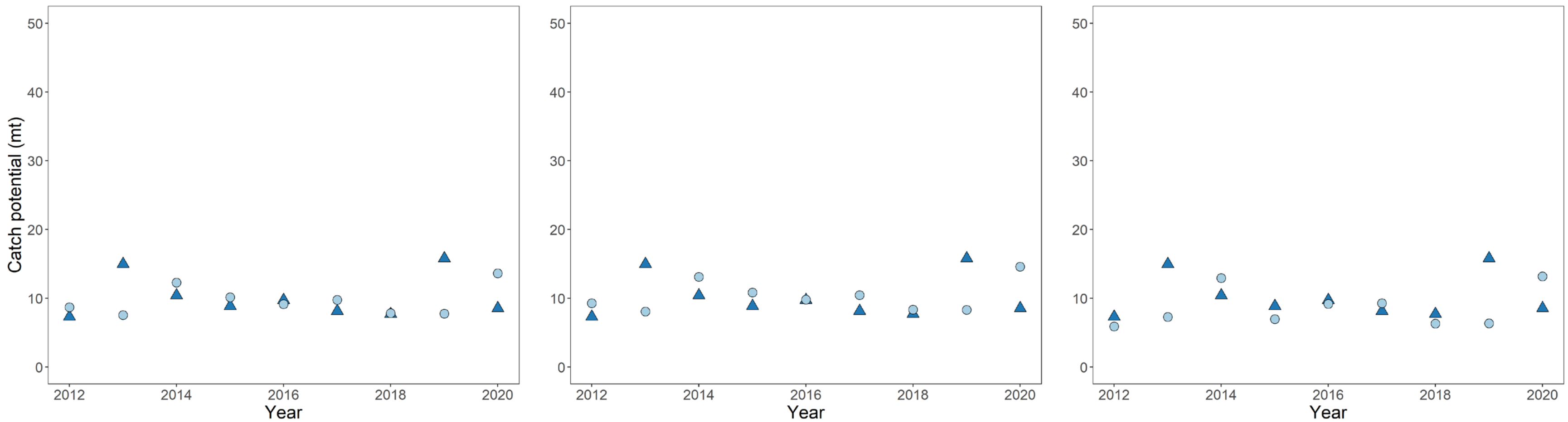

Figure 61. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.05 for SFA 29W Subarea A for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

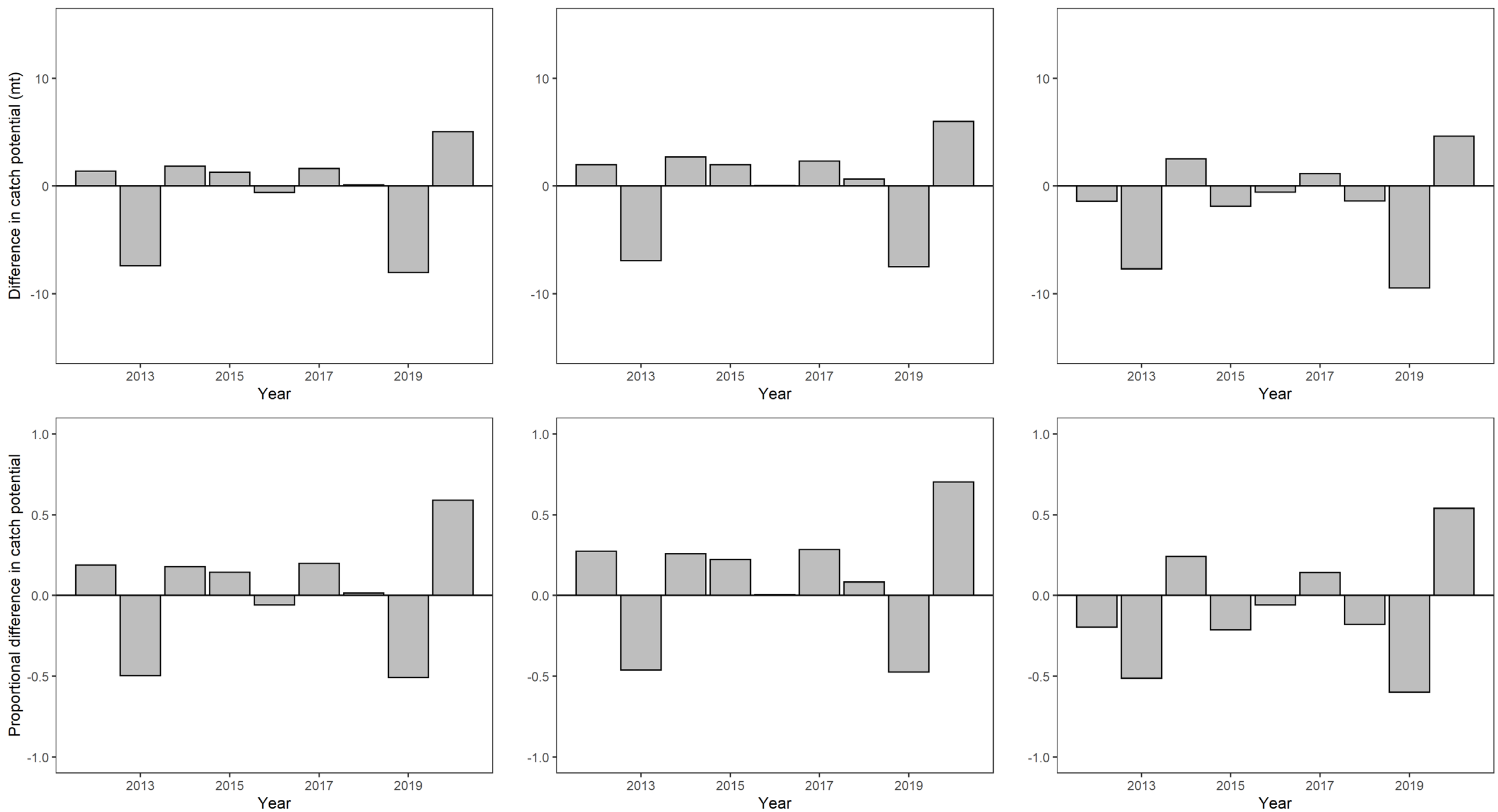

Figure 62. Difference in maximum catch between using a one−year projection for year t and a two−year projection for year t where exploitation is 0.05 for SFA 29W Subarea A. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

