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Simulations to compare the performance of two length-based estimators of total mortality rate

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Introduction

Mean length-based methods to estimate instantaneous total mortality rates, *Z*, are important assessment tools for data-poor stocks. One commonly used method was developed by Beverton and Holt (1956). The behavior of this method, especially in relation to bias, has been fairly well characterized. Another method by Ehrhardt and Ault (1992) was proposed to 'correct' the Beverton-Holt (BH) method for applications to length frequency distributions that are truncated at the upper end. The Ehrhardt-Ault (EA) method has zero bias at equilibrium when there is no variability in length at age but the reliability of the method has not been demonstrated under conditions of reasonable magnitude of growth variability. It is also unclear how one would determine the best input value for the upper length truncation parameter. This report presents additional simulation results to supplement the results in Then et al. (2015). The estimators, evaluation criteria, simulation procedures, and conditions simulated are given in Then et al. (2015).

References

Beverton, R. J. H., and S. J. Holt. 1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapports et Procès-Verbaux des Réunions 140(1):67-83.

Ehrhardt, N. M., and J. S. Ault. 1992. Analysis of two length-based mortality models applied to bounded catch length frequencies. Transactions of the American Fisheries Society 121:115-122.

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List of parameters

Z	instantaneous total mortality rate (year^{-1})
K	von Bertalanffy growth coefficient (year^{-1})
L_∞	von Bertalanffy asymptotic length
σ	variability in length at age (constant across ages; expressed as a percentage of the von Bertalanffy asymptotic length L_∞)
CV	coefficient of variation (used in this context to generate variability in length at age; expressed as a percentage of mean length at age)
L_c	length at first capture
L_λ	upper length truncation parameter (corresponding to the upper age of truncation, t_λ, in the Ehrhardt-Ault estimator)
$\bar{L}_{BH}$	mean length computed based on lengths L > length at first capture L_c
$\bar{L}_{EA}$	mean length based on lengths, L, with length at first capture $L_c < L <$ imposed L_λ

Effect of the magnitude of total mortality rate, *Z*, von Bertalanffy growth coefficient, *K*, type of growth variability, input mean length, and varying imposed upper length truncation L_λ

The following section contains results for percent bias (% Bias) and percent root mean square error (% RMSE) of the estimates of *Z* from the Beverton-Holt and Ehrhardt-Ault estimators. Simulations were based on a factorial design with five levels of *Z* (year^{-1}) and four levels of the von Bertalanffy growth coefficient, *K* (year^{-1}). Two different methods were used to simulate variability in length at age: (1) constant variability in length at age across ages, σ (expressed as a percentage of the von Bertalanffy asymptotic length L_∞), and (2) constant coefficient of variation, CV (expressed as a percentage of mean length at age), across ages. Three levels of variability in length at age were examined: 0, 3 and 7%. The input mean length for the Ehrhardt-Ault estimator was calculated using two different methods: (1) $\bar{L}_{EA}$ - based on lengths, *L*, with length at first capture $L_c < L <$ imposed L_λ and (2) $\bar{L}_{BH}$ - based on lengths $L >$ length at first capture L_c. Simulated age distributions were generated with truncation and length samples were analyzed with six different values for imposed L_λ, corresponding to scenarios of over- truncation, actual truncation and under-truncation of length samples. Important simulation conditions are highlighted as headers for the following figures to facilitate ease of reading.

Simulation Conditions: variability, σ = 0; mean length for the EA estimator = $\bar{L}_{EA}$

