Agenda Item G.5
Attachment 1 (**Electronic Only**)
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Status of Dover sole (*Microstomus pacificus*) along the U.S. West Coast in 2021

by
Chantel R. Wetzel[1]
Aaron M. Berger[2]

[1]Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, Washington 98112
[2]Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2032 Southeast OSU Drive, Newport, Oregon 97365

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Disclaimer

One Page Summary

- This assessment for Dover sole incorporates a wide range of data sources: landings data and discard estimates; survey indices of abundance, length- and/or age-composition data for each fishery or survey (with conditional age-at-length data used for the surveys); information on weight-at-length, maturity-at-length, and fecundity-at-length; information on natural mortality and the steepness of the Beverton-Holt stock-recruitment relationship; and estimates of ageing error.
- The longest time series of fishery-independent information off the U.S. west coast arises from the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) that has been conducted annually from 2003 - 2019. The length and age data from this survey were highly influential on the model estimates of stock size and status. Additionally, these data were used to externally estimate starting parameter values by sex for length-at-age and the fixed values by sex for length-weight relationship.
- Dover sole off the U.S. west coast appear to have complex movement patterns, moving across depths, likely driven by season, spawning, and by size. Additionally, observations indicate possible sex-specific aggregations where a higher proportion of female fish are found in shallower (less than 300 m) and deeper waters (greater than 900 m), with higher proportion of males observed at intermediate depths (300 - 700 m).
- The model parameterization allowed for sex-specific selectivity with female Dover sole never fully selected (maximum selectivity less than 1.0). Large female Dover sole are observed at the deepest depth sampled (1,280 m) off the West Coast and likely extend into unobserved deeper depths. Lack of full selectivity of female Dover sole results in a fraction of unobserved spawning biomass in the population, increasing uncertainty in the estimate of the stock scale that the base model may not fully capture (via asymptotic error assumptions around estimated parameters).
- The model was highly sensitive to the assumed value of natural mortality. The base model fixed the instantaneous rate of natural mortality for females at the median of the prior, 0.108 per year, and estimated male natural mortality as an offset from the female value. When estimated, female natural mortality was well below the median of the prior, at 0.082 per year, which did not appear well supported by longevity information and resulted in estimates of survey catchability at or above 2.0. However, the relative difference in natural mortality by sex appeared to be well defined across reasonable ranges of natural mortality which informed the decision to only estimate male natural mortality parameterized as an offset from the fixed female value.
- The estimated spawning biomass at the beginning of 2021 was 232,065 mt (~95 percent asymptotic intervals: 154,153 to 309,977 mt), which when compared to unfished spawning biomass (294,070 mt) equates to a relative stock status level of 79 percent (~95 percent asymptotic intervals: 71 to 87 percent). The estimated scale of the stock (SB_0) from this assessment, 294,070 mt, is lower than the value estimated in the 2011 assessment of 469,866 mt but well within the 2011 ~95 percent asymptotic interval (182,741 - 756,991 mt).
- Fishing intensity (1 - SPR) over the past decade has been well below the target $\text{SPR}_{30\%}$, ranging between 0.11 and 0.2. The estimated target spawning biomass based on the 25 percent management target is 73,518. Sustainable total yield, landings plus discards, using $\text{SPR}_{30\%}$ is estimated at 22,891 mt.

Executive Summary

Stock

This assessment reports the status of Dover sole (*Microstomus pacificus*) off the U.S. west coast using data through 2020. Dover sole are also harvested from the waters off the Canadian coast and in the Gulf of Alaska, and although those catches were not included in this assessment, it is not certain if those populations contribute to the biomass of Dover sole off the U.S. west coast. Dover sole exhibit complex seasonal and ontogenetic movement, moving to deeper waters based on size but also shifting seasonally, moving from shallower feeding grounds on the continental shelf during the summer months to deeper spawning habitat on the outer continental shelf and slope in the winter. However, the specific mechanisms that drive stock structure and related variability over space and time, are not well understood.

Landings

Dover sole were first landed in California in the early part of the 20th century with landings beginning in Oregon and Washington in the 1940's (Figure i). Landings remained relatively constant throughout the 1950s and 1960s before increasing rapidly into the early 1990s. Subsequently, the landings declined by nearly 60 percent in California and Oregon/Washington until 2007 when harvest guidelines increased the allowable catch leading to increased landings between 2007 - 2010. Since 2011, landings have been steadily decreasing, where the landings in 2020 is the lowest on record since the 1940s (Table i). There are multiple factors that have led to the recent low landings of Dover sole (e.g., co-occurrence with constraining stocks, market forces).

Groundfish trawl fisheries account for the majority of Dover sole landings off the West Coast, with fixed gears, shrimp trawls, and recreational fisheries collectively make up a very small amount of fishing mortality (less that 1 percent of the total). Some discarding of Dover sole has occurred in these fisheries, primarily prior to the implementation of the Individual Fishing Quota (IFQ) Catch Shares Program in 2011. Discard mortality was estimated within the model based on data of discarding rates and lengths across time. Landings and the estimates of total mortality are reported (Table i).

Table i: Recent landings by fleet, total landings summed across fleets, and the total mortality including discards.

