**Validation of a feedback harvest control rule in data-limited conditions for managing multispecies fisheries**

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**Supplementary materials**

*Supplementary tables S1-S5*

Table S1a. Alternative set I of parameter values for the three species in the multispecies fishery under assumption of surplus production model (Schaefer model) without process error.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  Parameter | Definition | Species 1 | Species 2 | Species 3 |
| *r*  | Intrinsic growth rate | 0.5 | 0.5 | 0.5 |
| *K* | Carrying capacity | 50 000 | 20 000 | 10 000 |
| MSY | Maximum sustainable yield | 2 500 | 2 500 | 2 500 |
| *B*MSY | Biomass produced at the MSY level | 25 000 | 10 000 | 5 000 |

Table S1b. Alternative set II of parameter values for the three species in the multispecies fishery under assumption of surplus production model (Schaefer model) without process error.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Definition | Species 1 | Species 2 | Species 3 |
| *r*  | Intrinsic growth rate | 0.2 | 0.5 | 1.0 |
| *K* | Carrying capacity | 20 000 | 20 000 | 20 000 |
| MSY | Maximum sustainable yield | 2 500 | 2 500 | 2 500 |
| *B*MSY | Biomass produced at the MSY level | 25 000 | 10 000 | 5 000 |

Table S2. Summary of the performance measures (probability of overfishing [POF], yield status [C/MSY ], biomass status [B/BMSY], management failure [failure], and coefficient of variation [CV]) when applying an alternative harvest control rule (denoted by the abbreviation 0.5-1.0-1.0-0.8) to three species (slow-growing [Sp. 1], medium-growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data or single-species data, and under three critical biomass-trend scenarios: BH – BL, BM – BM, and BL – BH.

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Performance measures | Mixed-species results | Single-species results |
| Sp. 1 | CV | Sp. 2 | CV | Sp. 3 | CV | Total | CV | Sp. 1 | CV | Sp. 2 | CV | Sp. 3 | CV | Total | CV |
| BH – BL | *P*OF | 0.81 | – | 0.06 | – | 0.00 | – | – | – | 0.39 | – | 0.16 | – | 0.01 | – | – | – |
| *C/*MSY | 0.25 | 0.58 | 0.66 | 0.26 | 0.45 | 0.29 | 0.46 | – | 0.10 | 0.10 | 0.50 | 0.15 | 0.51 | 0.19 | 0.42 | – |
| *B/B*MSY | 0.28 | 0.56 | 1.41 | 0.34 | 1.66 | 0.24 | 0.73 | – | 0.29 | 0.26 | 1.17 | 0.30 | 1.62 | 0.26 | 0.68 | – |
| Failure | 0.01 | – | 0.00 | – | 0.01 | – | 0.02 | – | 0.60 | – | 0.19 | – | 0.01 | – | 0.68 | – |
| BM – BM | *P*OF | 0.36 | – | 0.00 | – | 0.00 | – | – | – | 0.36 | – | 0.02 | – | 0.00 | – | – | – |
| *C/*MSY | 0.54 | 0.37 | 0.52 | 0.28 | 0.31 | 0.31 | 0.46 | – | 0.37 | 0.18 | 0.53 | 0.21 | 0.34 | 0.20 | 0.44 | – |
| *B/B*MSY | 0.87 | 0.46 | 1.60 | 0.28 | 1.76 | 0.23 | 1.16 | – | 0.76 | 0.40 | 1.58 | 0.29 | 1.73 | 0.23 | 1.09 | – |
| Failure | 0.00 | – | 0.00 | – | 0.01 | – | 0.01 | – | 0.22 | – | 0.01 | – | 0.01 | – | 0.23 | – |
| BL – BH | *P*OF | 0.00 | – | 0.00 | – | 0.00 | – | – | – | 0.00 | – | 0.00 | – | 0.00 | – | – | – |
| *C/*MSY | 0.23 | 0.24 | 0.12 | 0.26 | 0.06 | 0.28 | 0.14 | – | 0.19 | 0.15 | 0.12 | 0.21 | 0.06 | 0.20 | 0.13 | – |
| *B/B*MSY | 1.61 | 0.35 | 1.83 | 0.23 | 1.87 | 0.21 | 1.70 | – | 1.59 | 0.34 | 1.83 | 0.23 | 1.89 | 0.21 | 1.69 | – |
| Failure | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – |

Table S3. Summary of the performance measures (probability of overfishing [POF], yield status [C/MSY ], biomass status [B/BMSY], management failure [failure], and coefficient of variation [CV]) when applying an alternative harvest control rule (denoted by the abbreviation 1.5-1.0-1.0-0.8) to three species (slow-growing [Sp. 1], medium-growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data or single-species data, and under three critical biomass-trend scenarios: BH – BL, BM – BM, and BL – BH.