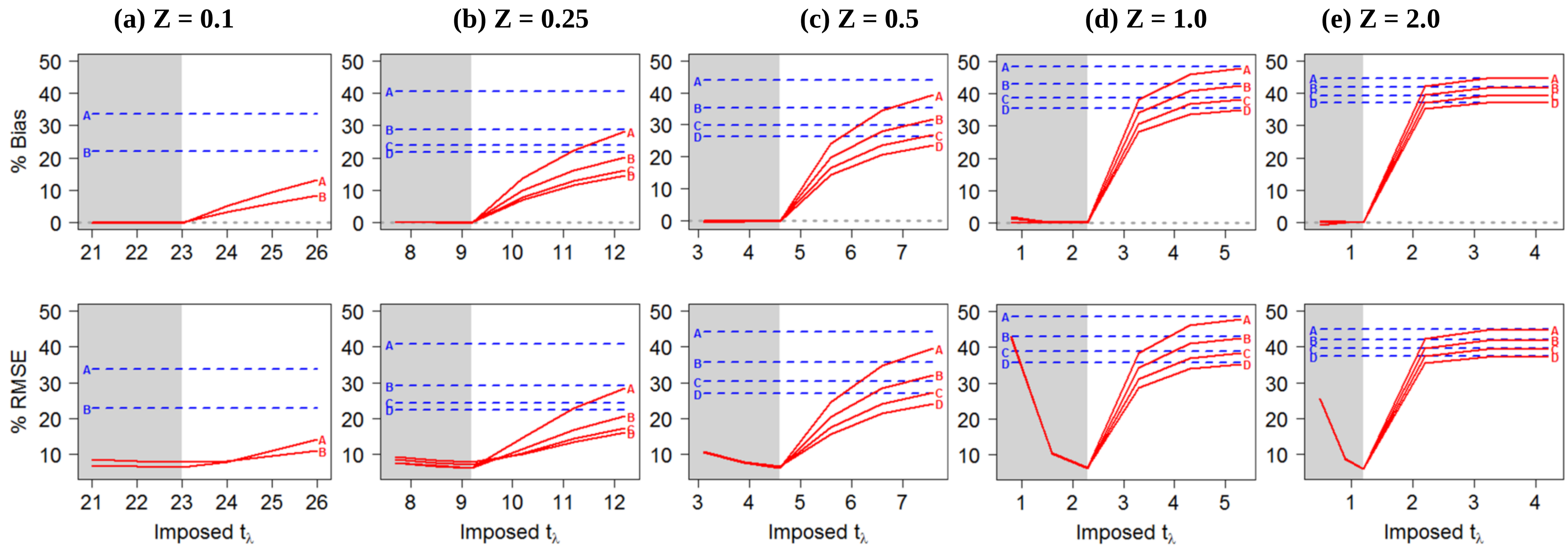

FIGURE 1. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (*Z*) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of *Z*. Length frequency data were generated with a constant variability in length at age, σ = 0%, and combinations of *Z* = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and von Bertalanffy growth coefficient *K* = 0.1, 0.4, 0.7 and 1 yr^{-1}. The mean length for the EA estimator, $\bar{L}_{EA}$, was computed on lengths *L*, with length at first capture $L_c < L <$ imposed L_λ.

Simulation Conditions: variability, σ = 0; mean length for the EA estimator = $\bar{L}_{BH}$

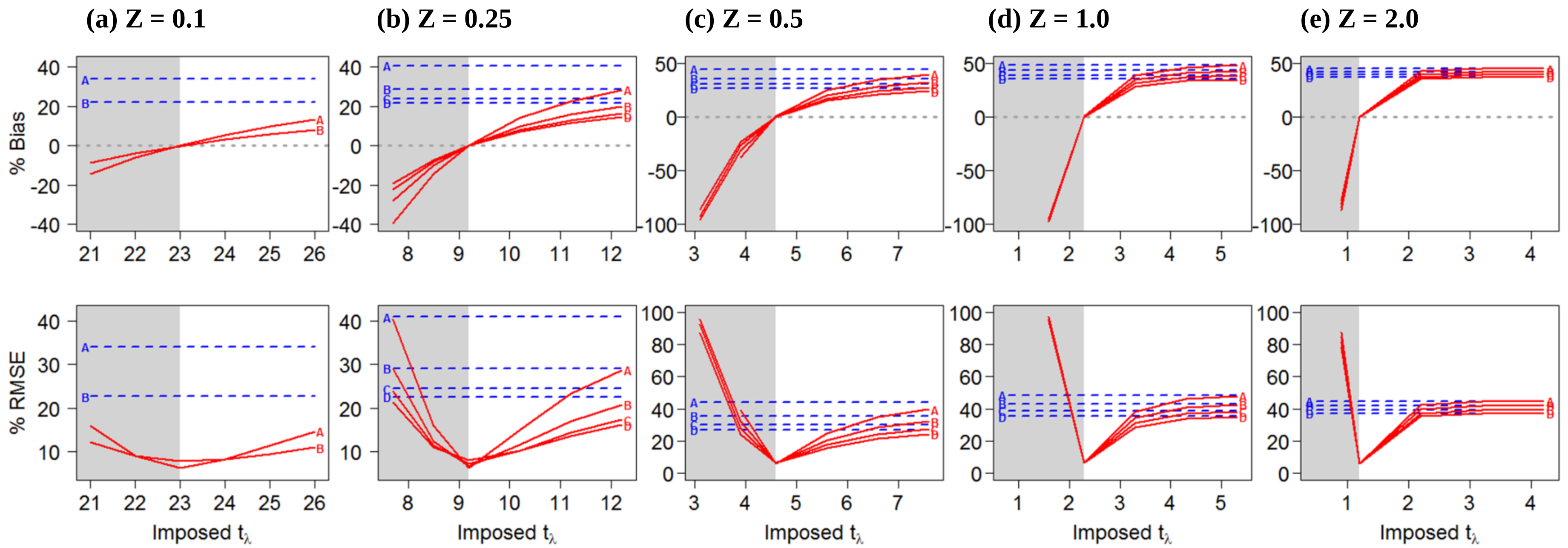

FIGURE 2. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (*Z*) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of *Z*. Length frequency data were generated with a constant variability in length at age, σ = 0%, and combinations of *Z* = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and von Bertalanffy growth coefficient *K* = 0.1, 0.4, 0.7 and 1 yr^{-1}. The mean length for the EA estimator, $\bar{L}_{BH}$, was computed on lengths *L* > length at first capture, L_c.