Year	CA	OR WA	Total Landings	Total Dead
2011	2401.08	5381.29	7782.37	7893.18
2012	2160.60	5167.29	7327.89	7429.72
2013	2217.77	5752.41	7970.18	8077.92
2014	1954.98	4494.25	6449.23	6543.10
2015	1892.58	4434.15	6326.73	6354.50
2016	1808.26	5510.11	7318.37	7349.81
2017	2196.85	5694.75	7891.60	7925.06
2018	1640.28	4780.99	6421.27	6447.41
2019	1397.44	4369.42	5766.86	5789.61
2020	1616.99	3070.65	4687.64	4706.57

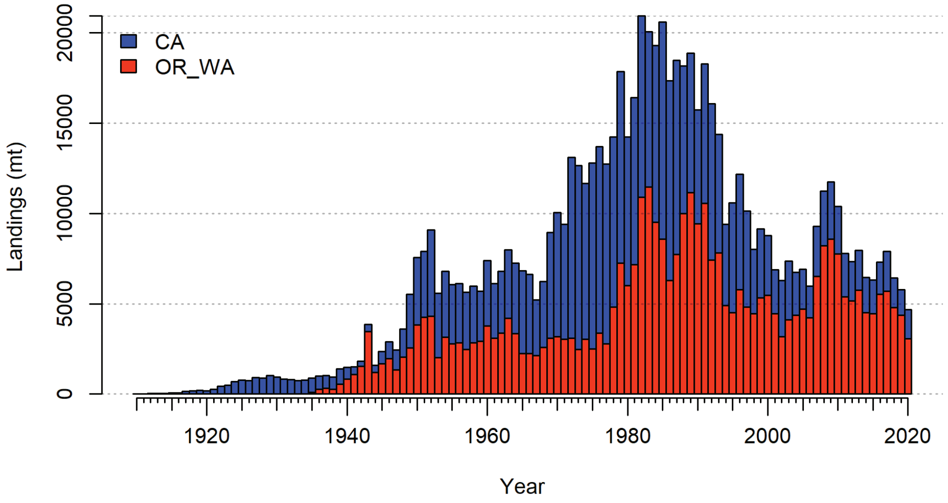

Figure i: Landings by fleet used in the base model where catches in metric tons by fleet are stacked.

Data and Assessment

This stock assessment for Dover sole off the west coast of the U.S. was developed using the length- and age-structured model Stock Synthesis (version 3.30.16). The previous stock assessment of Dover sole was conducted in 2011 and estimated the stock to be increasing with a stock status determination of 84 percent of virgin (or unfished) spawning biomass at the beginning of 2011. During the development of this assessment, model specifications including fleet structure, landings, data, and model structural assumptions were re-evaluated. Similar to the previous assessment, a single coastwide population was modeled allowing for area-specific fleets and separate growth and mortality parameters for each sex (i.e., a two-sex model). The model time domain is 1911 to 2020, with a 12 year forecast beginning in 2021.

All the data sources included in the base model for Dover sole have been re-evaluated for this assessment, including improvements and updates in the data (and associated analyses) that were used in the previous assessment. Estimate of landings prior to the mid-1980s have also been updated using the new historical catch reconstruction time series for Oregon. Survey data from the Alaska Fisheries Science Center (AFSC) and Northwest Fisheries Science Center (NWFSC) have been used to construct four sets of relative abundance indices, each spanning different time periods, were independently developed using a spatio-temporal delta-generalized linear mixed model (i.e., VAST).

The definition of fishing fleets changed in this assessment relative to those in the 2011 assessment. Two fishing fleets are now defined in the model: 1) a combined gear California fleet and 2) a combined gear Oregon/Washington fleet. The fleet grouping for Oregon and Washington was suggested by State representatives during the pre-assessment data meeting because of similarities in fishing across this region while also avoiding the inherent difficulties associated with separating data between Oregon and Washington due to the intermixing of fishing and landing locations across state boundaries.

This assessment integrates data and information from multiple sources into one modeling framework. Specifically, the assessment uses landings data and discard estimates; survey indices of abundance, length- and/or age-composition data for each fishery or survey (with conditional age-at-length data used for the Northwest Fisheries Science Center Slope Survey (NWFSC Slope Survey) and WCGBTS); information on weight-at-length, maturity-at-length, and fecundity-at-length; information on natural mortality and the steepness of the Beverton-Holt stock-recruitment relationship; and estimates of ageing error. The base model was tuned to account for the weighting of composition data as well as the specification of recruitment variance and recruitment bias adjustments. Estimates of recruitment at equilibrium spawning biomass (R_0), annual recruitment deviations, sex-specific length-based selectivity of the fisheries and surveys, retention for each of the fishery fleets, catchability of the surveys, sex-specific growth, the time series of spawning biomass, age and size structure, and current and projected future stock status are derived outputs of the model.

Multiple sources of uncertainty are explicitly included in this assessment, including parameter uncertainty using prior distributions, observational uncertainty through standard deviations of survey estimates, and model uncertainty through a comprehensive sensitivity analyses to data source and model structural assumptions. A base model was selected that best fit the observed data while concomitantly balancing the desire to capture the central tendency across those sources of uncertainty, ensure model realism and tractability, and promote robustness to potential model misspecification.

Stock Biomass

The terms "spawning output" and "spawning biomass" are used interchangeably in this document in reference to total female spawning biomass. For the purposes of this assessment, female spawning biomass is assumed to be proportional to egg and larval production (i.e., spawning output). The estimated spawning biomass at the beginning of 2021 was 232,065 mt (~95 percent asymptotic intervals: 154,153 to 309,977 mt, Table ii and Figure ii), which when compared to unfished spawning biomass (294,070 mt) equates to a relative stock status level of 79 percent (~95 percent asymptotic intervals: 71 to 87 percent, Figure iii). Overall, spawning stock biomass has steadily declined from near unfished levels in the 1940s to a time series low of 60 percent of unfished levels in 1994 following high landings in the 1980s and early 1990s. Over the past two decades, spawning stock biomass has generally been increasing as total landings have decreased. The stock is estimated to be well above the management target of $SB_{25\%}$ in 2021 and has remained well above the target throughout the time series (Table ii and Figure iii).