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Performance measures | Mixed-species results | Single-species results |
| Sp. 1 | CV | Sp. 2 | CV | Sp. 3 | CV | Total | CV | Sp. 1 | CV | Sp. 2 | CV | Sp. 3 | CV | Total | CV |
| BH – BL | *P*OF | 0.83 | – | 0.04 | – | 0.00 | – | – | – | 0.52 | – | 0.11 | – | 0.01 | – | – | – |
| *C/*MSY | 0.25 | 0.58 | 0.68 | 0.30 | 0.46 | 0.29 | 0.46 | – | 0.19 | 0.64 | 0.61 | 0.38 | 0.48 | 0.35 | 0.43 | – |
| *B/B*MSY | 0.28 | 0.53 | 1.41 | 0.34 | 1.66 | 0.25 | 0.73 | – | 0.44 | 0.68 | 1.48 | 0.38 | 1.64 | 0.26 | 0.85 | – |
| Failure | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.05 | – | 0.01 | – | 0.01 | – | 0.07 | – |
| BM – BM | *P*OF | 0.36 | – | 0.00 | – | 0.00 | – | – | – | 0.30 | – | 0.01 | – | 0.00 | – | – | – |
| *C/*MSY | 0.58 | 0.41 | 0.53 | 0.30 | 0.31 | 0.30 | 0.47 | – | 0.48 | 0.46 | 0.52 | 0.35 | 0.32 | 0.33 | 0.44 | – |
| *B/B*MSY | 0.84 | 0.44 | 1.59 | 0.28 | 1.77 | 0.23 | 1.14 | – | 0.97 | 0.51 | 1.61 | 0.29 | 1.76 | 0.23 | 1.23 | – |
| Failure | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – |
| BL – BH | *P*OF | 0.00 | – | 0.00 | – | 0.00 | – | – | – | 0.00 | – | 0.00 | – | 0.00 | – | – | – |
| *C/*MSY | 0.24 | 0.30 | 0.13 | 0.26 | 0.07 | 0.27 | 0.14 | – | 0.20 | 0.32 | 0.11 | 0.35 | 0.06 | 0.33 | 0.13 | – |
| *B/B*MSY | 1.60 | 0.35 | 1.83 | 0.23 | 1.90 | 0.21 | 1.69 | – | 1.64 | 0.36 | 1.85 | 0.23 | 1.86 | 0.21 | 1.72 | – |
| Failure | 0.00 | – | 0.00 | – | 0.01 | – | 0.01 | – | 0.00 | – | 0.00 | – | 0.01 | – | 0.01 | – |

Table S4. Summary of performance measures (probability of overfishing [POF], yield status [C/MSY ], biomass status [B/BMSY], management failure [failure], and coefficient of variation [CV]) when applying an alternative harvest control rule (denoted by the abbreviation 2.0-1.0-1.0-0.8) to three species (slow-growing [Sp. 1], medium-growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data or single-species data, and under three critical biomass-trend scenarios: BH – BL, BM – BM, and BL – BH.