Simulation Conditions: variability, σ = 3%; mean length for the EA estimator = $\bar{L}_{EA}$

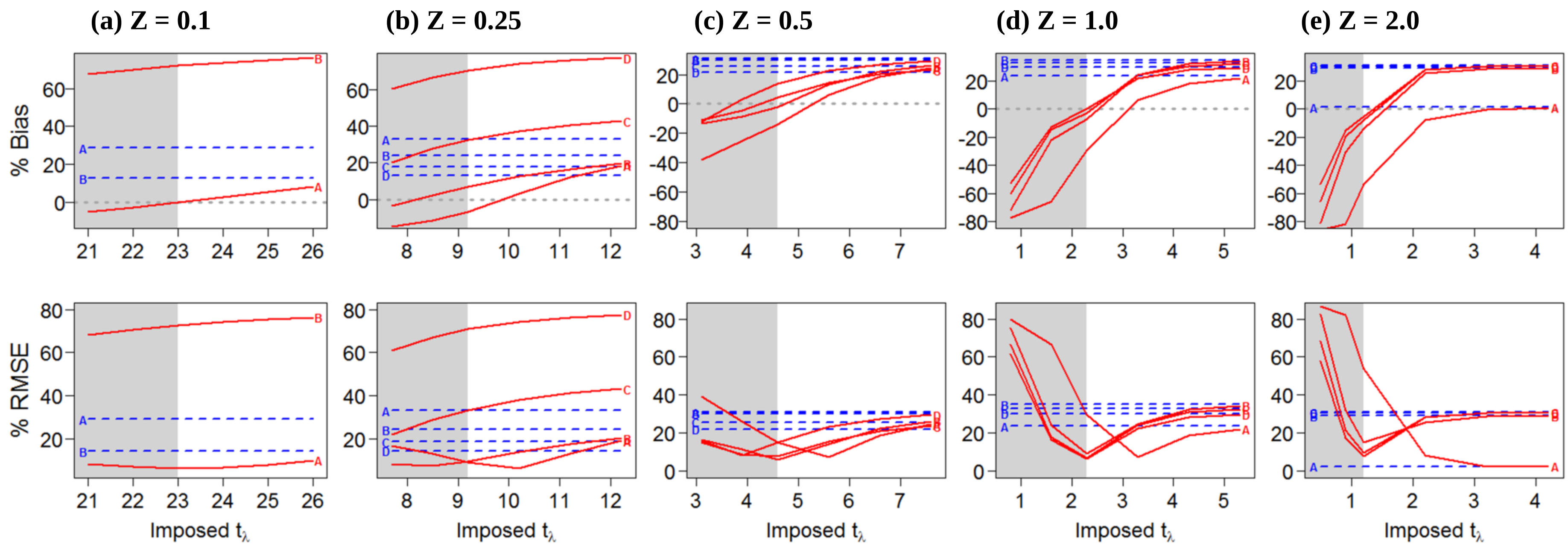

FIGURE 3. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (Z) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of Z. Length frequency data were generated with a constant variability in length at age, σ = 3%, and combinations of Z = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and von Bertalanffy growth coefficient K = 0.1, 0.4, 0.7 and 1 yr^{-1}. The mean length for the EA estimator, $\bar{L}_{EA}$, was computed on lengths L, with length at first capture $L_c < L <$ imposed L_λ.

Simulation Conditions: variability, σ = 3%; mean length for the EA estimator = $\overline{L}_{BH}$