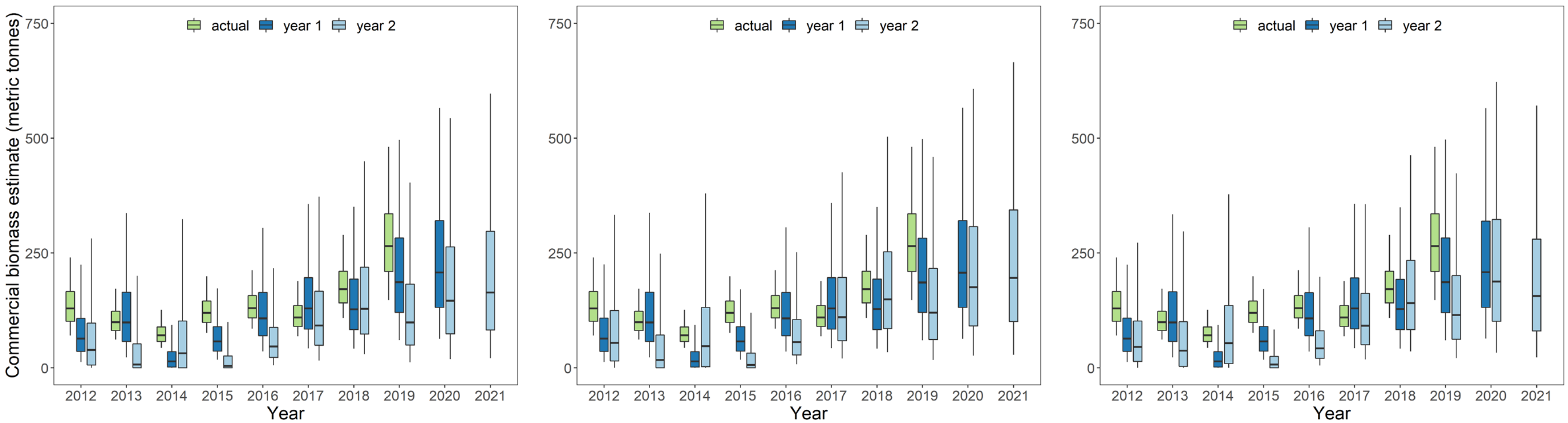

Figure 63. Evaluation of the model projection performance from 2012 to 2021 for SFA 29W Subarea B. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to t−1 (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 and 2021 assume landings of 55 mt in each respective year is caught from the subarea. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

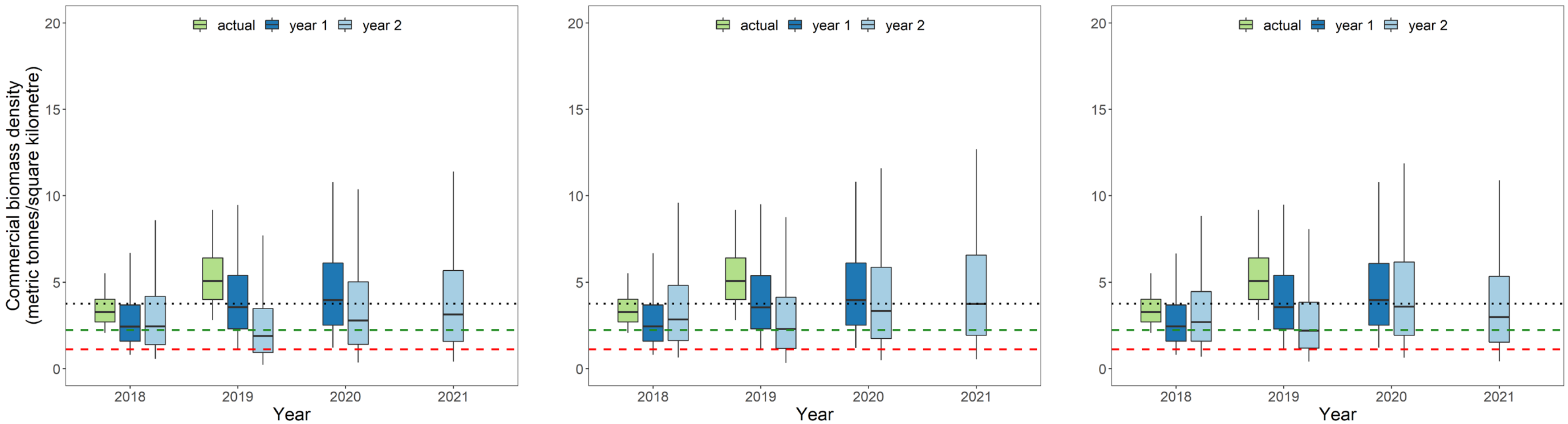

Figure 64. Evaluation of the model projection performance from 2018 to 2021 for SFA 29W Subarea B relative to the upper stock reference (USR; green dashed line) and limit reference point (LRP; red dashed line). Density at Maximum Sustainable Yield (D_{MSY}) is indicated by the horizontal dotted black line. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 and 2021 assume landings of 55 mt in each respective year is caught from the subarea. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

