#### 2021 Vermilion and Sunset Rockfish Stock Assessment and STAR Panel Report Overview

Agenda Item C.6.a Supplemental STAR Panel Presentation 1 (Vermilion and Sunset) September 2021



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Photo by Sabrina Beyer (NMFS)

### **Previous Assessments**

- Full assessment attempted in 2005, not adopted due to uncertainties
- Index-based data-moderate assessment attempted in 2013, but not reviewed
- Managing on OFL/ABC from DB-SRA data-poor assessment since 2011



Photo by Marine Applied Research and Exploration

## 2021 Assessment Spatial Structure

- Four separate assessment areas
- Cryptic species, vermilion vs. sunset rockfish south of Point Conception
- Disparate distribution of catch in OR and WA and differing regulation history



Figure 2: Map of the assessment area with the 3 nm California stat water boundary. The northern California model includes areas from Point Conception to the California-Oregon border and the southern California assessment includes areas from Point Conception to the USA-Mexico border.



Figure 1: Oregon and Washington coastlines with rocky habitat indicated by brown shaded areas. Circled areas represent areas of primary vermilion rockfish occurence.

## Data Sources

- More data in the south than north given abundance
- All Areas: Catch, length, age, conditional age at length
  - Catch is predominantly from recreational and hook and line commercial fisheries
- Washington: No index, low sample size and paucity of length and age data meeting n>10 per year
- Oregon: Fishery dependent ORBS recreational dockside Index (2001-2020)
- Northern California:
  - Fishery Dependent: MRFSS Dockside PC Index, CRFS PR dockside index, CDFW/CalPoly onboard CPFV index, DWV onboard CPFV Index
  - Fishery Independent: SWFSC Groundfish Ecology Cruise, Abrams Thesis Study, WCBTS, CCFRP
- Southern California: See sources to the right



Figure 1: Summary of data sources used in the base model.

# Model Description

- Fully integrated length and age structured assessment conducted in Stock Synthesis
- Fixed steepness (h) of the stock/recruitment curve at Thorson-Dorn prior from metaanalysis of 0.72
  - Estimated 0.73 south of Point Conception
- Fixed weight at length, maturity at length, fecundity at length and recruitment variability
- Estimated sex specific growth and recruitment
- Estimated female natural mortality (*M*) with a diffuse prior based on Hamel (2015) with maximum age of 54 years assumed
  - Male *M* fixed equal

|                     | Southern   | Northern   |        |            |
|---------------------|------------|------------|--------|------------|
| Model Parameters    | California | California | Oregon | Washington |
| M_female            | 0.130      | 0.086      | 0.080  | 0.085      |
| L_inf Female        | 55.378     | 55.184     | 57.184 | 57.106     |
| VonBert_K_Fem       | 0.156      | 0.147      | 0.146  | 0.093      |
| M_male              | 0.130      | 0.080      | 0.073  | 0.087      |
| L_inf Male          | 52.000     | 49.940     | 54.193 | 54.240     |
| VonBert_K_Male      | 0.137      | 0.199      | 0.180  | 0.109      |
| LN(R0)              | 6.697      | 6.041      | 2.793  | 0.908      |
| h                   | 0.730      | 0.720      | 0.720  | 0.720      |
| sigma_R             | 0.500      | 0.500      | 0.600  | 0.600      |
| RecrDev_1998        | -0.434     | 0.566      | 1.758  | -0.049     |
| RecrDev_1999        | 1.353      | 1.139      | 0.759  | 0.520      |
| RecrDev_2000        | 0.678      | 0.476      | -0.383 | 1.370      |
| RecrDev_2015        | 0.030      | -0.215     | 1.738  | -0.177     |
| RecrDev_2016        | 0.895      | 1.472      | -0.324 | -0.044     |
|                     |            |            |        |            |
| Derived Parameters  |            |            |        |            |
| во                  | 978        | 1145       | 29     | 3          |
| FracUnfished (2021) | 48%        | 43%        | 73%    | 56%        |
| OFL_FSPR (2021)     | 169.3      | 149.0      | 13.0   | 0.9        |
| MSY SPRproxy        | 148.3      | 139.0      | 8.0    | 0.8        |

Values in standard text are estimated, those in italics are fixed.

## Model Evaluation

- Sensitivity analyses conducted by the STAT
  - Alternative weighting of length/age composition data
  - Data removal-leave one out
  - Alternative catch history
  - Etc. numerous additional sensitivities
  - Natural mortality (M) is the major axis of uncertainty
- Requests from the STAR panel
  - Mostly related to indices of abundance
    - Time blocking for regulation changes or separate fleets accounting for changes in survey areas/protocols
    - Minor changes from the base model
- Tests for retrospective patterns
  - Sequential removal of years of data to see if depletion trends change
    - Some pattern for Oregon and Washington due to recent recruitment
    - No strong patterns in California
- Convergence tests passed
  - Reasonable parameter values
  - Acceptable fits to data
  - Jittering conducted
  - Inverted hessian





### Depletion and Stock Status



# Technical Merits and Deficiencies (Highlights)

#### <u>Merits</u>

- Washington:
  - Robust despite lack and paucity of length and age data
- Oregon:
  - Fishery age data for estimation of *M*/growth
- Northern California:
  - High resolution data onboard CPFV data
- Southern California:
  - Representativeness of Hook and Line Survey
  - Accounting for regulation changes through time blocking

#### **Deficiencies**

- Washington:
  - General lack of encounters providing data
- Oregon:
  - No fishery independent indices
- Northern California:
  - Lack of age data
- Southern California:
  - Inability to distinguish between species or populations

## Major Research and Data Needs

- Coastwide hook and line survey providing a fishery independent index of abundance, length and age data in open and closed areas
- Ongoing research on a Saltonstall/Kennedy grant to study vermilion rockfish population structure and the extent of the distribution of sunset rockfish
- Accounting for shifts in management affecting availability differing size classes or numbers of fish for composition and indices
- Additional age and length data from the fishery



## Endorsement, Category, Next Assessment

- SSC endorsed all assessments as BSIA for use in management
- Category Recommendations
  - Washington: Category 2 due to wide confidence bounds, default sigma = 1.0
  - Oregon: Category 1 since primarily vermilion rockfish, default sigma = 0.5
  - Northern California: Category 1 since primarily vermilion rockfish, default sigma = 0.5
  - Southern California: Category 2 due to sunset rockfish, default sigma = 1.0
- SSC recommended the next assessment be a full assessment given ongoing research and this being the first assessment

## **Decision Tables**

- Primary axis of uncertainty is natural mortality (M)
- Southern California bivariate matrix with *M* and *h*, since *h* was estimated
- Values associated with 12.5 and 87.5 quantile values likelihood bracket uncertainty
- Catch series 2021/2022 projected by GMT, remainder full attainment, under
  - 1. P\* 0.45
  - 2. P\* 0.40
  - 3. Long-term MSY (SPR 50%) with and without buffer