Table ii: Estimated recent trend in spawning biomass and the fraction unfished and the 95 percent intervals.

Year	Spawning Biomass (mt)	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2011	221913	145783.9	298042.1	0.75	0.67	0.84
2012	220118	144422.4	295813.6	0.75	0.67	0.83
2013	218371	143170.7	293571.3	0.74	0.66	0.82
2014	216973	142101.2	291844.8	0.74	0.66	0.82
2015	217507	142620.1	292393.9	0.74	0.66	0.82
2016	219403	144148.4	294657.6	0.75	0.67	0.82
2017	221755	145892.4	297617.6	0.75	0.68	0.83
2018	224177	147622.8	300731.2	0.76	0.68	0.84
2019	227036	149849.3	304222.7	0.77	0.69	0.85
2020	229626	151976.5	307275.5	0.78	0.70	0.86
2021	232065	154152.5	309977.5	0.79	0.71	0.87

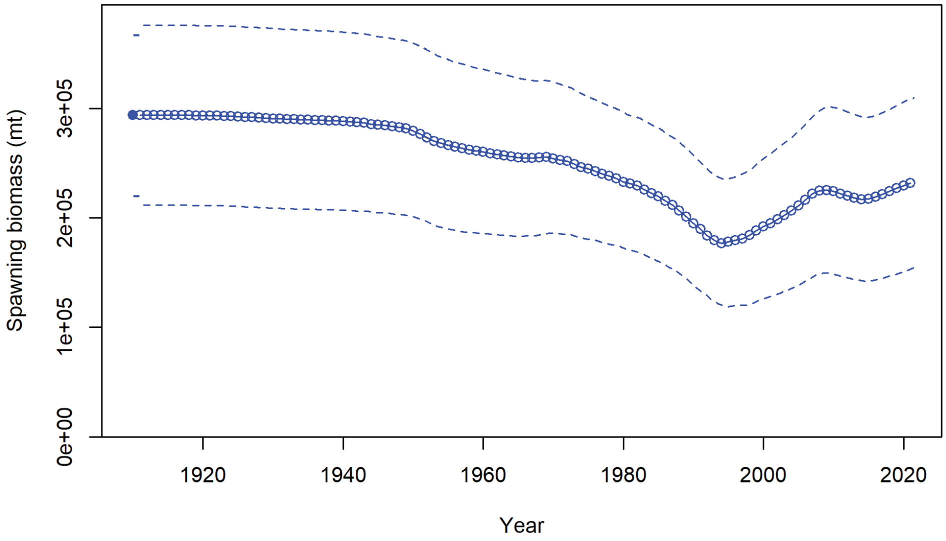

Figure ii: Estimated time series of spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

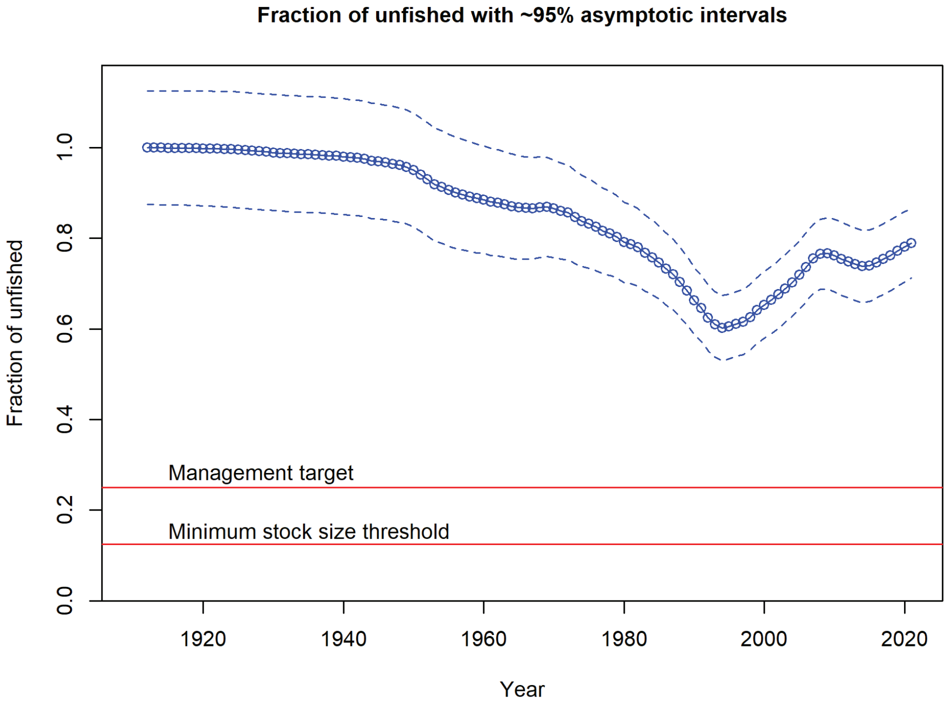

Figure iii: Estimated time series of fraction of unfished spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

Recruitment

There is large uncertainty associated with annual differences in recruitment across much of the time series due to a lack of informative data during the early period and little contrast in composition and index data in the later period to signal much variation in cohort strength (Table iii and Figure iv). Data were most informative from the early-2000s to the mid-2010s, where estimates showed periods of below average recruitment (2002-2006) and above average recruitment (2008-2010). The 2000 and 2009 year classes are estimated to be the largest across the time series and were well determined as being above average (i.e., ~95 percent asymptotic intervals did not span 0, Figure v). Overall, the Dover sole stock has not been reduced to levels that would provide considerable information on how recruitment changes with across spawning biomass levels (i.e., inform the steepness parameter). Thus, all recruitment is based on a fixed assumption about steepness ($h = 0.80$) and recruitment variability ($\sigma_R = 0.35$).