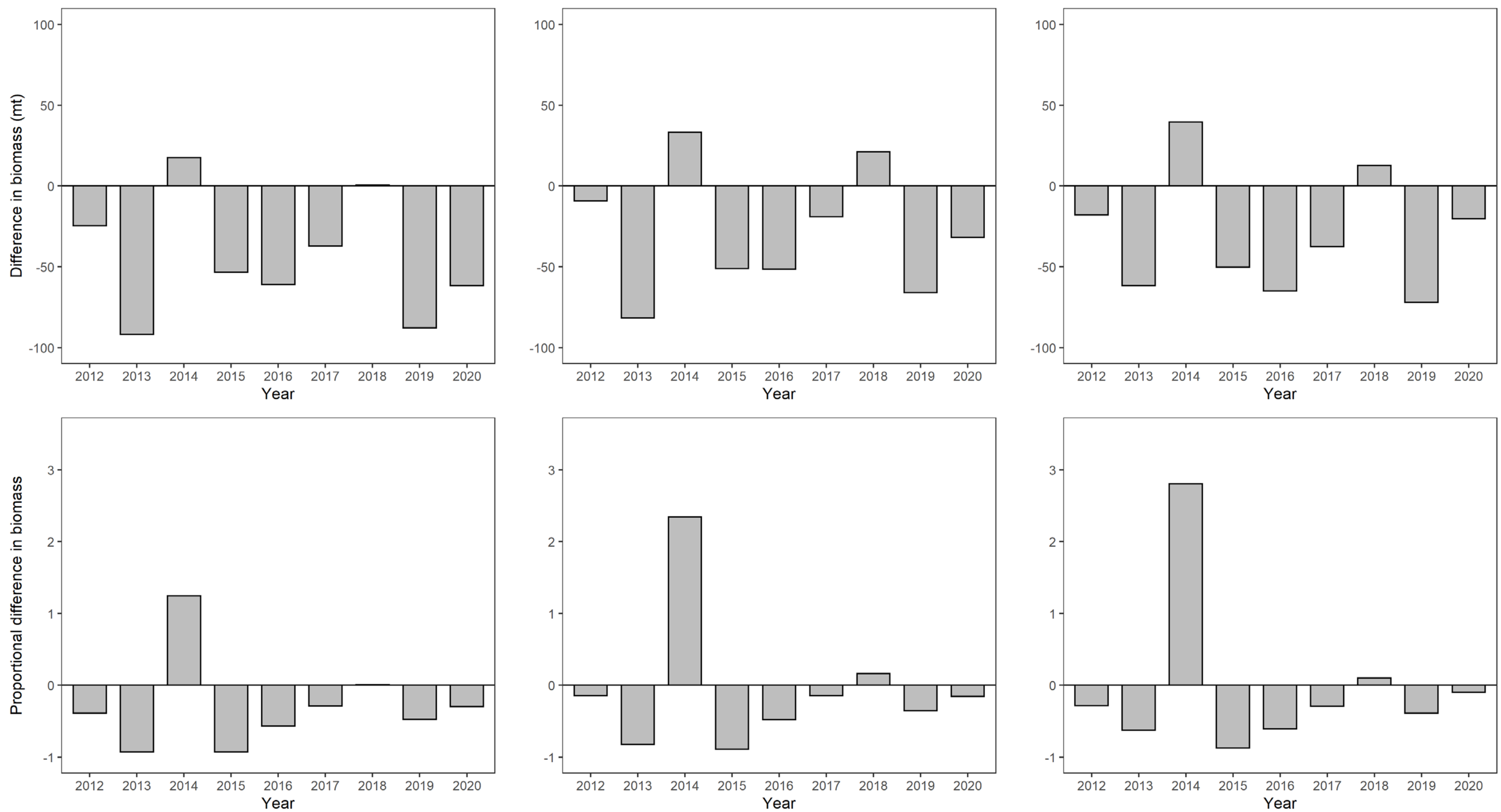

Figure 65. Difference in commercial biomass between two−year and one−year projections for each year t from 2012 to 2020 for SFA 29W Subarea B. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

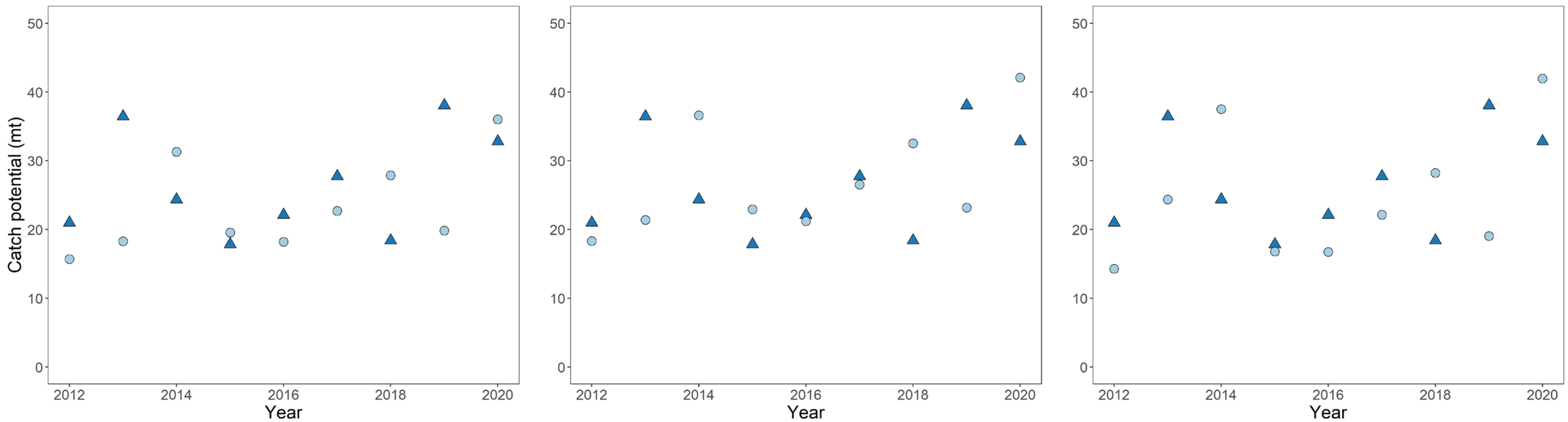

Figure 66. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.06 for SFA 29W Subarea B for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