Washington (Low state of nature declines to below MSST)

Oregon (Low state of nature more robust)

|            |      |       | Female $M = 0.067$ ;<br>Male =0.069 |                      | Female M<br>Male • | l = 0.084;<br>=0.086 | Female M = 0.099;<br>Male =0.100 |                      |
|------------|------|-------|-------------------------------------|----------------------|--------------------|----------------------|----------------------------------|----------------------|
|            | Year | Catch | Spawning<br>Output                  | Fraction<br>Unfished | Spawning<br>Output | Fraction<br>Unfished | Spawning<br>Output               | Fraction<br>Unfished |
|            | 2021 | 2.69  | 0.68                                | 0.31                 | 1.55               | 0.56                 | 3.62                             | 0.81                 |
|            | 2022 | 3.26  | 0.50                                | 0.23                 | 1.38               | 0.50                 | 3.44                             | 0.77                 |
|            | 2023 | 0.62  | 0.28                                | 0.13                 | 1.16               | 0.42                 | 3.21                             | 0.72                 |
|            | 2024 | 0.61  | 0.26                                | 0.12                 | 1.15               | 0.42                 | 3.20                             | 0.72                 |
|            | 2025 | 0.61  | 0.25                                | 0.11                 | 1.15               | 0.42                 | 3.19                             | 0.72                 |
| P*=0.45    | 2026 | 0.61  | 0.24                                | 0.11                 | 1.15               | 0.42                 | 3.18                             | 0.72                 |
| sigma=1.0  | 2027 | 0.61  | 0.24                                | 0.11                 | 1.16               | 0.42                 | 3.18                             | 0.72                 |
| -          | 2028 | 0.62  | 0.24                                | 0.11                 | 1.17               | 0.43                 | 3.19                             | 0.72                 |
|            | 2029 | 0.62  | 0.24                                | 0.11                 | 1.18               | 0.43                 | 3.20                             | 0.72                 |
|            | 2030 | 0.62  | 0.24                                | 0.11                 | 1.20               | 0.44                 | 3.21                             | 0.72                 |
|            | 2031 | 0.63  | 0.24                                | 0.11                 | 1.21               | 0.44                 | 3.23                             | 0.73                 |
|            | 2032 | 0.63  | 0.24                                | 0.11                 | 1.23               | 0.45                 | 3.24                             | 0.73                 |
|            | 2021 | 2.69  | 0.68                                | 0.31                 | 1.55               | 0.56                 | 3.62                             | 0.81                 |
|            | 2022 | 3.26  | 0.50                                | 0.23                 | 1.38               | 0.50                 | 3.44                             | 0.77                 |
|            | 2023 | 0.54  | 0.28                                | 0.13                 | 1.16               | 0.42                 | 3.21                             | 0.72                 |
|            | 2024 | 0.53  | 0.27                                | 0.12                 | 1.16               | 0.42                 | 3.20                             | 0.72                 |
|            | 2025 | 0.53  | 0.26                                | 0.12                 | 1.16               | 0.42                 | 3.20                             | 0.72                 |
| P*=0.4     | 2026 | 0.53  | 0.26                                | 0.12                 | 1.17               | 0.43                 | 3.20                             | 0.72                 |
| sigma=1.0  | 2027 | 0.53  | 0.26                                | 0.12                 | 1.18               | 0.43                 | 3.21                             | 0.72                 |
|            | 2028 | 0.53  | 0.27                                | 0.12                 | 1.20               | 0.44                 | 3.22                             | 0.72                 |
|            | 2029 | 0.53  | 0.27                                | 0.12                 | 1.22               | 0.44                 | 3.24                             | 0.73                 |
|            | 2030 | 0.53  | 0.28                                | 0.13                 | 1.24               | 0.45                 | 3.26                             | 0.73                 |
|            | 2031 | 0.52  | 0.29                                | 0.13                 | 1.26               | 0.46                 | 3.28                             | 0.74                 |
|            | 2032 | 0.52  | 0.30                                | 0.13                 | 1.28               | 0.47                 | 3.30                             | 0.74                 |
|            | 2021 | 2.69  | 0.68                                | 0.31                 | 1.55               | 0.56                 | 3.62                             | 0.81                 |
|            | 2022 | 3.26  | 0.50                                | 0.22                 | 1.38               | 0.50                 | 3.44                             | 0.77                 |
|            | 2023 | 0.77  | 0.28                                | 0.13                 | 1.15               | 0.42                 | 3.21                             | 0.72                 |
|            | 2024 | 0.77  | 0.25                                | 0.11                 | 1.14               | 0.41                 | 3.18                             | 0.72                 |
| FMSY proxy | 2025 | 0.77  | 0.23                                | 0.10                 | 1.12               | 0.41                 | 3.16                             | 0.71                 |
| SPR=0.5    | 2026 | 0.77  | 0.21                                | 0.09                 | 1.11               | 0.40                 | 3.15                             | 0.71                 |
|            | 2027 | 0.77  | 0.19                                | 0.09                 | 1.11               | 0.40                 | 3.14                             | 0.71                 |
|            | 2028 | 0.77  | 0.18                                | 0.08                 | 1.11               | 0.40                 | 3.13                             | 0.70                 |
|            | 2029 | 0.77  | 0.17                                | 0.03                 | 1.11               | 0.40                 | 3.13                             | 0.70                 |
|            | 2030 | 0.77  | 0.16                                | 0.07                 | 1.11               | 0.40                 | 3.13                             | 0.70                 |
|            | 2031 | 0.77  | 0.15                                | 0.07                 | 1.12               | 0.41                 | 3.14                             | 0.71                 |
|            | 2032 | 0.77  | 0.14                                | 0.06                 | 1.12               | 0.41                 | 3.15                             | 0.71                 |