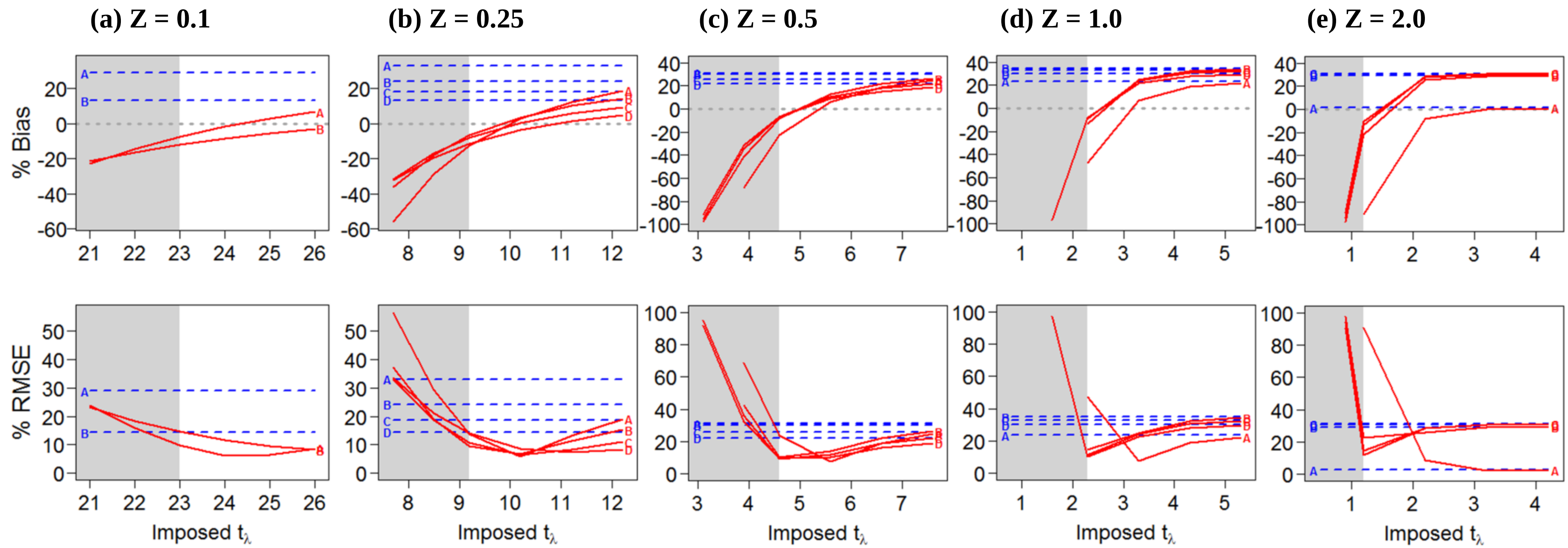

FIGURE 4. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (Z) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of Z. Length frequency data were generated with a constant variability in length at age, σ = 3%, and combinations of Z = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and von Bertalanffy growth coefficient K = 0.1, 0.4, 0.7 and 1 yr^{-1}. The mean length for the EA estimator, $\overline{L}_{BH}$, was computed on lengths L > length at first capture, L_c.

Simulation Conditions: variability, CV = 3%; mean length for the EA estimator = $\bar{L}_{EA}$