Table iii: Estimated recent trend in recruitment and recruitment deviations and the 95 percent intervals.

Year	Recruitment	Lower Interval	Upper Interval	Recruitment Deviations	Lower Interval	Upper Interval
2011	204214	127585.52	326865.9	0.02	-0.37	0.41
2012	238648	154157.64	369445.6	0.18	-0.16	0.53
2013	161941	98865.06	265259.4	-0.21	-0.64	0.21
2014	166317	100364.16	275609.8	-0.19	-0.63	0.24
2015	199178	114941.63	345148.0	-0.02	-0.51	0.47
2016	205309	107885.30	390709.3	0.00	-0.61	0.61
2017	206028	103251.00	411110.2	-0.01	-0.67	0.66
2018	208863	103767.15	420400.4	0.00	-0.68	0.67
2019	209235	103020.66	424956.4	0.00	-0.69	0.69
2020	209423	103120.09	425309.9	0.00	-0.69	0.69
2021	209596	103213.09	425629.0	0.00	-0.69	0.69

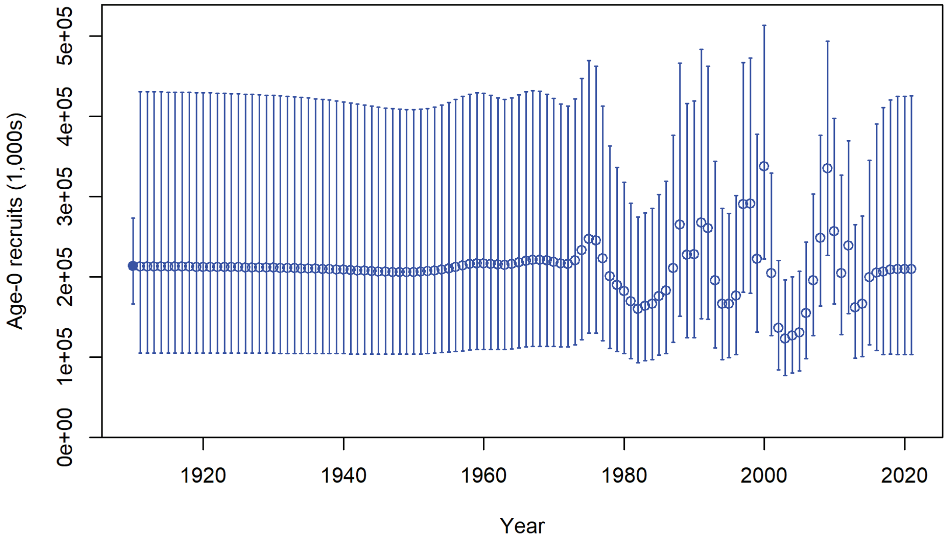

Figure iv: Estimated time series of age-0 recruits (1000s) for the base model with 95 percent intervals.

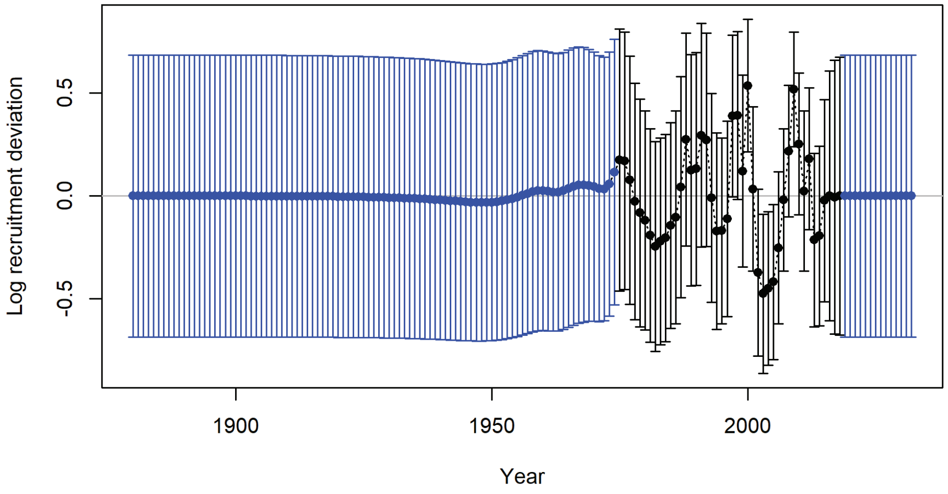

Figure v: Estimated time series of recruitment deviations.

Exploitation Status

Trends in fishing intensity (1 - SPR) largely mirrored that of landings given the relative lack of large variations in annual recruitment such that there was a steady increase from the 1940s to the mid to late 1980s before decreasing to current levels of 0.11 for 2020 (Figure vi). The maximum fishing intensity was 0.45 in 1991, well below the target harvest rate of 0.70 (1 - $SPR_{30\%}$). Fishing intensity over the past decade has ranged between 0.11 and 0.2 and the exploitation rate has been low (0.01 - 0.02, Table iv). Current estimates indicate that Dover sole spawning biomass is greater than 3 times higher than the target biomass level ($SB_{25\%}$), and fishing intensity remains well below the target harvest rate.

Table iv: Estimated recent trend in the 1-SPR where SPR is the spawning potential ratio the exploitation rate, and the 95 percent intervals.