|            |      |       | Female M = 0.071;<br>Male =0.065 |          | Female Male | l = 0.079;<br>=0.073 | Female M = 0.085;<br>Male =0.079 |          |
|------------|------|-------|----------------------------------|----------|-------------|----------------------|----------------------------------|----------|
|            | Year | Catch | Spawning                         | Fraction | Spawning    | Fraction             | Spawning                         | Fraction |
|            |      |       | Output                           | Unfished | Output      | Unfished             | Output                           | Unfished |
|            | 2021 | 12.96 | 17.70                            | 0.62     | 21.37       | 0.73                 | 24.46                            | 0.79     |
|            | 2022 | 12.96 | 17.76                            | 0.62     | 21.53       | 0.73                 | 24.68                            | 0.80     |
|            | 2023 | 12.60 | 17.89                            | 0.63     | 21.79       | 0.74                 | 25.01                            | 0.81     |
|            | 2024 | 12.45 | 17.93                            | 0.63     | 21.92       | 0.75                 | 25.20                            | 0.82     |
|            | 2025 | 12.19 | 17.81                            | 0.63     | 21.85       | 0.74                 | 25.16                            | 0.82     |
| P*=0.45    | 2026 | 11.89 | 17.56                            | 0.62     | 21.63       | 0.74                 | 24.93                            | 0.81     |
| sigma=0.5  | 2027 | 11.56 | 17.23                            | 0.60     | 21.29       | 0.72                 | 24.58                            | 0.80     |
|            | 2028 | 11.24 | 16.86                            | 0.59     | 20.90       | 0.71                 | 24.16                            | 0.78     |
|            | 2029 | 10.93 | 16.46                            | 0.58     | 20.48       | 0.70                 | 23.70                            | 0.77     |
|            | 2030 | 10.63 | 16.06                            | 0.56     | 20.04       | 0.68                 | 23.23                            | 0.75     |
|            | 2031 | 10.36 | 15.67                            | 0.55     | 19.62       | 0.67                 | 22.76                            | 0.74     |
|            | 2032 | 10.10 | 15.29                            | 0.54     | 19.21       | 0.65                 | 22.31                            | 0.72     |
|            | 2021 | 12.96 | 17.70                            | 0.62     | 21.37       | 0.73                 | 24.46                            | 0.79     |
|            | 2022 | 12.96 | 17.76                            | 0.62     | 21.53       | 0.73                 | 24.68                            | 0.80     |
|            | 2023 | 11.77 | 17.89                            | 0.63     | 21.79       | 0.74                 | 25.01                            | 0.81     |
|            | 2024 | 11.60 | 18.00                            | 0.63     | 21.99       | 0.75                 | 25.27                            | 0.82     |
|            | 2025 | 11.34 | 17.96                            | 0.63     | 21.99       | 0.75                 | 25.30                            | 0.82     |
| P*=0.4     | 2026 | 11.04 | 17.78                            | 0.62     | 21.84       | 0.74                 | 25.14                            | 0.82     |
| sigma=0.5  | 2027 | 10.72 | 17.53                            | 0.62     | 21.58       | 0.73                 | 24.87                            | 0.81     |
|            | 2028 | 10.41 | 17.22                            | 0.60     | 21.25       | 0.72                 | 24.51                            | 0.79     |
|            | 2029 | 10.10 | 16.89                            | 0.59     | 20.89       | 0.71                 | 24.11                            | 0.78     |
|            | 2030 | 9.82  | 16.56                            | 0.58     | 20.52       | 0.70                 | 23.70                            | 0.77     |
|            | 2031 | 9.55  | 16.23                            | 0.57     | 20.15       | 0.69                 | 23.29                            | 0.76     |
|            | 2032 | 9.29  | 15.91                            | 0.56     | 19.80       | 0.67                 | 22.89                            | 0.74     |
|            | 2021 | 12.96 | 17.70                            | 0.62     | 21.37       | 0.73                 | 24.46                            | 0.79     |
|            | 2022 | 12.96 | 17.76                            | 0.62     | 21.53       | 0.73                 | 24.68                            | 0.80     |
|            | 2023 | 7.95  | 17.89                            | 0.63     | 21.79       | 0.74                 | 25.01                            | 0.81     |
|            | 2024 | 7.95  | 18.32                            | 0.64     | 22.30       | 0.76                 | 25.58                            | 0.83     |
| FMSY proxy | 2025 | 7.95  | 18.59                            | 0.65     | 22.62       | 0.77                 | 25.92                            | 0.84     |
| SPR=0.5    | 2026 | 7.95  | 18.72                            | 0.66     | 22.75       | 0.77                 | 26.05                            | 0.84     |
|            | 2027 | 7.95  | 18.73                            | 0.66     | 22.75       | 0.77                 | 26.03                            | 0.84     |
|            | 2028 | 7.95  | 18.66                            | 0.66     | 22.65       | 0.77                 | 25.89                            | 0.84     |
|            | 2029 | 7.95  | 18.53                            | 0.65     | 22.47       | 0.76                 | 25.67                            | 0.83     |
|            | 2030 | 7.95  | 18.36                            | 0.64     | 22.25       | 0.76                 | 25.39                            | 0.82     |
|            | 2031 | 7.95  | 18.16                            | 0.64     | 21.99       | 0.75                 | 25.09                            | 0.81     |
|            | 2032 | 7.95  | 17.94                            | 0.63     | 21.71       | 0.74                 | 24.76                            | 0.80     |