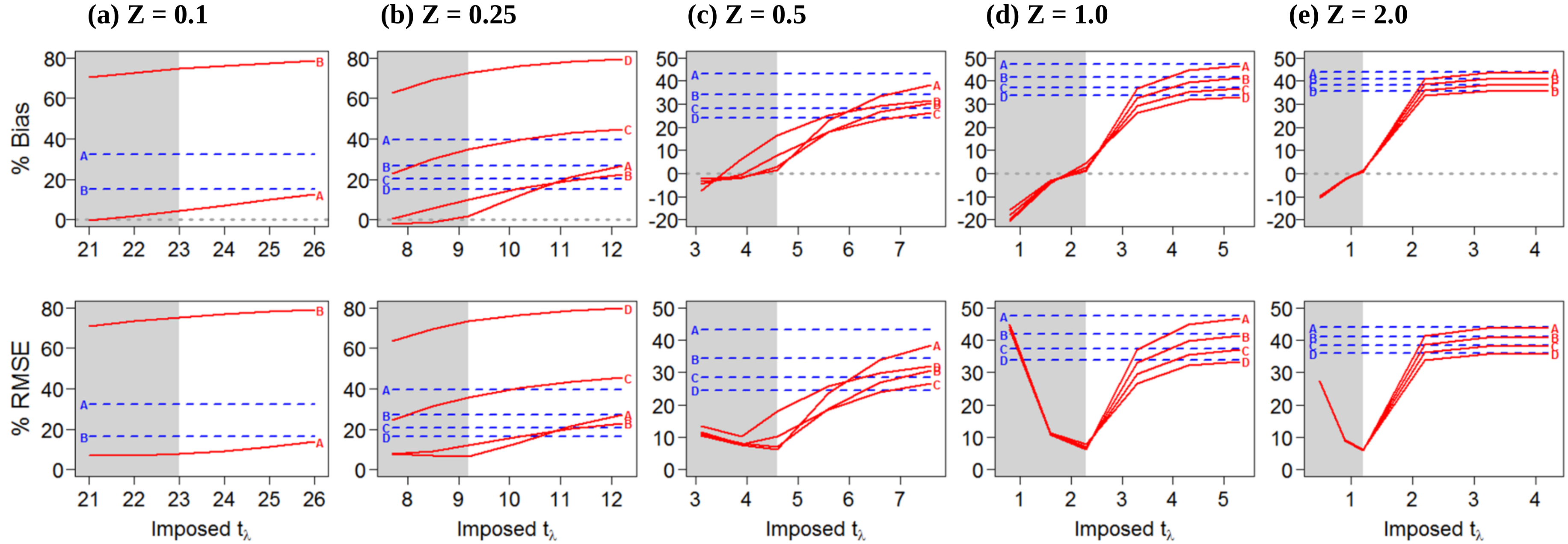

FIGURE 5. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (Z) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of Z. Length frequency data were generated with a constant coefficient of variation in length-at-age, CV = 3%, and combinations of Z = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and von Bertalanffy growth coefficient K = 0.1, 0.4, 0.7 and 1 yr^{-1}. The mean length for the EA estimator, $\bar{L}_{EA}$, was computed on lengths L, with length at first capture L_c < L < imposed L_λ.

Simulation Conditions: variability, CV = 3%; mean length for the EA estimator = $\bar{L}_{BH}$

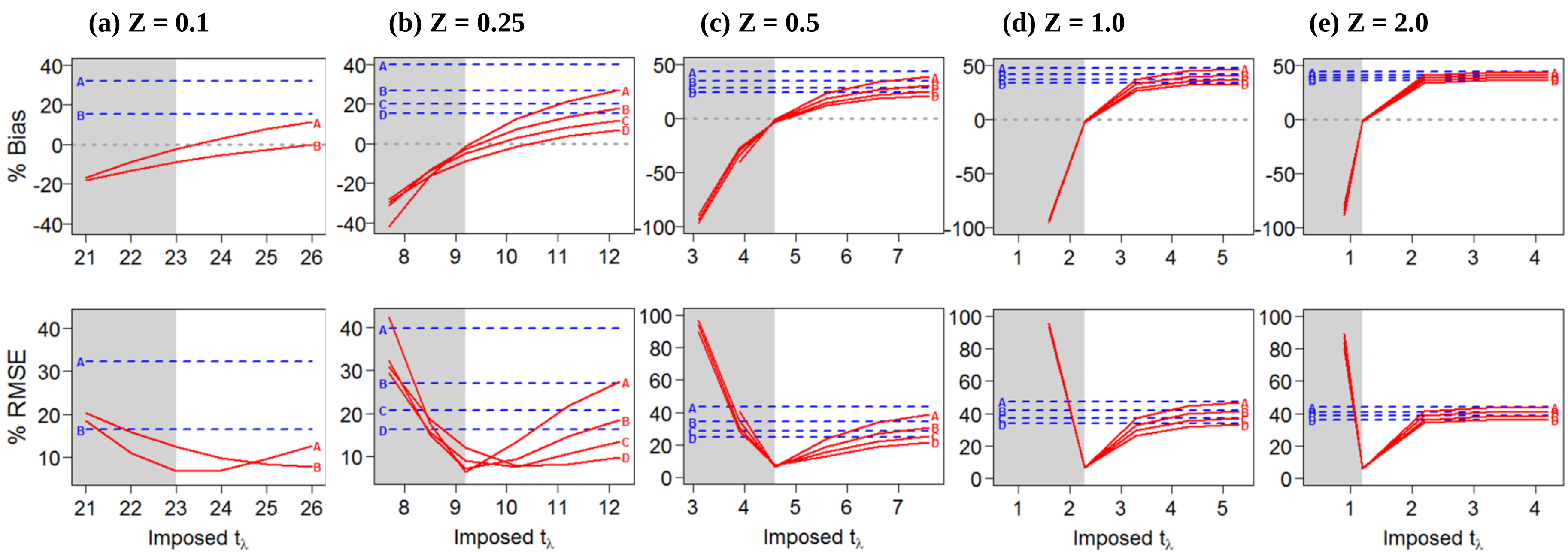

FIGURE 6. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (*Z*) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of *Z*. Length frequency data were generated with a constant coefficient of variation in length-at-age, CV = 3%, and combinations of *Z* = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and von Bertalanffy growth coefficient *K* = 0.1, 0.4, 0.7 and 1 yr^{-1}. The mean length for the EA estimator, $\bar{L}_{BH}$, was computed on lengths *L* > length at first capture, L_c.

Simulation Conditions: variability, CV = 7%; mean length for the EA estimator = $\bar{L}_{BH}$