Year	1-SPR	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2011	0.18	0.13	0.24	0.02	0.01	0.02
2012	0.18	0.13	0.23	0.02	0.01	0.02
2013	0.20	0.14	0.25	0.02	0.01	0.02
2014	0.17	0.12	0.21	0.01	0.01	0.02
2015	0.16	0.11	0.21	0.01	0.01	0.02
2016	0.18	0.13	0.23	0.02	0.01	0.02
2017	0.19	0.14	0.24	0.02	0.01	0.02
2018	0.15	0.11	0.20	0.01	0.01	0.02
2019	0.14	0.10	0.18	0.01	0.01	0.02
2020	0.11	0.08	0.14	0.01	0.01	0.01

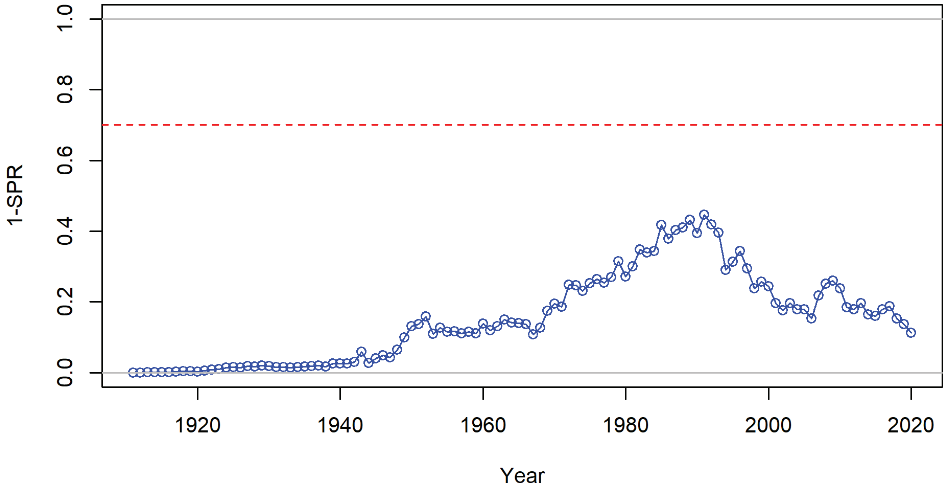

Figure vi: Estimated 1 - relative spawning ratio (SPR) by year for the base model. The management target is plotted as a red horizontal line and values above this reflect harvest in excess of the proxy harvest rate.

Ecosystem Considerations

Ecosystem factors have not been explicitly modeled in this assessment but there are several aspects of the California current ecosystem that may impact Dover sole population dynamics and warrant further research. Survival of Dover sole eggs and pelagic larvae that have a protracted pelagic phase are linked to water circulation patterns (King et al. 2011). The timing of settlement occurs typically between January and March and is correlated with Ekman transport, positive vertical velocity, and relatively warm bottom temperatures (Toole, Markle, and Donohoe 1997). Markle et al. (1992) hypothesized that juvenile Dover sole move inshore to nursery habitat by making vertical ascents during the night off bottom until they encounter suitable habitat. Tolimieri et al. (2020) identified multiple areas off the coast of southern California that had high densities of young Dover sole. This is consistent with the finding of Toole et al. (2011) that juvenile Dover sole 10 - 22 cm tended to move inshore during summer months. As Dover sole grow they generally move offshore into deep waters. Changing water temperature due to climate change may alter the winter onshore Ekman transport which could have impacts on juvenile survival and result in distributional shifts of favorable spawning grounds, or nursery habitats of Dover sole.

Reference Points

The 2021 spawning biomass relative to unfished equilibrium spawning biomass is well above the management target of 25 percent of unfished spawning biomass. The relative biomass compared to the ratio of the estimated SPR to the management target ($\text{SPR}_{30\%}$) across all model years are shown in Figure vii where warmer colors (red) represent early years and colder colors (blue) represent recent years. The relative biomass and estimated SPR have been well above the management biomass target (25 percent) and well below the SPR target across all model years. Figure viii shows the equilibrium curve based on a steepness value fixed at 0.8 with vertical dashed lines to indicate the estimate of fraction unfished at the start of 2021 (current) and the estimated management targets calculated based on the relative target biomass (B target), the SPR target, and the maximum sustainable yield (MSY).

Reference points were calculated using the estimated selectivities and catch distributions among fleets in the most recent year of the model, 2020 (Table v). Sustainable total yield, landings plus discards, using an $\text{SPR}_{30\%}$ is 22,891 mt. The spawning biomass equivalent to 25 percent of the unfished spawning biomass ($\text{SB}_{25\%}$) calculated using the SPR target ($\text{SPR}_{30\%}$) was 74,498 mt. Recent removals have been below the point estimate of the potential long-term yields calculated using an $\text{SPR}_{30\%}$ reference point and the population scale has been relatively stable or increasing over the last decade.

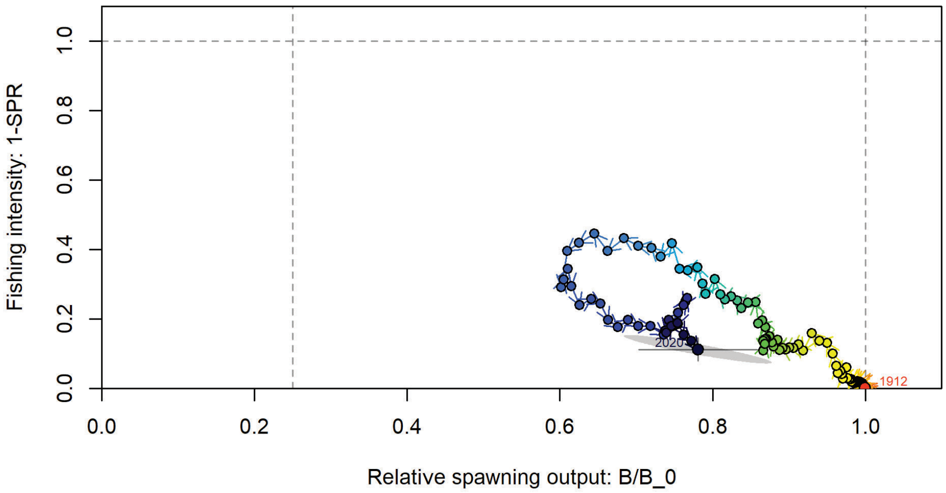

Figure vii: Phase plot of estimated 1-SPR versus fraction unfished for the base model.