|                           |      |   |            | Low Pro  | ductivity            | Base  | Model                | High Pro           | ductivity            |
|---------------------------|------|---|------------|--|----------------------|---|----------------------|--------------------|----------------------|
| Northern California       |      | Female M = $0.0769$<br>Male M = $0.0723$<br>NLL = $1031.34$ |            | Female M = $0.0856$<br>Male M = $0.0805$<br>NLL = $1032$ |                      | Female M = $0.0956$<br>Male M = $0.0899$<br>NLL = $1031.34$ |                      |                    |                      |
|                           | Year | Buffer  | Catch (mt) | Spawning<br>Output                                       | Fraction<br>Unfished | Spawning<br>Output  | Fraction<br>Unfished | Spawning<br>Output | Fraction<br>Unfished |
|                           | 2021 | 1.000   | 227        | 437  | 0.362                | 489   | 0.427                | 554                | 0.506                |
|                           | 2022 | 1.000   | 227        | 435  | 0.361                | 491   | 0.429                | 558                | 0.510                |
|                           | 2023 | 0.874   | 135        | 438  | 0.363                | 497   | 0.434                | 568                | 0.519                |
|                           | 2024 | 0.865   | 136        | 453  | 0.376                | 516   | 0.451                | 591                | 0.540                |
|                           | 2025 | 0.857   | 137        | 467  | 0.387                | 533   | 0.466                | 612                | 0.559                |
| $p^* = 0.45, \sigma =$    | 2026 | 0.849   | 136        | 477  | 0.396                | 547   | 0.478                | 629                | 0.575                |
| 1                         | 2027 | 0.841   | 134        | 485  | 0.402                | 558   | 0.487                | 642                | 0.587                |
|                           | 2028 | 0.833   | 132        | 491  | 0.407                | 566   | 0.494                | 652                | 0.595                |
|                           | 2029 | 0.826   | 130        | 496  | 0.411                | 572   | 0.500                | 658                | 0.602                |
|                           | 2030 | 0.818   | 128        | 499  | 0.414                | 577   | 0.504                | 663                | 0.606                |
|                           | 2031 | 0.810   | 127        | 502  | 0.416                | 580   | 0.507                | 666                | 0.608                |
|                           | 2032 | 0.803   | 125        | 505  | 0.418                | 583   | 0.509                | 667                | 0.610                |
|                           | 2021 | 1.000   | 227        | 437  | 0.362                | 489   | 0.427                | 554                | 0.506                |
|                           | 2022 | 1.000   | 227        | 435  | 0.361                | 491   | 0.429                | 558                | 0.510                |
|                           | 2023 | 0.762   | 118        | 438  | 0.363                | 497   | 0.434                | 568                | 0.519                |
|                           | 2024 | 0.747   | 118        | 456  | 0.378                | 519   | 0.453                | 593                | 0.542                |
|                           | 2025 | 0.733   | 118        | 472  | 0.392                | 539   | 0.470                | 616                | 0.563                |
| $p^* - 0.40, \sigma -$    | 2026 | 0.719   | 117        | 487  | 0.404                | 556   | 0.485                | 636                | 0.581                |
| 1                         | 2027 | 0.706   | 115        | 499  | 0.414                | 570   | 0.498                | 652                | 0.595                |
|                           | 2028 | 0.693   | 113        | 509  | 0.422                | 581   | 0.508                | 664                | 0.607                |
|                           | 2029 | 0.680   | 111        | 518  | 0.429                | 591   | 0.516                | 674                | 0.615                |
|                           | 2030 | 0.667   | 108        | 525  | 0.436                | 599   | 0.523                | 681                | 0.622                |
|                           | 2031 | 0.654   | 106        | 533  | 0.442                | 606   | 0.529                | 686                | 0.627                |
|                           | 2032 | 0.642   | 105        | 539  | 0.447                | 612   | 0.534                | 691                | 0.631                |
|                           | 2021 | 1.000   | 227        | 437  | 0.362                | 489   | 0.427                | 554                | 0.506                |
|                           | 2022 | 1.000   | 227        | 435  | 0.361                | 491   | 0.429                | 558                | 0.510                |
|                           | 2023 | 1.000   | 139        | 438  | 0.363                | 497   | 0.434                | 568                | 0.519                |
| Long-term                 | 2024 | 1.000   | 139        | 453  | 0.376                | 516   | 0.451                | 590                | 0.539                |
| Equil. Yield              | 2025 | 1.000   | 139        | 467  | 0.387                | 533   | 0.465                | 610                | 0.558                |
| (MSY proxy,               | 2026 | 1.000   | 139        | 477  | 0.396                | 546   | 0.477                | 627                | 0.573                |
| SPR <sub>norg</sub> ), no | 2027 | 1.000   | 139        | 485  | 0.402                | 557   | 0.486                | 639                | 0.584                |
| buffer                    | 2028 | 1.000   | 139        | 491  | 0.407                | 501   | 0.493                | 617                | 0.591                |
|                           | 2029 | 1.000   | 139        | 495  | 0.410                | 509   | 0.497                | 002                | 0.596                |
|                           | 2030 | 1.000   | 139        | 407  | 0.412                | 579   | 0.499                | 655                | 0.558                |
|                           | 2031 | 1.000   | 139        | 499  | 0.414                | 573   | 0.501                | 654                | 0.597                |
|                           | 2002 | 1,000   | 105        | 497  | 0.363                | 460   | 0.497                | 554                | 0.506                |
|                           | 2022 | 1.000   | 227        | 435  | 0.361                | 491   | 0.429                | 558                | 0.510                |
|                           | 2023 | 0.874   | 122        | 438  | 0.363                | 497   | 0.434                | 568                | 0.519                |
|                           | 2024 | 0.865   | 120        | 456  | 0.378                | 518   | 0.453                | 593                | 0.542                |
| Long-term                 | 2025 | 0.857   | 119        | 472  | 0.392                | 538   | 0.470                | 616                | 0.563                |
| Equil. Yield              | 2026 | 0.849   | 118        | 486  | 0.403                | 555   | 0.485                | 635                | 0.580                |
| (MSY proxy,               | 2027 | 0.841   | 117        | 498  | 0.413                | 569   | 0.497                | 651                | 0.595                |
| $SPR_{50\%}$ ),           | 2028 | 0.833   | 116        | 508  | 0.421                | 580   | 0.507                | 663                | 0.606                |
| with buffer               | 2029 | 0.826   | 116        | 516  | 0.428                | 589   | 0.515                | 672                | 0.614                |
|                           | 2030 | 0.818   | 115        | 522  | 0.433                | 596   | 0.521                | 678                | 0.620                |
|                           | 2031 | 0.810   | 114        | 528  | 0.438                | 602   | 0.526                | 682                | 0.624                |
|                           | 2032 | 0.803   | 113        | 533  | 0.442                | 606   | 0.529                | 685                | 0.626                |