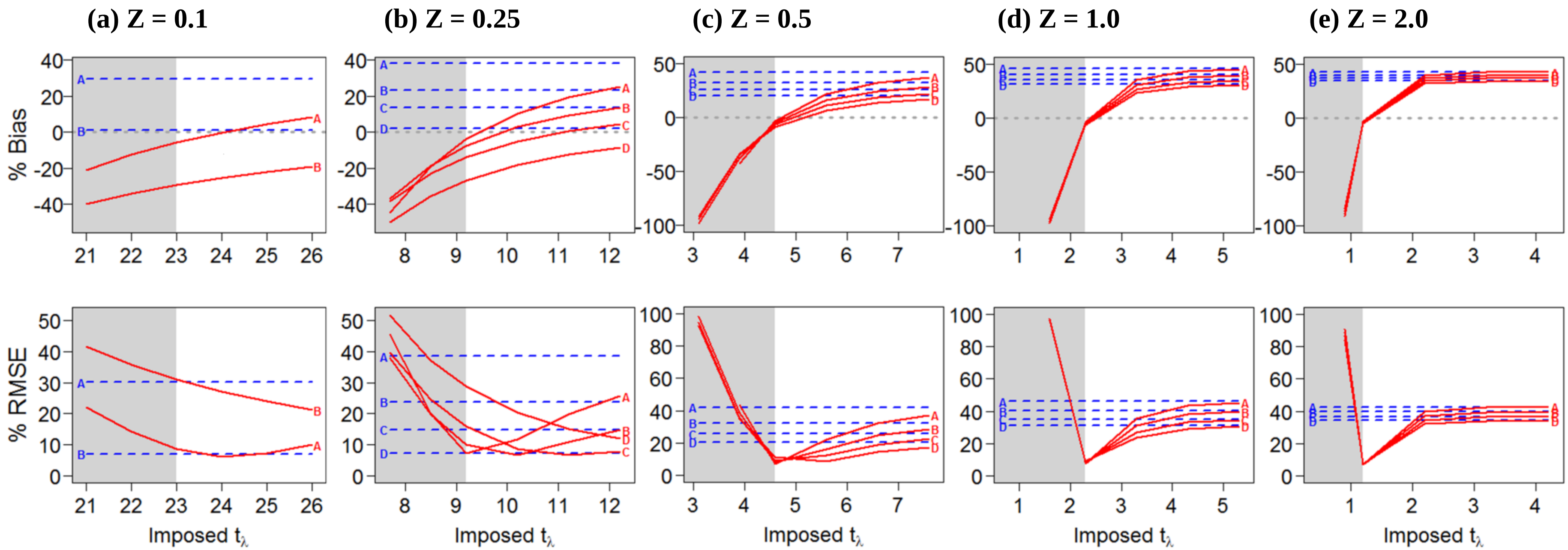

FIGURE 7. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (Z) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of Z. Length frequency data were generated with a constant coefficient of variation in length-at-age, CV = 7%, and combinations of Z = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and von Bertalanffy growth coefficient K = 0.1, 0.4, 0.7 and 1 yr^{-1}. The mean length for the EA estimator, $\bar{L}_{BH}$, was computed on lengths L > length at first capture, L_c.

Effect of the type and magnitude of variability in length at age, input mean length, and varying imposed upper length truncation L_λ

The following section contains results for percent bias (% Bias) and percent root mean square error (% RMSE) of the estimates of Z from the Beverton-Holt and Ehrhardt-Ault estimators. Simulations were based on a factorial design with five levels of Z (year^{-1}) and four levels of variability in length at age (fixed von Bertalanffy growth coefficient, K (year^{-1})). Two different methods were used to simulate variability in length at age: (1) constant variability in length at age across ages, σ (expressed as a percentage of the von Bertalanffy asymptotic length L_∞), and (2) constant coefficient of variation, CV (expressed as a percentage of mean length at age), across ages. The four levels of variability in length at age were: 0, 3, 6, and 9%. The mean length for the Ehrhardt-Ault estimator was calculated using two different methods: (1) $\overline{L}_{EA}$ - based on lengths, L, with length at first capture $L_c < L <$ imposed L_λ and (2) $\overline{L}_{BH}$ - based on lengths $L >$ length at first capture L_c. Simulated age distributions were generated with truncation and length samples were analyzed with six different values for imposed L_λ, corresponding to scenarios of over- truncation, actual truncation and under-truncation of lengths. Important simulation conditions are highlighted as headers for the following figures to facilitate ease of reading.

Simulation Condition: variability type = σ, mean length for the EA estimator = $\overline{L}_{BH}$