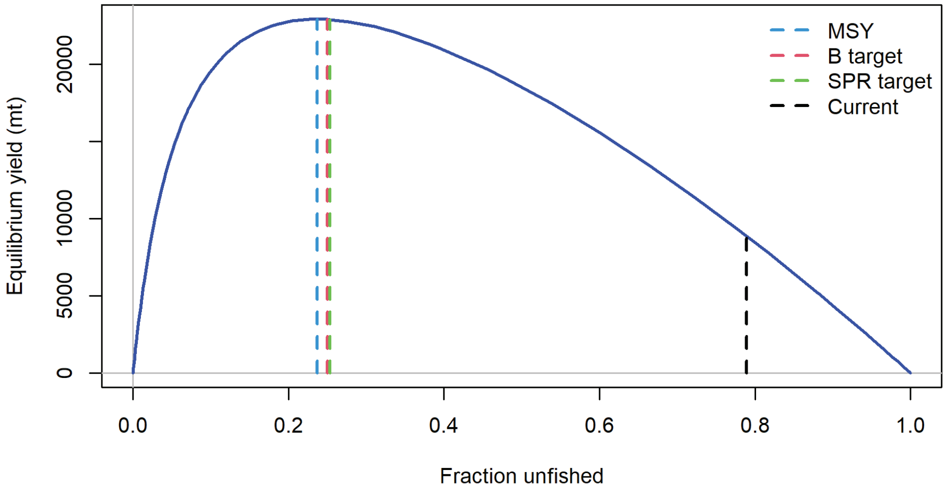

Figure viii: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivities and with steepness fixed at 0.80.

Table v: Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	294070	220699	367441
Unfished Age 3+ Biomass (mt)	594408	466269	722547
Unfished Recruitment (R0)	213096	159928	266264
Spawning Biomass (mt) (2021)	232065	154153	309977
Fraction Unfished (2021)	0.79	0.71	0.87
Reference Points Based SB25 Percent	-	-	-
Proxy Spawning Biomass (mt) SB25 Percent	73517	55175	91860
SPR Resulting in SB25 Percent	0.30	0.30	0.30
Exploitation Rate Resulting in SB25 Percent	0.12	0.12	0.12
Yield with SPR Based On SB25 Percent (mt)	22901	17705	28097
Reference Points Based on SPR Proxy for MSY	-	-	-
Proxy Spawning Biomass (mt) (SPR30)	74498	55910	93085
SPR30	0.30	-	-
Exploitation Rate Corresponding to SPR30	0.12	0.12	0.12
Yield with SPR30 at SB SPR (mt)	22891	17697	28084
Reference Points Based on Estimated MSY Values	-	-	-
Spawning Biomass (mt) at MSY (SB MSY)	69598	52425	86771
SPR MSY	0.28	0.28	0.29
Exploitation Rate Corresponding to SPR MSY	0.13	0.12	0.13
MSY (mt)	22919	17716	28122

Management Performance

Exploitation on Dover sole slowly increased starting around 1940 and reached a high in the early 1990s. After peaking in the 1990s exploitation rates declined steadily through 2006, increased from 2007 - 2010, but have steadily declined since. In the last ten years the annual catch limit (ACL) has been set well below the overfishing limit (OFL) and acceptable biological catch (ABC) (Table vi). Total mortality has ranged between 10 - 15 percent of the ACL in the most recent five years.

Table vi: The OFL, ABC, ACL, landings, and the estimated total mortality in metric tons.

Year	OFL	ABC	ACL	Landings	Est. Total Mortality
2011	44400	42436	25000	7782	7893
2012	44826	42843	25000	7328	7430
2013	92955	88865	25000	7970	8078
2014	77774	74352	25000	6449	6543
2015	66871	63929	50000	6327	6354
2016	59221	56615	50000	7318	7350
2017	89702	85755	50000	7892	7925
2018	90282	86310	50000	6421	6447
2019	91102	87094	50000	5767	5790
2020	92048	87998	50000	4688	4707

Unresolved Problems and Major Uncertainties

The base case model was developed with the goal of balancing parsimony with realism and fitting the data. To achieve parsimony, some simplification of model structure was assumed which may impact the interpretation and fit to specific data sets. The maturity-at-length or -at-age analysis conducted for this assessment identified possible differences in Dover sole south and north of Point Reyes. Currently, there is limited information on the movement of Dover sole by latitude or depth which could provide insights into the mechanisms behind these observed differences. Spatial estimates of biomass north and south of Point Reyes, using WCGBTS data averaged across the most recent five years, indicated that approximately 67 percent of the West Coast Dover sole biomass is estimated to be north of Point Reyes. Additionally, in recent years the majority of fishery data have been collected from ports north of Point Reyes, which limits the ability to support additional model complexity. Given the lack of information to inform the structure and parameterization of a spatial model, the base model assumed a single homogeneous population structure at this time. Future research into the biology and movement of Dover sole could facilitate future spatial modeling efforts if found to be the appropriate approach.