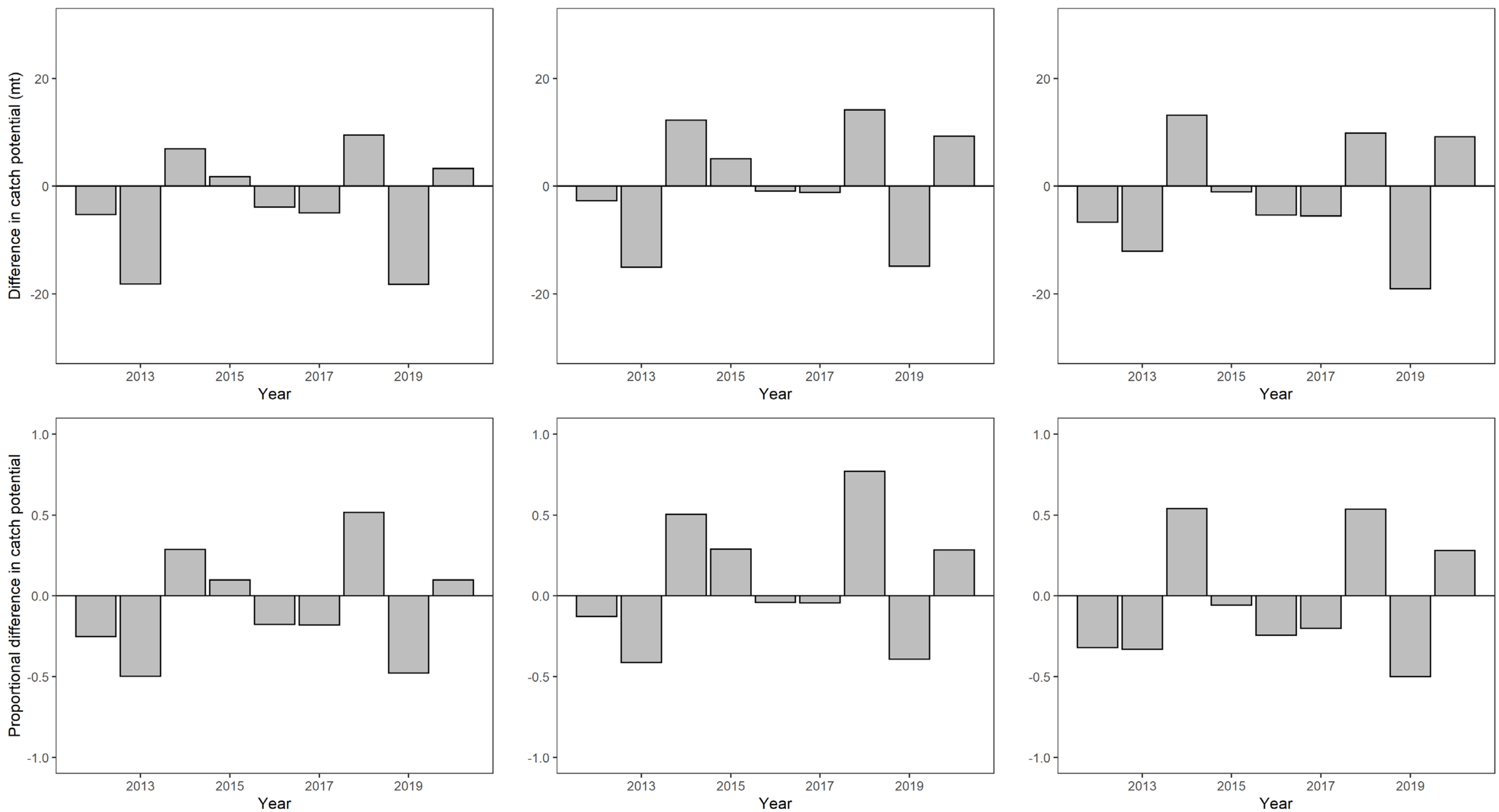

Figure 67. Difference in maximum catch between using a one−year projection for year t and a two−year projection for year t where exploitation is 0.06 for SFA 29W Subarea B. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

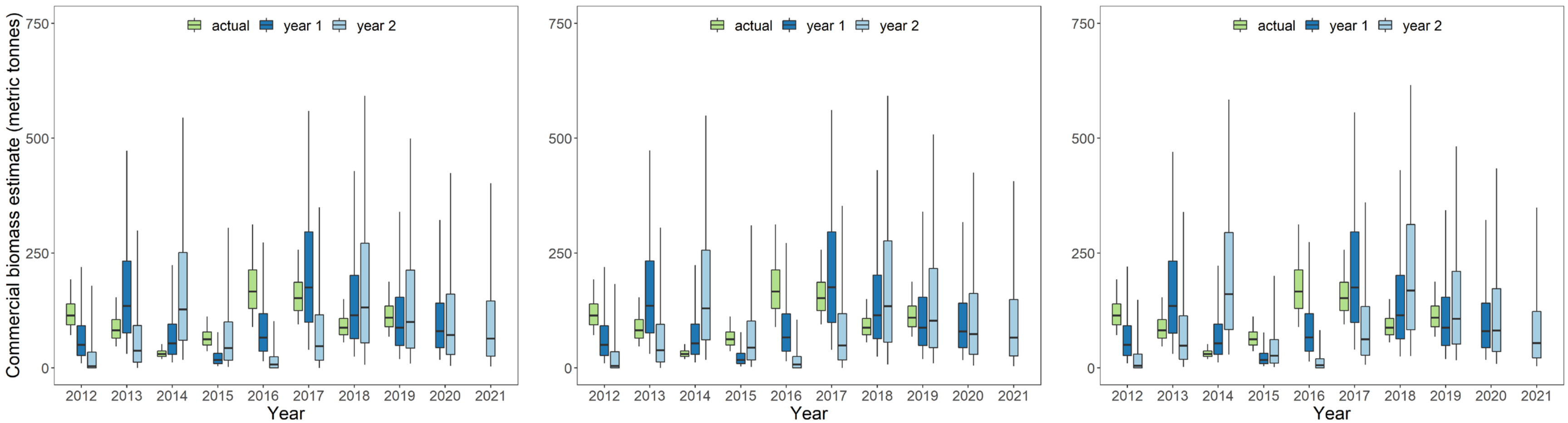

Figure 68. Evaluation of the model projection performance from 2012 to 2021 for SFA 29W Subarea C. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year t−1 (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 and 2021 assume landings of 20 mt in each respective year is caught from the subarea. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

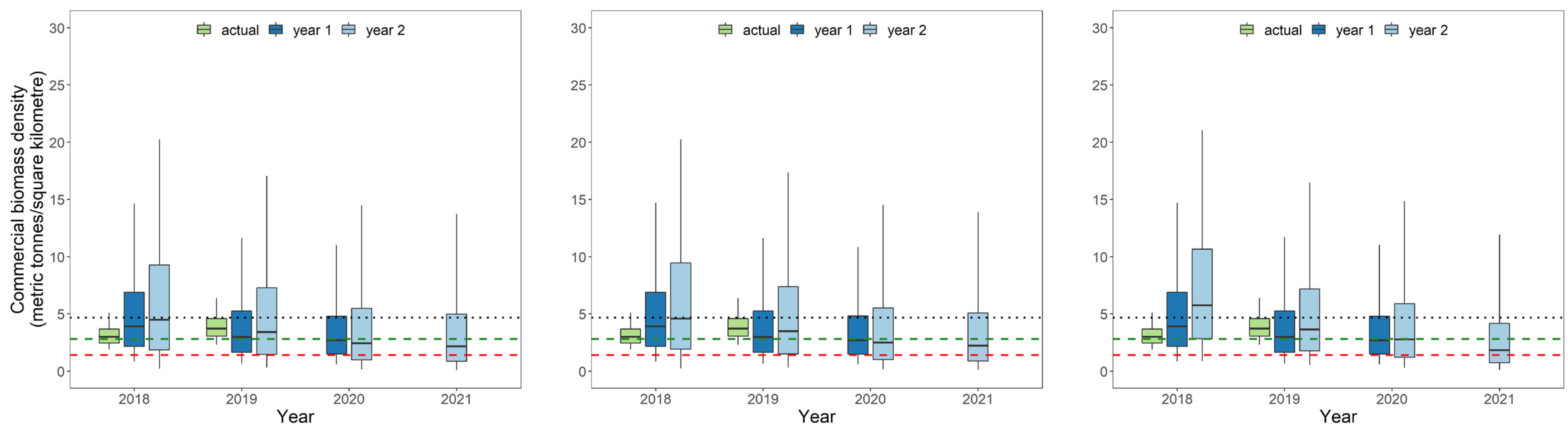

Figure 69. Evaluation of the model projection performance from 2018 to 2021 for SFA 29W Subarea C relative to the upper stock reference (USR; green dashed line) and limit reference point (LRP; red dashed line). Density at Maximum Sustainable Yield (D_{MSY}) is indicated by the horizontal dotted black line. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 and 2021 assume landings of 20 mt in each respective year is caught from the subarea. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