|   |                          |      | Low Productivity |            | Base Model         |                      | High Productivity  |                      |                    |                      |
|---|--------------------------|------|------------------|------------|--------------------|----------------------|--------------------|----------------------|--------------------|----------------------|
| $p^* = 0.45, \sigma = \begin{cases} 1 \\ p^* = 0.45, \sigma = \begin{cases} 2021 \\ 2022 \\ 1.000 \\ 2022 \\ 2022 \\ 1.000 \\ 2022 \\ 1.000 \\ 210 \\ 2022 \\ 1.000 \\ 210 \\ 2022 \\ 1.000 \\ 210 \\ 2022 \\ 2022 \\ 1.000 \\ 210 \\ 2022 \\ $   | Southern California      |      | M = 0.1125       |            | M = 0.1302         |                      | M = 0.1475         |                      |                    |                      |
| $ p^* = 0.45, \sigma = \begin{cases} 1 \\ p^* = 0.45, \sigma = \begin{cases} 2021 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 1 \\ 1 \\ 2022 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\$  |                          |      | h = 0.675        |            | h = 0.730          |                      | h = 0.875          |                      |                    |                      |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          |      |                  | NLL =      | NLL = 1015.23      |                      | NLL = 1013.02      |                      | NLL = 1014.72      |                      |
| $ \begin{array}{c} p^{*}=0.45,\sigma= \left[ \begin{array}{cccccccccccccccccccccccccccccccccccc$  |                          | Year | Buffer           | Catch (mt) | Spawning<br>Output | Fraction<br>Unfished | Spawning<br>Output | Fraction<br>Unfished | Spawning<br>Output | Fraction<br>Unfished |
| $ \begin{array}{c} & \begin{array}{c} & \begin{array}{c} 2022 & 1.000 \\ 2023 & 0.874 & 139 \\ 2024 & 0.885 & 137 \\ 1 \\ \end{array} \\ p^{*} = 0.45, \sigma = \begin{array}{c} 2025 & 0.871 & 136 \\ 2025 & 0.875 & 135 \\ 1 \\ 2025 & 0.887 & 135 \\ 2025 & 0.881 & 131 \\ 1 \\ 2020 & 0.813 & 133 \\ 1 \\ 2020 & 0.813 & 133 \\ 1 \\ 2020 & 0.813 & 131 \\ 1 \\ 2020 & 0.833 & 133 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.818 & 131 \\ 1 \\ 2030 & 0.762 \\ 2021 & 1.000 \\ 2022 & 1.001 \\ 2022 & 1.001 \\ 2022 & 1.001 \\ 2022 & 1.001 \\ 2022 & 1.001 \\ 2025 & 0.733 & 118 \\ 1 \\ 4 \\ 2024 & 0.747 \\ 1 \\ 1 \\ 2025 & 0.733 & 118 \\ 4 \\ 1 \\ 2025 & 0.733 & 118 \\ 4 \\ 1 \\ 4 \\ 20 \\ 2022 & 0.762 \\ 2025 & 0.733 \\ 1 \\ 1 \\ 4 \\ 2025 & 0.733 \\ 1 \\ 1 \\ 4 \\ 202 & 0.762 \\ 2025 & 0.733 \\ 1 \\ 1 \\ 4 \\ 202 & 0.762 \\ 2025 & 0.733 \\ 1 \\ 1 \\ 4 \\ 202 & 0.762 \\ 2025 & 0.733 \\ 1 \\ 1 \\ 4 \\ 4 \\ 20 \\ 2025 & 0.733 \\ 1 \\ 1 \\ 4 \\ 4 \\ 20 \\ 2025 & 0.771 \\ 1 \\ 4 \\ 4 \\ 20 \\ 2025 & 0.771 \\ 1 \\ 4 \\ 4 \\ 20 \\ 2025 & 0.673 \\ 1 \\ 1 \\ 4 \\ 4 \\ 4 \\ 3 \\ 3 \\ 2 \\ 2 \\ 2 \\ 2 \\ 2 \\ 2 \\ 2 \\ 2$   |                          | 2021 | 1.000            | 210        | 406                | 0.355                | 471                | 0.482                | 581                | 0.642                |
| $ \begin{array}{c} p^{*}=0.45,\sigma=\\ 1 \\ p^{*}=0.45,\sigma=\\ 1 \\ p^{*}=0.45,\sigma=\\ 1 \\ p^{*}=0.45,\sigma=\\ 2025 \\ 1 \\ p^{*}=0.45,\sigma=\\ 2026 \\ 1 \\ p^{*}=0.55,\sigma=\\ 2026 \\ 1 \\ p^{*}$                     |                          | 2022 | 1.000            | 210        | 407                | 0.357                | 474                | 0.485                | 585                | 0.646                |
| $ \begin{array}{c} p^* = 0.45, \sigma = \\ 1 \end{array} \left  \begin{array}{c} 2025 \\ 2025 \\ 1 \end{array} \right  0.857 \\ 1 36 \\ 2028 \\ 2028 \\ 0.833 \\ 2029 \\ 0.826 \\ 1 313 \\ 1 313 \\ 4 13 \\ 4 13 \\ 0.362 \\ 4 13 \\ 0.362 \\ 4 147 \\ 0.362 \\ 4 148 \\ 0.488 \\ 0.500 \\ 0.600 \\ 0.600 \\ 0.601 \\ 0.664 \\ 0.600 \\ 0.663 \\ 2029 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.202 \\ 0.203 \\ 0.203 \\ 0.181 \\ 1 31 \\ 4 15 \\ 0.361 \\ 4 14 \\ 0.362 \\ 4 90 \\ 0.501 \\ 4 90 \\ 0.501 \\ 1 0.502 \\ 4 90 \\ 0.501 \\ 3 97 \\ 0.659 \\ 2 000 \\ 0.651 \\ 2 000 \\ 0.661 \\ 0.661 \\ 0.661 \\ 0.661 \\ 0.661 \\ 0.651 \\ 2 000 \\ 0.661 \\ 0.651 \\ 2 002 \\ 1 0.00 \\ 2 010 \\ 0.651 \\ 0.522 \\ 0.531 \\ 0.51 \\ 0.522 \\ 0.51 \\ 0.51 \\ 0.522 \\ 0.51 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ $  |                          | 2023 | 0.874            | 139        | 408                | 0.358                | 477                | 0.488                | 589                | 0.651                |
| $ \begin{array}{c} p^*=0.45,\sigma=\\ 1 \end{array} = \begin{array}{c} 2026 \\ 2025 \\ 0.857 \\ 1 \end{array} = \begin{array}{c} 136 \\ 2026 \\ 2027 \\ 0.849 \\ 2027 \\ 0.841 \\ 2028 \\ 2023 \\ 0.833 \\ 133 \\ 131 \\ 413 \\ 413 \\ 0.362 \\ 448 \\ 0.499 \\ 0.501 \\ 599 \\ 0.600 \\ 0.661 \\ 599 \\ 0.660 \\ 0.665 \\ 2029 \\ 0.836 \\ 132 \\ 2030 \\ 0.818 \\ 131 \\ 131 \\ 415 \\ 0.367 \\ 493 \\ 0.501 \\ 493 \\ 0.501 \\ 597 \\ 0.502 \\ 597 \\ 0.659 \\ 2031 \\ 0.818 \\ 129 \\ 419 \\ 0.367 \\ 493 \\ 0.501 \\ 597 \\ 0.659 \\ 2031 \\ 0.818 \\ 129 \\ 419 \\ 0.367 \\ 493 \\ 0.501 \\ 599 \\ 0.651 \\ 2022 \\ 1.000 \\ 2022 \\ 1.000 \\ 2020 \\ 1000 \\ 2010 \\ 407 \\ 0.357 \\ 474 \\ 0.488 \\ 589 \\ 0.516 \\ 2022 \\ 1.000 \\ 2022 \\ 1.000 \\ 2022 \\ 1.000 \\ 2021 \\ 0.762 \\ 2022 \\ 1.000 \\ 2021 \\ 0.762 \\ 2022 \\ 1.000 \\ 2021 \\ 0.762 \\ 119 \\ 116 \\ 421 \\ 0.387 \\ 413 \\ 0.358 \\ 477 \\ 0.488 \\ 589 \\ 0.516 \\ 0.514 \\ 613 \\ 0.677 \\ 2029 \\ 0.680 \\ 112 \\ 442 \\ 0.377 \\ 450 \\ 0.514 \\ 613 \\ 0.677 \\ 2029 \\ 0.680 \\ 1112 \\ 442 \\ 0.377 \\ 450 \\ 0.514 \\ 613 \\ 0.677 \\ 2029 \\ 0.667 \\ 111 \\ 447 \\ 0.377 \\ 474 \\ 0.488 \\ 589 \\ 0.511 \\ 617 \\ 0.81 \\ 0.522 \\ 1.000 \\ 203 \\ 0.667 \\ 111 \\ 448 \\ 0.357 \\ 474 \\ 0.485 \\ 585 \\ 0.660 \\ 0.512 \\ 2023 \\ 0.667 \\ 111 \\ 447 \\ 0.377 \\ 474 \\ 0.485 \\ 585 \\ 0.646 \\ 0.80 \\ 0.522 \\ 615 \\ 0.528 \\ 616 \\ 0.80 \\ 0.522 \\ 615 \\ 0.679 \\ 203 \\ 0.667 \\ 111 \\ 448 \\ 0.357 \\ 474 \\ 0.485 \\ 588 \\ 0.511 \\ 617 \\ 0.81 \\ 0.521 \\ 0.51 \\ 0.521 \\ 0.51 \\ 0.521 \\ 0.51 \\ 0.521 \\ 0.51 \\ 0.521 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.55 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.51 \\ 0.52 \\ 0.51 \\ 0.51 \\ 0.51 \\ 0.51 \\ 0.51 \\ 0.55 $   |                          | 2024 | 0.865            | 137        | 411                | 0.360                | 482                | 0.493                | 595                | 0.658                |