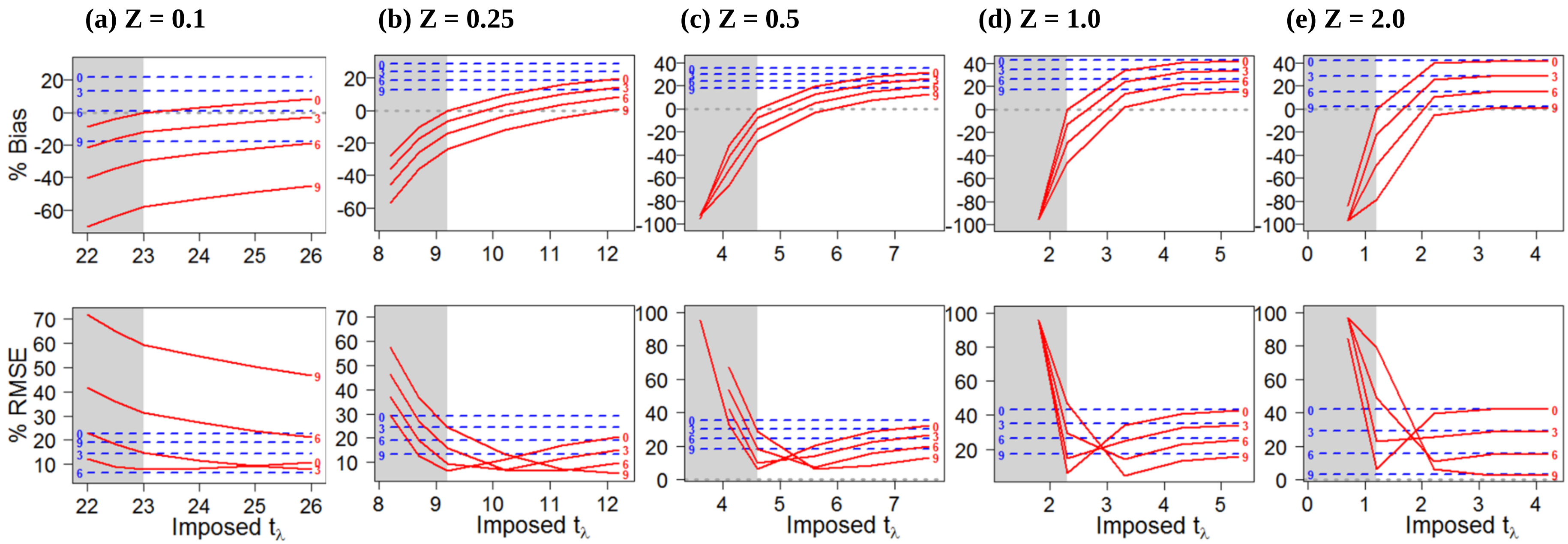

FIGURE 8. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (Z) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of Z. Length frequency data were generated with combinations of Z = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and variability in length at age, σ = 0, 3, 6, and 9 %. The von Bertalanffy growth coefficient K was fixed at 0.4 yr^{-1}. The mean length for the EA estimator, $\overline{L}_{BH}$, was computed on lengths L > length at first capture, L_c.

Simulation Condition: variability type = CV, mean length for the EA estimator = $\bar{L}_{EA}$