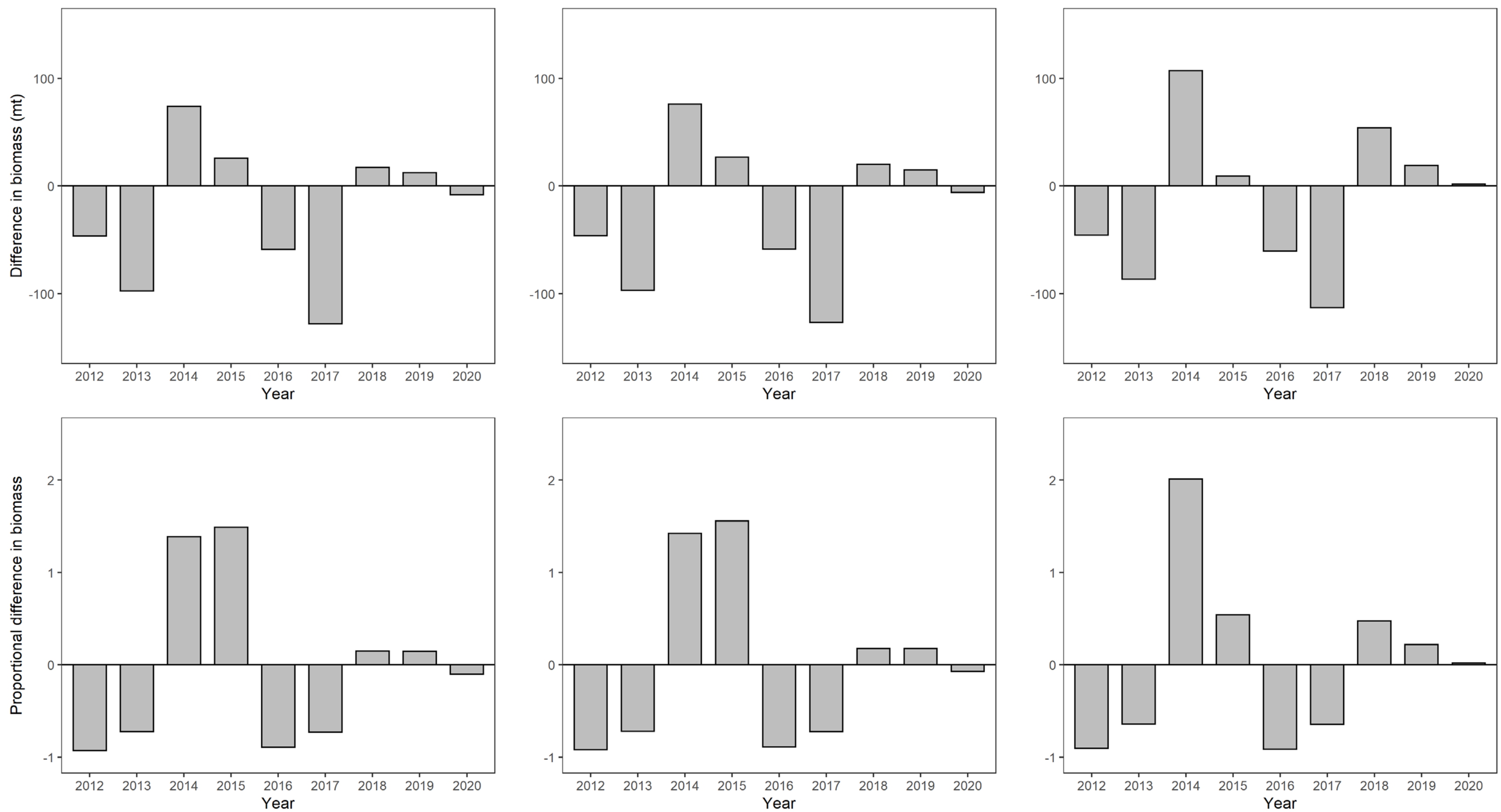

Figure 70. Difference in commercial biomass between two−year and one−year projections for each year t from 2012 to 2020 for SFA 29W Subarea C. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

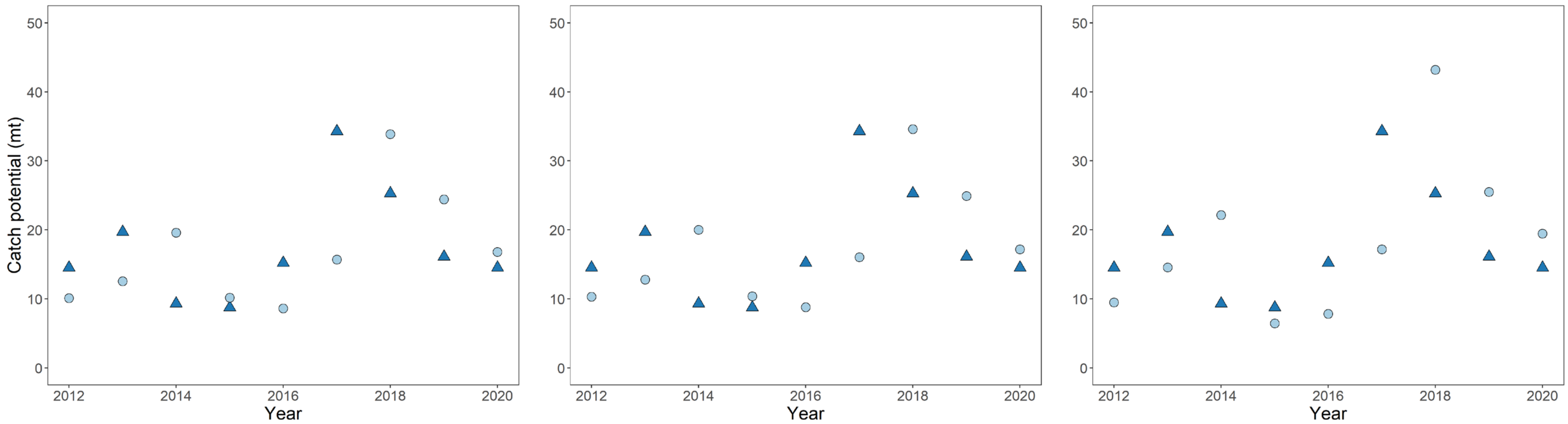

Figure 71. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.06 for SFA 29W Subarea C for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