| $ \begin{array}{c} p^{*}=0.45, \sigma= \\ 1 \\ p^{*}=0.45, \sigma= \\ 2027 \\ 2028 \\ 0.811 \\ 2028 \\ 0.811 \\ 2030 \\ 0.818 \\ 131 \\ 141 \\ 415 \\ 0.362 \\ 448 \\ 0.362 \\ 449 \\ 0.500 \\ 600 \\ 0.663 \\ 491 \\ 0.500 \\ 600 \\ 0.501 \\ 597 \\ 0.651 \\ 597 \\ 0.657 \\ 2030 \\ 0.818 \\ 131 \\ 141 \\ 415 \\ 0.365 \\ 491 \\ 0.367 \\ 493 \\ 0.501 \\ 491 \\ 0.503 \\ 594 \\ 0.567 \\ 2032 \\ 0.803 \\ 129 \\ 419 \\ 0.367 \\ 493 \\ 0.561 \\ 491 \\ 0.561 \\ 491 \\ 0.503 \\ 594 \\ 0.567 \\ 493 \\ 0.504 \\ 595 \\ 0.503 \\ 597 \\ 0.657 \\ 2032 \\ 0.503 \\ 129 \\ 419 \\ 0.367 \\ 493 \\ 0.567 \\ 471 \\ 0.485 \\ 585 \\ 0.666 \\ 490 \\ 0.501 \\ 649 \\ 0.501 \\ 648 \\ 585 \\ 0.666 \\ 660 \\ 0.672 \\ 2022 \\ 1.000 \\ 2022 \\ 1.000 \\ 2021 \\ 0.72 \\ 118 \\ 418 \\ 0.366 \\ 490 \\ 0.501 \\ 649 \\ 0.506 \\ 649 \\ 0.501 \\ 649 \\ 0.506 \\ 658 \\ 0.514 \\ 613 \\ 0.677 \\ 2029 \\ 0.680 \\ 112 \\ 422 \\ 0.774 \\ 119 \\ 448 \\ 0.371 \\ 499 \\ 0.510 \\ 66 \\ 514 \\ 613 \\ 0.677 \\ 2029 \\ 0.680 \\ 112 \\ 422 \\ 0.778 \\ 2026 \\ 0.671 \\ 111 \\ 4477 \\ 0.382 \\ 510 \\ 0.525 \\ 616 \\ 0.514 \\ 613 \\ 0.677 \\ 2029 \\ 0.680 \\ 112 \\ 442 \\ 0.371 \\ 499 \\ 0.510 \\ 613 \\ 0.677 \\ 2029 \\ 0.680 \\ 112 \\ 422 \\ 0.778 \\ 506 \\ 0.514 \\ 613 \\ 0.677 \\ 2029 \\ 0.680 \\ 112 \\ 4427 \\ 0.371 \\ 499 \\ 0.510 \\ 613 \\ 0.677 \\ 2028 \\ 0.680 \\ 112 \\ 422 \\ 0.778 \\ 506 \\ 0.514 \\ 613 \\ 0.677 \\ 2028 \\ 0.680 \\ 112 \\ 4427 \\ 0.372 \\ 100 \\ 0.61 \\ 148 \\ 448 \\ 0.392 \\ 519 \\ 0.511 \\ 616 \\ 0.680 \\ 0.522 \\ 615 \\ 0.528 \\ 616 \\ 0.680 \\ 0.521 \\ 616 \\ 0.680 \\ 0.521 \\ 616 \\ 0.680 \\ 0.521 \\ 616 \\ 0.680 \\ 0.521 \\ 616 \\ 0.680 \\ 0.677 \\ 2027 \\ 1.00 \\ 148 \\ 448 \\ 0.355 \\ 471 \\ 0.485 \\ 585 \\ 0.661 \\ 0.661 \\ 2021 \\ 1.00 \\ 148 \\ 448 \\ 0.355 \\ 477 \\ 0.488 \\ 598 \\ 0.660 \\ 0.677 \\ 2027 \\ 1.00 \\ 148 \\ 448 \\ 0.355 \\ 471 \\ 0.485 \\ 585 \\ 0.661 \\ 0.677 \\ 2027 \\ 1.00 \\ 148 \\ 449 \\ 0.355 \\ 471 \\ 0.485 \\ 585 \\ 0.661 \\ 0.677 \\ 2027 \\ 1.00 \\ 148 \\ 449 \\ 0.355 \\ 471 \\ 0.485 \\ 585 \\ 0.660 \\ 0.677 \\ 2027 \\ 1.00 \\ 148 \\ 449 \\ 0.355 \\ 471 \\ 0.485 \\ 585 \\ 0.661 \\ 0.677 \\ 2027 \\ 1.00 \\ 148 \\ 449 \\ 0.355 \\ 471 \\ 0.485 \\ 585 \\ 0.661 \\ 0.677 \\ 598 \\ 0.661 \\ 0.677 \\ 2028 \\ 1.00 \\ 148 \\ 449 \\ 0.350 \\ 448 \\ 0.350 \\ 448 \\ 0.495 \\ 598 \\ 0.661 \\ 0.677 \\ 598 \\ 0.661 \\ 0.677 \\ $  |                          | 2025 | 0.857            | 136        | 413                | 0.361                | 485                | 0.496                | 599                | 0.662                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   | $p^* = 0.45, \sigma =$   | 2026 | 0.849            | 135        | 413                | 0.362                | 487                | 0.498                | 601                | 0.664                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   | 1                        | 2027 | 0.841            | 134        | 413                | 0.362                | 488                | 0.499                | 601                | 0.664                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2028 | 0.833            | 133        | 413                | 0.362                | 489                | 0.500                | 600                | 0.663                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2029 | 0.826            | 132        | 414                | 0.362                | 490                | 0.501                | 599                | 0.661                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2030 | 0.818            | 131        | 415                | 0.363                | 491                | 0.502                | 597                | 0.659                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2031 | 0.810            | 130        | 417                | 0.365                | 491                | 0.503                | 594                | 0.657                |
| $ \begin{array}{c} p^{*} = 0.40, \sigma = \\ 1 \\ p^{*} = 0.40, \sigma = \\ 1 $  |                          | 2032 | 0.803            | 129        | 419                | 0.367                | 493                | 0.504                | 592                | 0.654                |
| $ \begin{array}{c} p^{*} = 0.40, \sigma = \\ 1 \\ p^{*} = 0.40, \sigma = \\ 1 $  |                          | 2021 | 1.000            | 210        | 406                | 0.355                | 471                | 0.482                | 581                | 0.642                |
| $ \begin{array}{c} p^* = 0.40, \sigma = \\ 1 \\ p^* = 0.40, \sigma $ |                          | 2022 | 1.000            | 210        | 407                | 0.357                | 474                | 0.485                | 585                | 0.646                |