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Performance measures | Mixed-species results | Single-species results |
| Sp. 1 | CV | Sp. 2 | CV | Sp. 3 | CV | Total | CV | Sp. 1 | CV | Sp. 2 | CV | Sp. 3 | CV | Total | CV |
| BH – BL | *P*OF | 0.83 | – | 0.04 | – | 0.00 | – | – | – | 0.36 | – | 0.09 | – | 0.01 | – | – | – |
| *C/*MSY | 0.24 | 0.58 | 0.68 | 0.33 | 0.45 | 0.30 | 0.46 | – | 0.20 | 0.69 | 0.61 | 0.46 | 0.45 | 0.44 | 0.42 | – |
| *B/B*MSY | 0.25 | 0.52 | 1.41 | 0.33 | 1.70 | 0.25 | 0.72 | – | 0.57 | 0.66 | 1.48 | 0.36 | 1.70 | 0.26 | 0.94 | – |
| Failure | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.01 | – | 0.01 | – | 0.01 | – | 0.03 | – |
| BM – BM | *P*OF | 0.35 | – | 0.00 | – | 0.00 | – | – | – | 0.24 | – | 0.01 | – | 0.00 | – | – | – |
| *C/*MSY | 0.58 | 0.43 | 0.53 | 0.31 | 0.31 | 0.31 | 0.47 | – | 0.49 | 0.53 | 0.48 | 0.45 | 0.30 | 0.43 | 0.43 | – |
| *B/B*MSY | 0.84 | 0.43 | 1.60 | 0.28 | 1.77 | 0.23 | 1.15 | – | 1.04 | 0.47 | 1.64 | 0.28 | 1.78 | 0.23 | 1.28 | – |
| Failure | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.01 | – | 0.01 | – |
| BL – BH | *P*OF | 0.00 | – | 0.00 | – | 0.00 | – | – | – | 0.00 | – | 0.00 | – | 0.00 | – | – | – |
| *C/*MSY | 0.25 | 0.33 | 0.13 | 0.27 | 0.07 | 0.28 | 0.15 | – | 0.21 | 0.40 | 0.11 | 0.43 | 0.06 | 0.41 | 0.13 | – |
| *B/B*MSY | 1.58 | 0.35 | 1.85 | 0.23 | 1.87 | 0.21 | 1.68 | – | 1.63 | 0.35 | 1.87 | 0.23 | 1.87 | 0.21 | 1.72 | – |
| Failure | 0.00 | – | 0.00 | – | 0.01 | – | 0.01 | – | 0.00 | – | 0.00 | – | 0.01 | – | 0.01 | – |

Table S5. Summary of performance measures (probability of overfishing [*POF*], yield status [*C/MSY* ], biomass status [*B/BMSY*], management failure [failure], and coefficient of variation [CV]) when applying an alternative harvest control rule (denoted by the abbreviation 2.5-1.0-1.0-0.8) to three species (slow-growing [Sp. 1], medium-growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data or single-species data, and under three critical biomass-trend scenarios: BH – BL, BM – BM, and BL – BH.

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Performance measures | Mixed-species results | Single-species results |
| Sp. 1 | CV | Sp. 2 | CV | Sp. 3 | CV | Total | CV | Sp. 1 | CV | Sp. 2 | CV | Sp. 3 | CV | Total | CV |
| BH – BL | *P*OF | 0.78 | – | 0.05 | – | 0.00 | – | – | – | 0.30 | – | 0.09 | – | 0.01 | – | – | – |
| *C/*MSY | 0.26 | 0.61 | 0.67 | 0.36 | 0.44 | 0.33 | 0.45 | – | 0.22 | 0.75 | 0.57 | 0.57 | 0.42 | 0.56 | 0.41 | – |
| *B/B*MSY | 0.30 | 0.52 | 1.42 | 0.33 | 1.68 | 0.25 | 0.75 | – | 0.68 | 0.66 | 1.56 | 0.36 | 1.71 | 0.27 | 1.03 | – |
| Failure | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.01 | – | 0.01 | – | 0.01 | – | 0.03 | – |
| BM – BM | *P*OF | 0.36 | – | 0.00 | – | 0.00 | – | – | – | 0.22 | – | 0.01 | – | 0.00 | – | – | – |
| *C/*MSY | 0.57 | 0.46 | 0.53 | 0.33 | 0.31 | 0.32 | 0.47 | – | 0.49 | 0.62 | 0.46 | 0.54 | 0.29 | 0.52 | 0.41 | – |
| *B/B*MSY | 0.82 | 0.43 | 1.60 | 0.27 | 1.76 | 0.23 | 1.13 | – | 1.12 | 0.47 | 1.70 | 0.28 | 1.77 | 0.24 | 1.35 | – |
| Failure | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – |
| BL – BH | *P*OF | 0.00 | – | 0.00 | – | 0.00 | – | – | – | 0.00 | – | 0.00 | – | 0.00 | – | – | – |
| *C/*MSY | 0.26 | 0.36 | 0.13 | 0.29 | 0.07 | 0.29 | 0.15 | – | 0.21 | 0.50 | 0.10 | 0.53 | 0.06 | 0.50 | 0.12 | – |
| *B/B*MSY | 1.59 | 0.34 | 1.82 | 0.23 | 1.87 | 0.21 | 1.68 | – | 1.65 | 0.35 | 1.85 | 0.23 | 1.88 | 0.21 | 1.73 | – |
| Failure | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – | 0.00 | – |