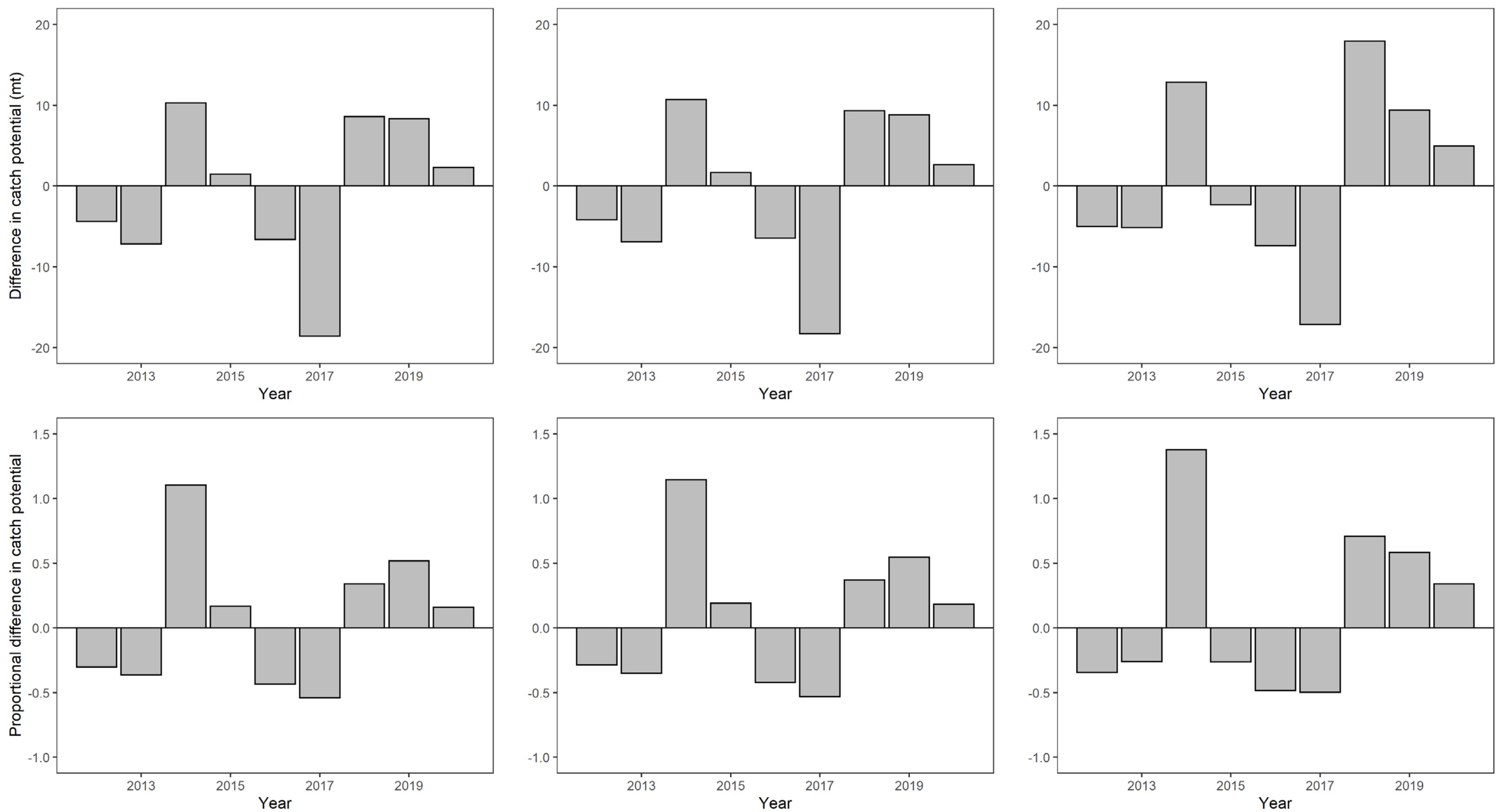

Figure 72. Difference in maximum catch between using a one−year projection for year t and a two−year projection for year t where exploitation is 0.06 for SFA 29W Subarea C. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

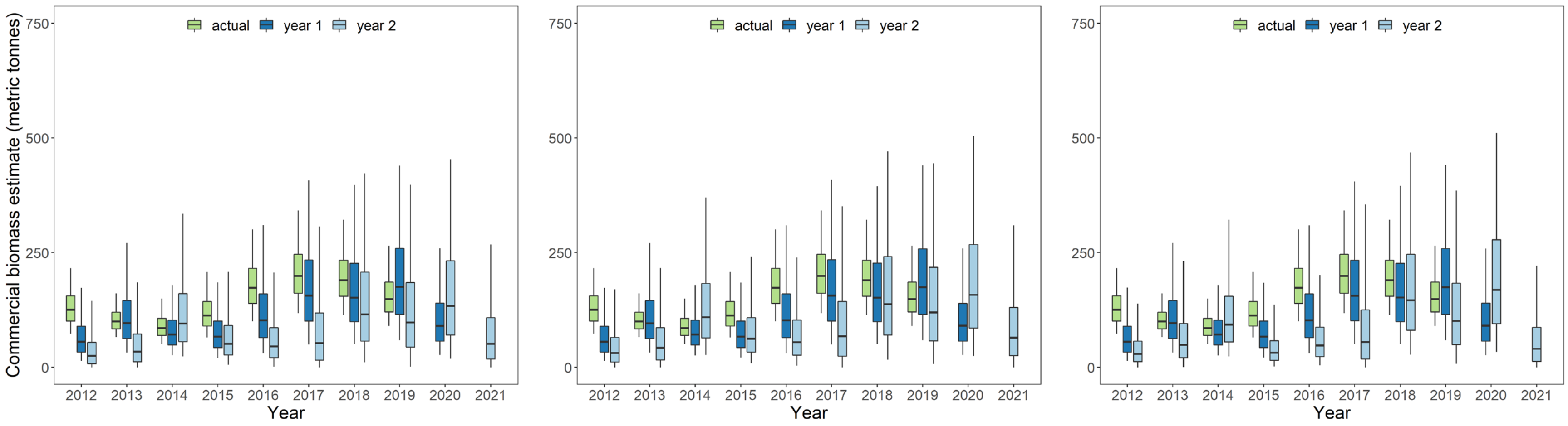

Figure 73. Evaluation of the model projection performance from 2012 to 2021 for SFA 29W Subarea D. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2012 predictions based on data up to and including 2012). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year t-1 (e.g., 2012 predictions based on data up to and including 2011). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2012 predictions based on data up to and including 2010). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 and 2021 assume landings of 65 mt in each respective year is caught from the subarea. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