| $ \begin{array}{c} p^{*}=0.40, \sigma = \\ 1 \\ p^{*}=0.40, \sigma = \\ 1 \\ p^{*}=0.40, \sigma = \\ 1 \\ p^{*}=0.40, \sigma = \\ 2025 & 0.733 & 118 & 418 & 0.366 & 490 & 0.501 & 604 & 0.667 \\ 2026 & 0.719 & 116 & 421 & 0.368 & 495 & 0.506 & 608 & 0.672 \\ 2027 & 0.706 & 115 & 424 & 0.371 & 499 & 0.510 & 611 & 0.675 \\ 2028 & 0.693 & 114 & 427 & 0.374 & 503 & 0.514 & 613 & 0.677 \\ 2029 & 0.680 & 112 & 432 & 0.378 & 506 & 0.518 & 614 & 0.678 \\ 2030 & 0.667 & 111 & 437 & 0.382 & 510 & 0.522 & 615 & 0.679 \\ 2031 & 0.654 & 109 & 442 & 0.355 & 471 & 0.452 & 581 & 0.642 \\ 2022 & 1.000 & 210 & 406 & 0.355 & 471 & 0.482 & 581 & 0.642 \\ 2022 & 1.000 & 210 & 406 & 0.355 & 477 & 0.488 & 589 & 0.661 \\ 2022 & 1.000 & 148 & 413 & 0.362 & 484 & 0.495 & 598 & 0.666 \\ 2025 & 1.000 & 148 & 413 & 0.364 & 488 & 0.499 & 603 & 0.665 \\ 2026 & 1.000 & 148 & 413 & 0.362 & 484 & 0.495 & 598 & 0.660 \\ 2027 & 1.000 & 148 & 413 & 0.362 & 489 & 0.501 & 604 & 0.667 \\ 2028 & 1.000 & 148 & 413 & 0.362 & 489 & 0.501 & 604 & 0.667 \\ 2028 & 1.000 & 148 & 413 & 0.362 & 489 & 0.501 & 604 & 0.667 \\ 2028 & 1.000 & 148 & 413 & 0.362 & 489 & 0.501 & 604 & 0.667 \\ 2028 & 1.000 & 148 & 409 & 0.358 & 486 & 0.497 & 598 & 0.660 \\ 2029 & 1.000 & 148 & 393 & 0.345 & 471 & 0.482 & 581 & 0.642 \\ 2031 & 1.000 & 148 & 393 & 0.345 & 471 & 0.482 & 581 & 0.642 \\ 2032 & 1.000 & 148 & 393 & 0.345 & 471 & 0.482 & 581 & 0.642 \\ 2021 & 1.000 & 148 & 393 & 0.358 & 486 & 0.497 & 598 & 0.665 \\ 2022 & 1.000 & 148 & 393 & 0.355 & 471 & 0.482 & 581 & 0.642 \\ 2031 & 0.874 & 130 & 406 & 0.355 & 471 & 0.482 & 581 & 0.642 \\ 2023 & 0.874 & 130 & 406 & 0.355 & 471 & 0.482 & 581 & 0.642 \\ 2024 & 0.855 & 128 & 415 & 0.364 & 486 & 0.497 & 599 & 0.662 \\ 2025 & 0.875 & 123 & 425 & 0.372 & 500 & 0.511 & 612 & 0.675 \\ 2026 & 0.813 & 124 & 425 & 0.372 & 500 & 0.511 & 612 & 0.675 \\ 2030 & 0.818 & 122 & 424 & 0.371 & 499 & 0.510 & 606 & 0.699 \\ 2031 & 0.810 & 121 & 424 & 0.371 & 499 & 0.510 & 606 & 0.699 \\ 2031 & 0.810 & 121 & 424 & 0.371 & 499 & 0.510 & 606 & 0.699 \\ 2031 & 0.810 & 121 & 424 & 0.371 & 498 & 0.509 & 598 & 0.660 \\ \end{array}$  |                          | 2023 | 0.762            | 121        | 408                | 0.358                | 477                | 0.488                | 589                | 0.651                |
| $ \begin{array}{c} p^* = 0.40, \sigma = \\ 1 \\ 1 \\ \\ \begin{array}{c} 2025 & 0.733 \\ 2027 & 0.706 & 115 \\ 2027 & 0.706 & 115 \\ 2028 & 0.693 & 114 \\ 421 & 0.371 \\ 424 & 0.371 \\ 499 & 0.510 \\ 499 & 0.510 \\ 611 & 0.675 \\ 2028 & 0.693 & 114 \\ 427 & 0.374 \\ 503 & 0.514 \\ 613 & 0.677 \\ 2029 & 0.680 & 112 \\ 432 & 0.374 \\ 506 & 0.518 \\ 614 & 0.678 \\ 2030 & 0.667 \\ 2031 & 0.654 \\ 109 \\ 2032 & 0.642 \\ 108 \\ 448 \\ 0.392 \\ 2032 \\ 0.642 \\ 108 \\ 448 \\ 0.392 \\ 519 \\ 0.556 \\ 616 \\ 0.526 \\ 616 \\ 0.680 \\ 0.526 \\ 616 \\ 0.681 \\ 0.526 \\ 616 \\ 0.681 \\ 0.526 \\ 616 \\ 0.681 \\ 0.526 \\ 616 \\ 0.681 \\ 0.526 \\ 616 \\ 0.681 \\ 0.526 \\ 616 \\ 0.681 \\ 0.526 \\ 616 \\ 0.681 \\ 0.526 \\ 0.518 \\ 614 \\ 0.679 \\ 2032 \\ 0.642 \\ 100 \\ 2022 \\ 1.000 \\ 210 \\ 406 \\ 0.355 \\ 471 \\ 0.488 \\ 589 \\ 0.51 \\ 0.660 \\ 0.202 \\ 1.000 \\ 148 \\ 413 \\ 0.362 \\ 448 \\ 0.362 \\ 448 \\ 0.499 \\ 603 \\ 0.665 \\ 0.227 \\ 1.000 \\ 148 \\ 413 \\ 0.362 \\ 489 \\ 0.500 \\ 602 \\ 0.665 \\ 0.228 \\ 1.000 \\ 148 \\ 413 \\ 0.362 \\ 489 \\ 0.500 \\ 602 \\ 0.665 \\ 0.228 \\ 1.000 \\ 148 \\ 413 \\ 0.362 \\ 489 \\ 0.500 \\ 602 \\ 0.665 \\ 0.660 \\ 0.202 \\ 0.00 \\ 148 \\ 409 \\ 0.356 \\ 448 \\ 0.491 \\ 0.501 \\ 604 \\ 0.665 \\ 0.660 \\ 0.665 \\ 0.228 \\ 0.000 \\ 148 \\ 399 \\ 0.350 \\ 477 \\ 0.488 \\ 584 \\ 0.660 \\ 0.665 \\ 0.228 \\ 0.000 \\ 148 \\ 399 \\ 0.350 \\ 471 \\ 0.488 \\ 584 \\ 0.660 \\ 0.665 \\ 0.231 \\ 0.00 \\ 148 \\ 399 \\ 0.350 \\ 471 \\ 0.488 \\ 589 \\ 0.651 \\ 0.232 \\ 1.000 \\ 148 \\ 399 \\ 0.350 \\ 471 \\ 0.488 \\ 589 \\ 0.651 \\ 0.232 \\ 0.833 \\ 120 \\ 425 \\ 0.372 \\ 501 \\ 0.512 \\ 611 \\ 0.675 \\ 0.598 \\ 0.660 \\ 0.665 \\ 0.660 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.665 \\ 0.660 \\ 0.665 \\ 0.511 \\ 612 \\ 0.67 \\ 0.511 \\ 606 \\ 0.665 \\ 0.660 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.511 \\ 0.60 \\ 0.66 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.665 \\ 0.598 \\ 0.660 \\ 0.511 \\ 0.60 \\ 0.598 \\ 0.660 \\ 0.511 \\ 0.60 \\ 0.69 \\ 0.511 \\ 0.60 \\ 0.60 \\ 0.598 \\ 0.60 \\ 0.511 \\ 0.60 \\ 0.60 \\ 0.598 \\ 0.60 \\ 0.511 \\ 0.60 \\ 0.60 \\ 0.598 \\ 0.60 \\ 0.511 \\ 0.60 \\ 0.598 \\ 0.60 \\ 0.511 \\ 0.60 \\ 0.60 \\ 0.598 \\ 0.60 \\ 0.511 \\ 0.60 \\ 0.598 \\ 0.60 \\ 0.$   |                          | 2024 | 0.747            | 119        | 413                | 0.362                | 484                | 0.495                | 598                | 0.660                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   |                          | 2025 | 0.733            | 118        | 418                | 0.366                | 490                | 0.501                | 604                | 0.667                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   | $p^* = 0.40, \sigma =$   | 2026 | 0.719            | 116        | 421                | 0.368                | 495                | 0.506                | 608                | 0.672                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   | 1                        | 2027 | 0.706            | 115        | 424                | 0.371                | 499                | 0.510                | 611                | 0.675                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2028 | 0.693            | 114        | 427                | 0.374                | 503                | 0.514                | 613                | 0.677                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2029 | 0.680            | 112        | 432                | 0.378                | 506                | 0.518                | 614                | 0.678                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2030 | 0.667            | 111        | 437                | 0.382                | 510                | 0.522                | 615                | 0.679                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2031 | 0.654            | 109        | 442                | 0.387                | 515                | 0.526                | 616                | 0.680                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   |                          | 2032 | 0.642            | 108        | 448                | 0.392                | 213                | 0.531                | 617                | 0.681                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   |                          | 2021 | 1.000            | 210        | 406                | 0.355                | 471                | 0.482                | 581                | 0.642                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   |                          | 2022 | 1.000            | 210        | 407                | 0.357                | 474                | 0.485                | 585                | 0.646                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   |                          | 2023 | 1.000            | 148        | 408                | 0.358                | 477                | 0.488                | 589                | 0.651                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   | Long-term                | 2024 | 1.000            | 148        | 413                | 0.362                | 484                | 0.495                | 598                | 0.660                |
| $            \begin{array}{ c c c c c c c c c c c c c c c c c c c$  | Equil. Yield             | 2025 | 1.000            | 148        | 410                | 0.364                | 488                | 0.499                | 603                | 0.065                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   | (MSY proxy,              | 2026 | 1.000            | 148        | 415                | 0.364                | 490                | 0.501                | 604                | 0.667                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   | SPR <sub>50%</sub> ), no | 2027 | 1.000            | 148        | 413                | 0.362                | 489                | 0.500                | 502                | 0.005                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   | buffer                   | 2028 | 1.000            | 148        | 405                | 0.354                | 480                | 0.497                | 502                | 0.654                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2029 | 1.000            | 148        | 399                | 0.350                | 477                | 0.488                | 584                | 0.646                |
| $ \begin{array}{ c c c c c c c c c c c c c c c c c c c$   |                          | 2031 | 1.000            | 148        | 393                | 0.345                | 471                | 0.482                | 576                | 0.637                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   |                          | 2032 | 1.000            | 148        | 388                | 0.339                | 466                | 0.476                | 568                | 0.628                |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$  |                          | 2021 | 1.000            | 210        | 406                | 0.355                | 471                | 0.482                | 581                | 0.642                |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$  |                          | 2021 | 1.000            | 210        | 400                | 0.355                | 471                | 0.485                | 585                | 0.642                |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$  |                          | 2023 | 0.874            | 130        | 408                | 0.358                | 477                | 0.488                | 589                | 0.651                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   |                          | 2024 | 0.865            | 128        | 415                | 0.364                | 486                | 0.497                | 599                | 0.662                |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$  | Long-term                | 2025 | 0.857            | 127        | 420                | 0.368                | 493                | 0.504                | 607                | 0.670                |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $   | Equil. Yield             | 2026 | 0.849            | 126        | 423                | 0.370                | 497                | 0.508                | 611                | 0.675                |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$  | (MSY proxy,              | 2027 | 0.841            | 125        | 424                | 0.372                | 500                | 0.511                | 612                | 0.676                |
| with buffer 2029 0.826 123 425 0.372 501 0.512 609 0.673   2030 0.818 122 424 0.371 500 0.511 606 0.669   2031 0.810 121 424 0.371 499 0.510 602 0.665   2032 0.803 120 423 0.371 498 0.509 598 0.660   | $SPR_{50\%}),$           | 2028 | 0.833            | 124        | 425                | 0.372                | 501                | 0.512                | 611                | 0.675                |
| 2030 0.818 122 424 0.371 500 0.511 606 0.669   2031 0.810 121 424 0.371 499 0.510 602 0.665   2032 0.803 120 423 0.371 498 0.509 598 0.660  | with buffer              | 2029 | 0.826            | 123        | 425                | 0.372                | 501                | 0.512                | 609                | 0.673                |
| 2031 0.810 121 424 0.371 499 0.510 602 0.665   2032 0.803 120 423 0.371 498 0.509 598 0.660   |                          | 2030 | 0.818            | 122        | 424                | 0.371                | 500                | 0.511                | 606                | 0.669                |
| 2032 0.803 120 423 0.371 498 0.509 598 0.660  |                          | 2031 | 0.810            | 121        | 424                | 0.371                | 499                | 0.510                | 602                | 0.665                |
|   |                          | 2032 | 0.803            | 120        | 423                | 0.371                | 498                | 0.509                | 598                | 0.660                |