Uncertainty in natural mortality translates into uncertain estimates of both status and sustainable fishing levels for Dover sole. In the base model, a balance between fixing and estimating this key parameter was achieved by fixing female natural mortality at the median of the prior while estimating the relative difference in male natural mortality. The difference between male and female natural mortality appeared to be well informed (likelihood profile) with estimates consistent with the data and biology of Dover sole across its range (U.S. west coast, Canada, U.S. Alaska waters). The likelihood profile across values of female natural mortality supported lower values, which were not expected *a priori* based on the available age data and were largely driven by length data from the AFSC slope survey. This could be due to limited information about maximum age for Dover sole in the data, the limited selection of female Dover sole by the fisheries and surveys or could indicate model misspecification. It is unclear what is driving this behavior in the model.

Dover sole life history exhibit strong relationships with depth that indicate the stock is more complex than the model assumes. Small fish are found in shallow water, with the median observed size increasing with depth. However, the variability of sizes observed by sex increases moving from deeper to shallower waters. Specifically, the WCGBTS observes large females at the deepest depths sampled but also observe some of the largest female Dover sole in waters less than 300 meters. In addition, there is a pattern of sex ratio by depth with more males being found in middle depths and more females found in shallow and deeper depths. These patterns are apparent in the summer fisheries and surveys. It is uncertain how the patterns affect the data (they may be a cause of the bi-modal length distributions seen in the slope surveys) and if these patterns can be effectively modeled to produce better fits to the data and better predictions of biomass while still preserving model parsimony.

Scientific Uncertainty

The model estimated uncertainty around the 2021 spawning biomass was $\sigma = 0.17$ and the uncertainty around the OFL was $\sigma = 0.16$. This is likely an underestimate of overall uncertainty because of the necessity to fix several population dynamic parameters (e.g., steepness, recruitment variance, female natural mortality) and no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

Harvest Projections and Decision Table

The forecast of stock abundance and yield was developed using the base model. The total catches in 2021 and 2022 were set at 10,000 mt, well below the adopted 50,000 mt ACL for those year, based on recommendations from the Groundfish Management Team (GMT). These assumed removals are likely higher than what the true removals may be in 2021 and 2023 but have limited impact in the stock status and future removals during the projected period in the base model. The exploitation rate for 2023 and beyond is based upon an SPR of 30 percent and the 25:5 harvest control rule. The average exploitation rates, across recent years, by fleet were used to distribute catches during the forecast period. The ABC values were estimated using a category 1 time-varying σ_y starting at 0.50 combined with a P* value of 0.45. The catches in the base model during the projection period, 2023 - 2032 were set equal to the year-specific ABC using the current flatfish harvest control rule, 25:5 (Table vii).

The axes of uncertainty in the decision table are based on the uncertainty around female natural mortality. The default category 1 σ value of 0.50 was used to identify the low and high states of nature relative to the estimated 2021 spawning biomass (i.e., 1.15 standard deviations corresponding to the 12.5 and 87.5 percentiles). A search across female natural mortality values was done to identify the natural mortality value that resulted in current year spawning biomass values for the low and high states of nature based on the percentiles. The female natural mortality values that corresponded with the lower and upper percentiles were 0.084 yr^{-1} and 0.126 yr^{-1}.

Initial explorations were conducted using the model estimated uncertainty around 2021 spawning biomass of $\sigma = 0.17$ rather than the higher default category 1 σ value. However, the range of the low and high states of nature relative to the base model were determined to not adequately capture uncertainty based on feedback received during the STAR panel review. Model estimated uncertainty is an underestimate of the true uncertainty around the stock size since it only captures within model uncertainty and does not account for structural uncertainties. Applying a higher σ value allowed the low and high states of nature to capture a larger uncertainty range around the base model which may be more in line with the cumulative model and structural uncertainty. It was noted that the low and high states of nature results in catchability values (low state of nature catchability = 2.0 and high state of nature catchability = 0.56) for the WCGBTS that were factors higher or lower than the base model catchability (1.072). Catchability values could potentially provide understanding of the plausibility of alternative states; however, adequately interpreting values of catchability comes with inherent challenges due to changes in other key model parameters (e.g., selectivity).

Three alternative catch streams were created for the decision table (Table viii). The first option uses ABC values which are adjusted based on time-varying σ_y starting at 0.50 and increasing annually combined with a P* value of 0.45. The two alternative catch streams assume fixed catches of either 7,000 or 20,000 mt for the 10 year projection period. All of these options assume full attainment of the catch values.

Across the low and high states of nature and across alternative future harvest scenarios the fraction of unfished ranges between 0.023 - 0.895 by the end of the 10 year projection period (Table viii). The low state of nature assuming full ABC removals results in a nearly depleted stock at the end of the time series. This is due to the assumption or removing the full ABC derived from the base model to the low state of nature which had an overall lower unfished spawning biomass associated with a low natural mortality value which results in a more depleted stock in 2021 relative to the base model.

Table vii: Projections of potential OFLs (mt), ABCs (mt), the buffer (ABC = buffer x OFL), estimated spawning biomass, and fraction unfished. The adopted OFL, ABC, and ACL for 2021 and 2022 reflect adopted management limits and the assumed removal is the removal assumptions applied for 2021 and 2022. The full ABC was assumed to be removed for 2023 - 2032