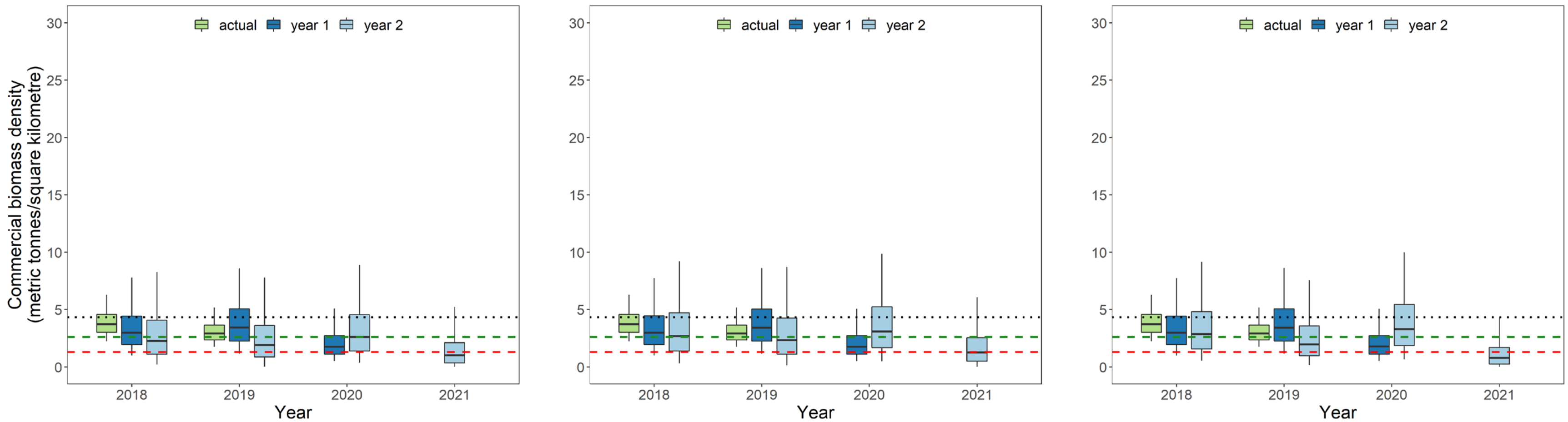

Figure 74. Evaluation of the model projection performance from 2018 to 2021 for SFA 29W Subarea D relative to the upper stock reference (USR; green dashed line) and limit reference point (LRP; red dashed line). Density at Maximum Sustainable Yield (D_{MSY}) is indicated by the horizontal dotted black line. Green box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t (e.g., 2018 predictions based on data up to and including 2018). Dark blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-1$ (e.g., 2018 predictions based on data up to and including 2017). Light blue box and whisker plots summarize posterior distributions of commercial biomass in year t based on model fit to year $t-2$ (e.g., 2018 predictions based on data up to and including 2016). Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projections for 2020 and 2021 assume landings of 65 mt in each respective year is caught from the subarea. Prediction evaluations presented for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and the status quo assumption (i.e., same conditions as the one−year projections in year $t-1$; right panel).

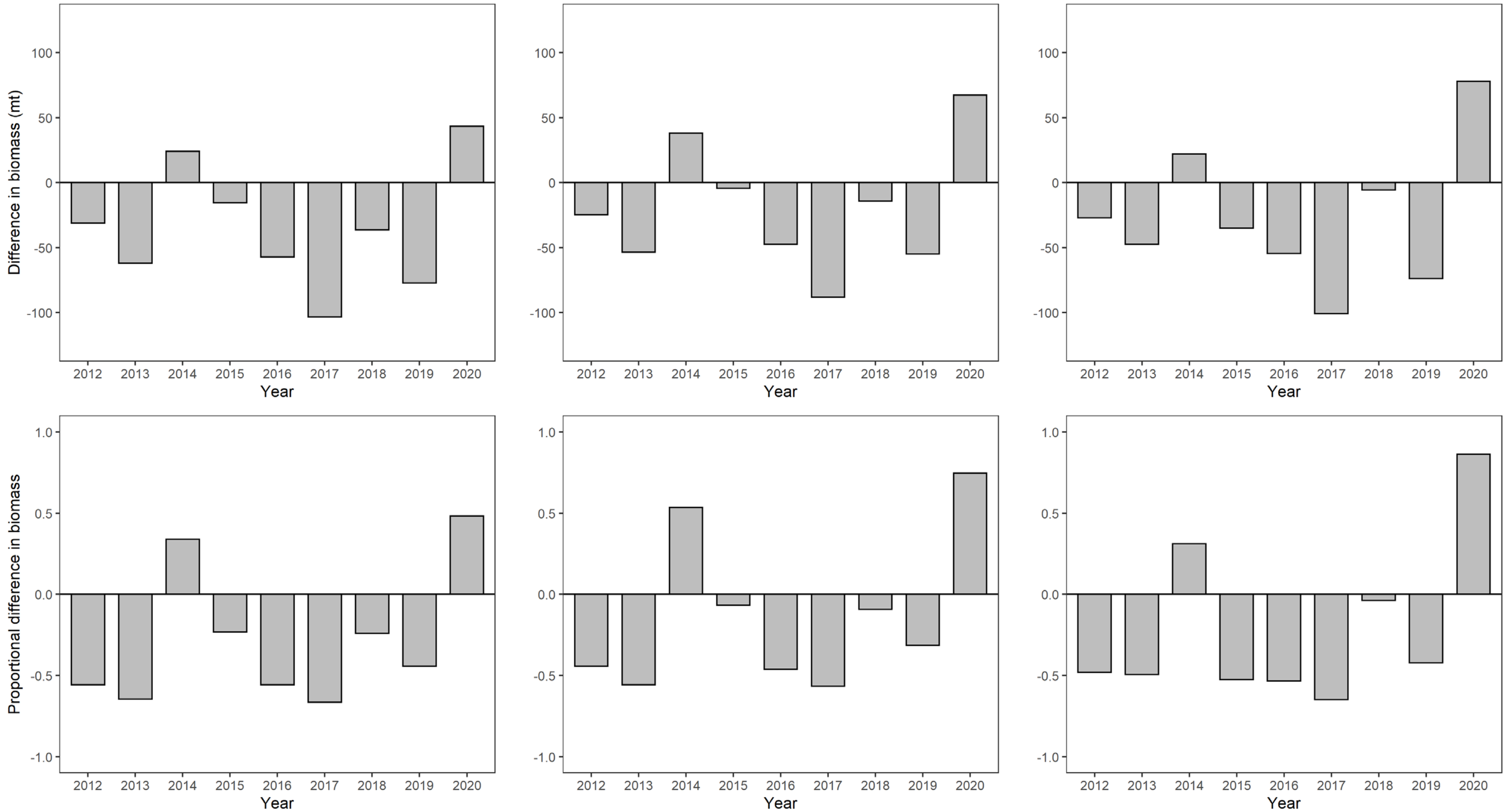

Figure 75. Difference in commercial biomass between two−year and one−year projections for each year (t) from 2012 to 2020 for SFA 29W Subarea D. Top panel in tonnes (mt) of meats and bottom panel as a proportion. Positive values indicate that the two−year projected commercial biomass for year t was higher than the one−year projected estimate of commercial biomass in year t. Negative values indicate that the two−year projected commercial biomass for year t was lower than the one−year projected commercial biomass in year t.