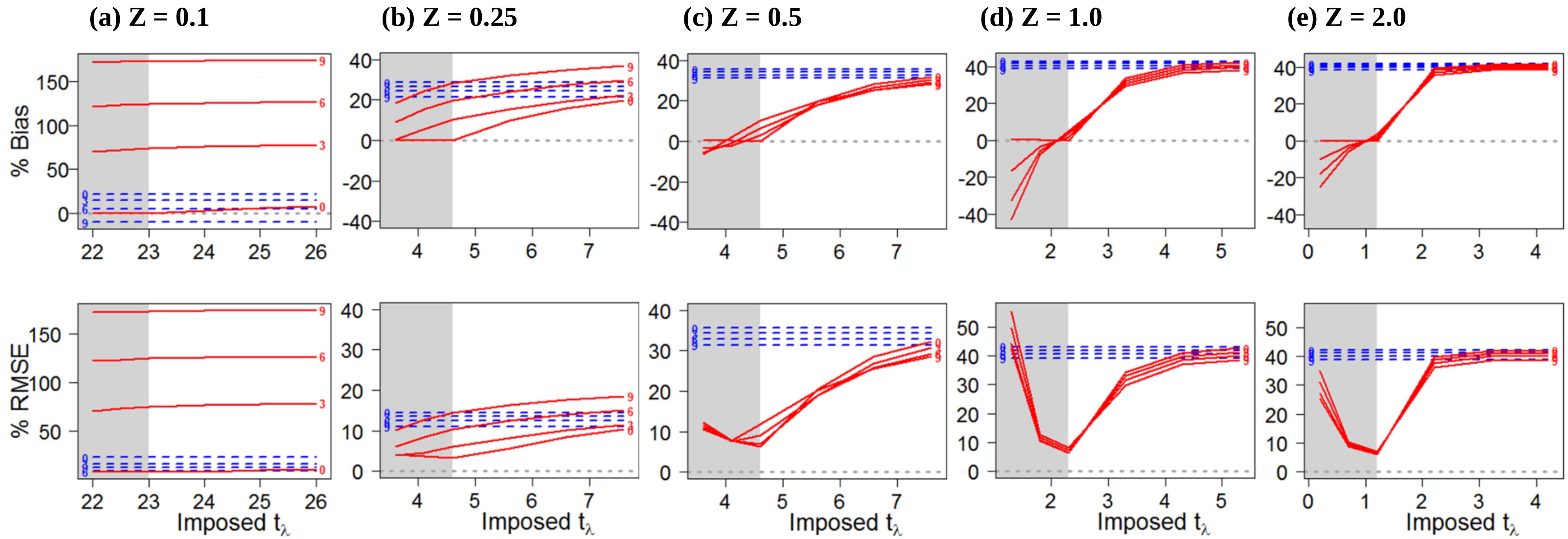

FIGURE 9. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (Z) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of Z. Length frequency data were generated with combinations of Z = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and variability in length at age, CV = 0, 3, 6, and 9 %. The von Bertalanffy growth coefficient K was fixed at 0.4 yr^{-1}. The mean length for the EA estimator, $\bar{L}_{EA}$, was computed on lengths L, with length at first capture $L_c < L <$ imposed L_λ.

Simulation Condition: variability type = CV, mean length for the EA estimator = $\bar{L}_{BH}$

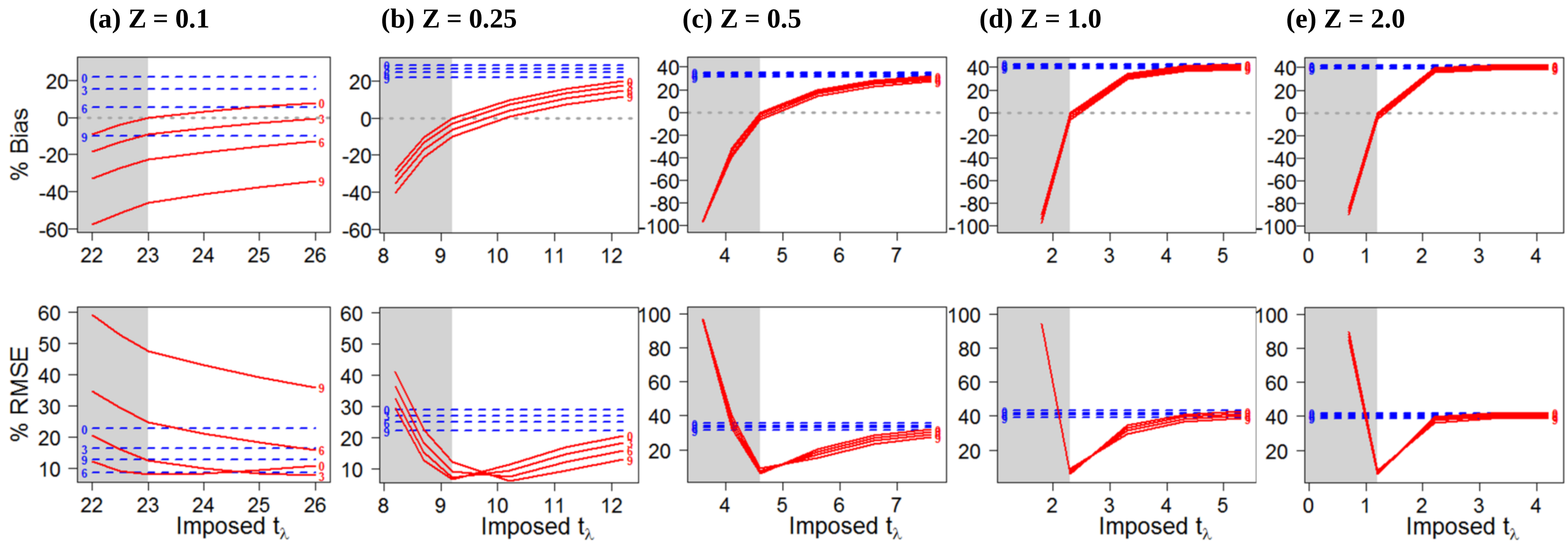

FIGURE 10. Percent bias (% Bias) and percent root mean square error (% RMSE) of the total mortality rate (*Z*) estimates of the Beverton Holt (BH, dashed blue lines) and Ehrhardt-Ault (EA, solid red lines) estimators versus the degree of truncation imposed by the data analyst. The x-axis is shown in age scale (t_λ) for clarity but the corresponding length L_λ is imposed on the length samples when applying the EA estimator. Shaded region denotes over- truncation (imposed L_λ < actual L_λ), unshaded region denotes under-truncation and the boundary denotes actual age of upper truncation t_λ in each simulation, which is a function of *Z*. Length frequency data were generated with combinations of *Z* = (a) 0.1, (b) 0.25 (c) 0.5, (d) 1.0, and (e) 2.0 yr^{-1} and variability in length at age, CV = 0, 3, 6, and 9 %. The von Bertalanffy growth coefficient *K* was fixed at 0.4 yr^{-1}. The mean length for the EA estimator, $\bar{L}_{BH}$, was computed on lengths *L* > length at first capture, L_c.