Year	Adopted OFL (mt)	Adopted ABC (mt)	Adopted ACL (mt)	Assumed Removal (mt)	OFL (mt)	ABC (mt)	Buffer	Spawning Biomass (mt)	Fraction Unfished
2021	93547	84192	50000	10000	-	-	-	232065	0.79
2022	87540	78436	50000	10000	-	-	-	231642	0.79
2023	-	-	-	-	63834	59684	0.935	230918	0.79
2024	-	-	-	-	55859	51949	0.93	207333	0.71
2025	-	-	-	-	49608	45937	0.926	187284	0.64
2026	-	-	-	-	44769	41277	0.922	170449	0.58
2027	-	-	-	-	41053	37646	0.917	156459	0.53
2028	-	-	-	-	38217	34892	0.913	144943	0.49
2029	-	-	-	-	36050	32770	0.909	135500	0.46
2030	-	-	-	-	34389	31088	0.904	127779	0.43
2031	-	-	-	-	33108	29797	0.9	121483	0.41
2032	-	-	-	-	32100	28762	0.896	116323	0.40

Table viii: Decision table summary of 10 year projections beginning in 2023 for alternative states of nature based on an axis of uncertainty about female natural mortality for the base model. Columns range over low, mid, and high states of nature and rows range over different catch level assumptions. Values in italics indicate years where the stock size prevented the full catch removals.

			M = 0.084		M = 0.108		M = 0.126	
	Year	Catch	Spawning Biomass	Fraction Unfished	Spawning Biomass	Fraction Unfished	Spawning Biomass	Fraction Unfished
7,000 mt	2021	10,000	130,402	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,406	0.578	231,642	0.788	410,978	0.899
	2023	7,000	130,187	0.577	230,918	0.785	409,093	0.895
	2024	7,000	130,897	0.58	231,425	0.787	408,497	0.894
	2025	7,000	131,593	0.583	231,923	0.789	408,020	0.892
	2026	7,000	132,315	0.586	232,460	0.790	407,746	0.892
	2027	7,000	133,080	0.59	233,048	0.792	407,685	0.892
	2028	7,000	133,889	0.593	233,681	0.795	407,810	0.892
	2029	7,000	134,732	0.597	234,344	0.797	408,079	0.893
	2030	7,000	135,595	0.601	235,020	0.799	408,451	0.893
	2031	7,000	136,465	0.605	235,695	0.801	408,888	0.894
	2032	7,000	137,331	0.609	236,358	0.804	409,361	0.895
20,000 mt	2021	10,000	130,357	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,358	0.578	231,642	0.788	410,978	0.899
	2023	20,000	130,139	0.577	230,918	0.785	409,093	0.895
	2024	20,000	125,188	0.555	225,521	0.767	402,630	0.881
	2025	20,000	120,142	0.533	220,194	0.749	396,479	0.867
	2026	20,000	115,118	0.51	215,059	0.731	390,789	0.855
	2027	20,000	110,193	0.488	210,181	0.715	385,612	0.843
	2028	20,000	105,413	0.467	205,591	0.699	380,946	0.833
	2029	20,000	100,799	0.447	201,293	0.685	376,756	0.824
	2030	20,000	96,356	0.427	197,281	0.671	372,999	0.816
	2031	20,000	92,080	0.408	193,539	0.658	369,624	0.809
	2032	20,000	87,958	0.39	190,049	0.646	366,588	0.802
ABC P* 0.45	2021	10,000	130,402	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,406	0.578	231,642	0.788	410,978	0.899
	2023	59,685	130,187	0.577	230,918	0.785	409,093	0.895
	2024	51,949	106,617	0.473	207,333	0.705	384,636	0.841
	2025	45,937	85,730	0.38	187,284	0.637	364,461	0.797
	2026	41,277	67,417	0.299	170,449	0.580	348,088	0.761
	2027	37,646	51,561	0.229	156,459	0.532	334,996	0.733
	2028	34,892	38,054	0.169	144,943	0.493	324,682	0.710
	2029	32,770	26,754	0.119	135,500	0.461	316,642	0.693
	2030	31,088	17,564	0.078	127,779	0.434	310,450	0.679
	2031	29,797	*10432*	*0.046*	121,483	0.413	305,756	0.669
	2032	28,762	*5289*	*0.023*	116,323	0.396	302,239	0.661

Research and Data Needs

Investigating and or addressing the following items could improve future assessments of Dover sole:

- Spatiotemporal distribution patterns with depth: There are patterns of length and sex ratios with depth which may indicate that the stock is more complex than currently modeled. Further research into the causes of these patterns as well as differences between seasons would help with understanding the stock characteristics such that a more realistic model could be built. This may also provide further insight into migration and help determine if there are localized populations.
- Stock boundaries: A common question in stock assessments is whether or not the entire stock is being represented. Dover sole live deeper than the range of the fisheries and surveys. The assessment model attempts to account for out of area biomass through catchability coefficients and selectivity curves, but that portion of the stock is unknown and can only be conjectured. Research into abundance in deep areas would be useful to verify that the assessment adequately predicts the entire spawning stock of Dover sole.
- Unavailable biomass: The distribution of Dover sole covers a wide-depth range off the West Coast. Dover sole are observed by the WCGBTS out to 1,280 m, the maximum depth sampled, where the majority of Dover sole observations at these depths are females. The sex-specific movement of Dover sole across depths results in the model estimating that females‘ are never fully selected (maximum selectivity well below 1.0 or dome-shaped) by the fisheries or the surveys. This results in an assumption that there is some portion of cryptic biomass that is unavailable for selection by the fisheries or observation by the surveys. Improved understanding about sex-specific availability across depths by season and the proportion of Dover sole biomass, particularly female biomass, at depths beyond the range of the survey would improve future estimates of stock size.
- California Sampling for Ages: Since 1990, nearly 60 percent of fish aged have been landed at the Crescent City port with some years all aged fish being landed there. In contrast, the majority of Dover sole landed in California occur at the Eureka port (approximately 67 percent over the last 10 years). Ensuring that sampling is spread across California ports and otoliths selected for ageing are spread across ports proportional to area removals may provide additional insights to area-specific population attributes.