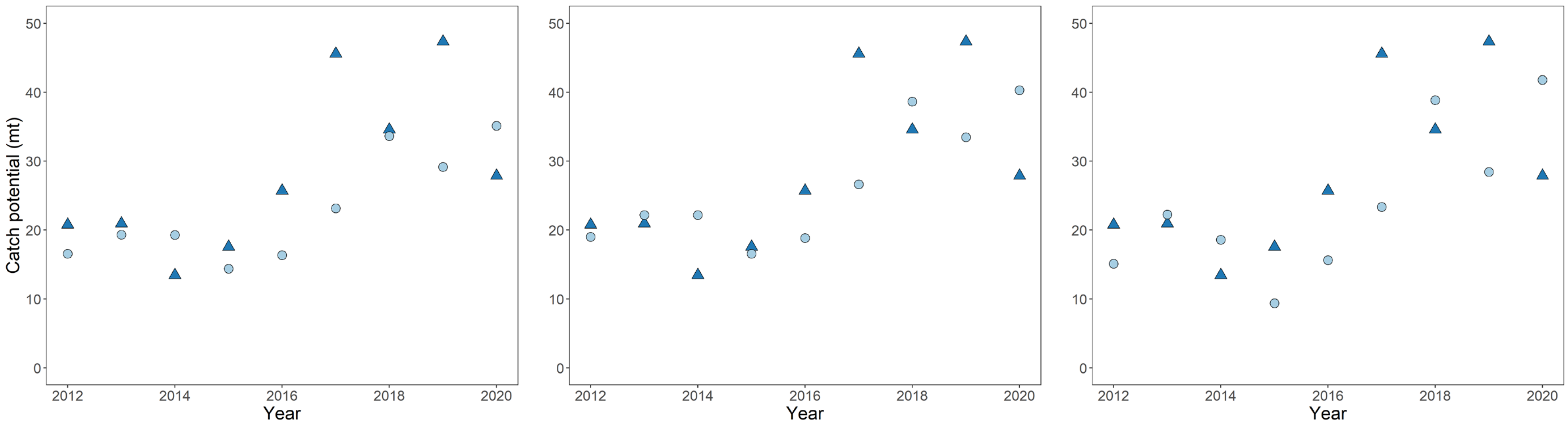

Figure 76. Maximum catch from one−year (dark blue triangles) and two−year projections (light blue circles) for year t where exploitation is 0.09 for SFA 29W Subarea D for three two−year projection scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).

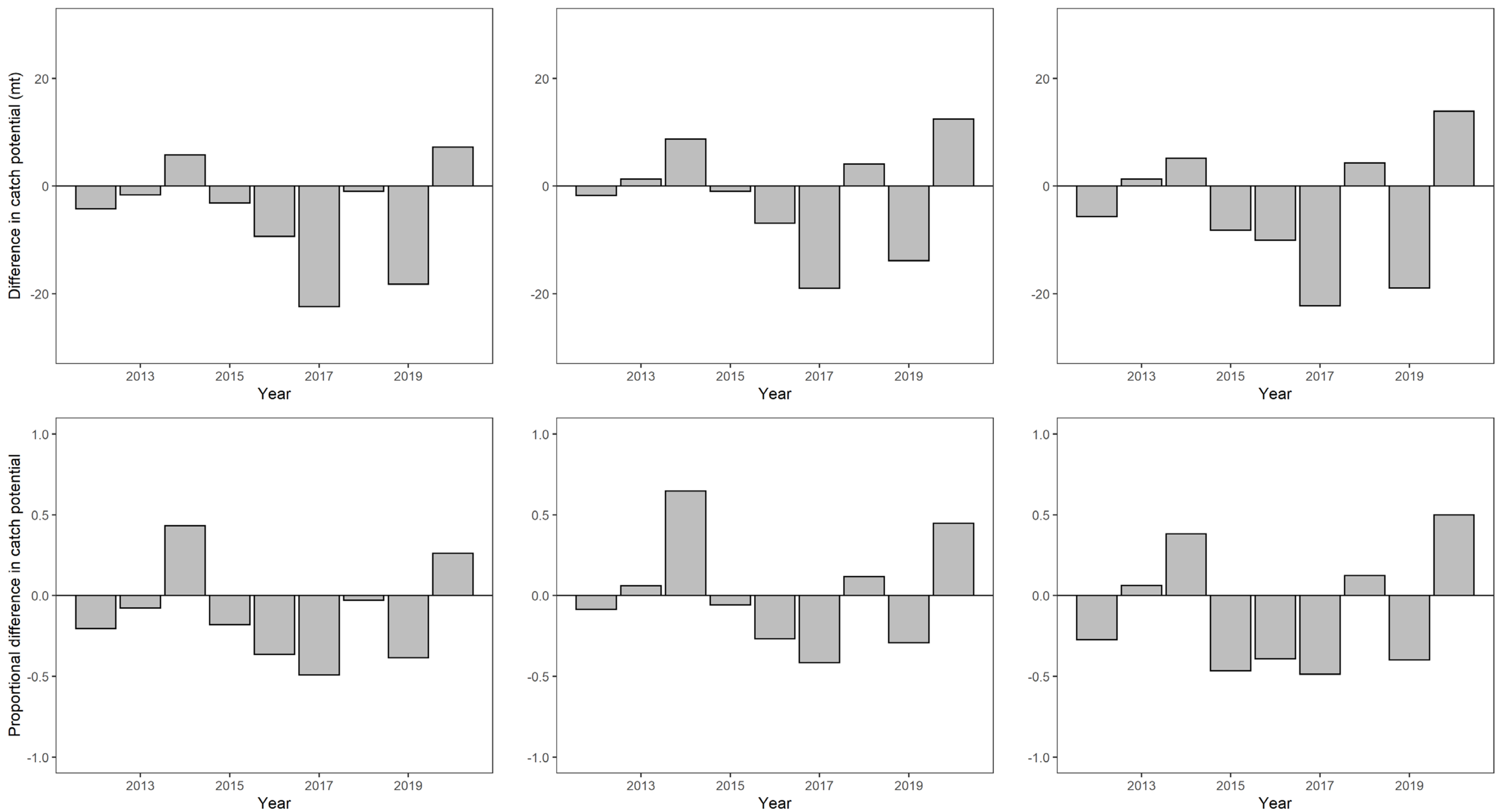

Figure 77. Difference in maximum allowable catch between using a one−year projection for year t and a 2−year projection for year t where exploitation is 0.09 for SFA 29W Subarea D. Top panels in tonnes (mt) and bottom panel as a proportion. Positive values indicate the associated catch limit is higher using the two−year projection than a one−year projection in year t. Negative values indicate the associated catch limit is lower using the two−year projection than a one−year projection in year t. Two−year projections conducted for three scenarios; zero surplus production (left panel), median surplus production (middle panel), and status quo (i.e., same conditions as the one−year projections in year $t-1$; right panel).