*Supplementary figures S1-S9*

Fig. S1. Biomass and catch trajectories for three species after applying the default feedback harvest control rule (denoted by the abbreviation 1.0-1.0-1.0-0.8) to both mixed-species and single-species data, for BL – BH scenario. Only 20 trajectories are shown in each figure; both σR and σm were fixed at 0.2. Bold horizontal lines through the biomass and catch trajectories, respectively, indicate the BMSY level and MSY level.

Fig. S2. Biomass and catch trajectories for three species after applying the default feedback harvest control rule (denoted by the abbreviation 1.0-1.0-1.0-0.8) to both mixed-species and single-species data, for BM – BM scenario. Only 20 trajectories are shown in each figure; both σR and σm were fixed at 0.2. Bold horizontal lines through the biomass and catch trajectories, respectively, indicate the BMSY level and MSY level.



Fig. S3. Biomass and catch trajectories for three species after applying the default feedback harvest control rule (denoted by the abbreviation 1.0-1.0-1.0-0.8) to both mixed-species and single-species data, for BH – BL scenario. Only 20 trajectories are shown in each figure; both σR and σm were fixed at 0.2. Bold horizontal lines through the biomass and catch trajectories, respectively, indicate the BMSY level and MSY level.



Fig*.* S4**.** Kobe-plot for the last management year, after applying the default feedback harvest control rule using $σ\_{R}$= 0.2 and $σ\_{I}$= 0.4to mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green and orange indicate species 1, 2 and 3, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares and triangles used for scenarios BH – BL, BM – BM and BL – BH, respectively. The solid red line indicates the overfishing threshold, while the dashed red line defines the overfished line.

Fig. S5. Biomass and catch status performance of the default feedback harvest control rule $σ\_{R}$= 0.2 and $σ\_{I}$= 0.4, with mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green, orange and black indicate species 1, 2, 3, and the total species, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares, and triangles used for scenarios BH – BL, BM – BM, and BL – BH, respectively. The solid red line indicates the MSY level, while the dashed red line defines the overfished line.

Fig*.* S6. Kobe-plot for the last management year, after applying the default feedback harvest control rule under alternative set I (Supplementary, Table 1a.) to mixed-species data (solid color) and single-species data (outline colors), under three critical scenarios. Blue, green and orange indicate species 1, 2 and 3, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares and triangles used for scenarios BH – BL, BM – BM and BL – BH, respectively. The solid red line indicates the overfishing threshold, while the dashed red line defines the overfished line.

Fig. S7. Biomass and catch status performance of the default feedback harvest control rule under alternative set I (Supplementary, Table 1a.) with mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green, orange and black indicate species 1, 2, 3, and the total species, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares, and triangles used for scenarios BH – BL, BM – BM, and BL – BH, respectively. The solid red line indicates the MSY level, while the dashed red line defines the overfished line.

Fig*.* S8. Kobe-plot for the last management year, after applying the default feedback harvest control rule under alternative set II (Supplementary, Table 1b.) to mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green and orange indicate species 1, 2 and 3, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares and triangles used for scenarios BH – BL, BM – BM and BL – BH, respectively. The solid red line indicates the overfishing threshold, while the dashed red line defines the overfished line.

Fig. S9. Biomass and catch status performance of the default feedback harvest control rule under alternative set II (Supplementary, Table 1b.) with mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green, orange and black indicate species 1, 2, 3, and the total species, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares, and triangles used for scenarios BH – BL, BM – BM, and BL – BH, respectively. The solid red line indicates the MSY level, while the dashed red line defines the overfished line.