## NOAA Technical Memorandum NMFS



MARCH 2016

# STATUS OF COMMON THRESHER SHARKS, ALOPIAS VULPINUS, ALONG THE WEST COAST OF NORTH AMERICA 

Steven L. H. Teo, Emiliano Garcia Rodriguez,<br>Oscar Sosa-Nishizaki

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency that establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries, is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.

SWFSC Technical Memorandums are accessible online at the SWFSC web site (http//swfsc.noaa.gov). Print copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151 (http://www.ntis.gov).

MARCH 2016

# STATUS OF COMMON THRESHER SHARKS, ALOPIAS VULPINUS, ALONG THE WEST COAST OF NORTH AMERICA 

Steven L. H. Teo ${ }^{1}$,<br>Emiliano Garcia Rodriguez², Oscar Sosa-Nishizaki²<br>${ }^{1}$ Fisheries Resources Division<br>Southwest Fisheries Science Center<br>National Marine Fisheries Service<br>National Oceanic and Atmospheric Administration<br>8901 La Jolla Shores Drive<br>La Jolla, CA 92037, USA<br>${ }^{2}$ Departamento de Oceanografía Biológica<br>Centro de Investigación Científica y de Educación Superior de Ensenada, CICESE<br>Carretera Ensenada-Tijuana No. 3918<br>Fraccionamiento Zona Playitas<br>Ensenada, Baja California,<br>C.P. 22860, Mexico

NOAA-TM-NMFS-SWFSC-557

U.S. DEPARTMENT OF COMMERCE<br>Penny S. Pritzker, Secretary of Commerce<br>National Oceanic and Atmospheric Administration<br>Dr. Kathryn D. Sullivan, Administrator<br>National Marine Fisheries Service<br>Eileen Sobeck, Assistant Administrator for Fisheries

Contents
EXECUTIVE SUMMARY ..... 5

1. Introduction ..... 18
1.1 Distribution, biology, and life history ..... 19
1.1.1 Distribution and seasonal movements ..... 19
1.1.2 Stock structure ..... 19
1.1.3 Reproductive biology ..... 20
1.1.4 Growth ..... 20
1.2 Historical and current fisheries in USA waters ..... 21
1.2.1 USA swordfish/shark drift gillnet (USDGN) ..... 21
1.2.2 USA nearshore set gillnet and small-mesh drift gillnet (USSN) ..... 22
1.2.3 USA recreational (USREC) ..... 23
1.3 Historical and current fisheries in Mexico waters. ..... 23
1.3.1 Mexico swordfish/shark drift gillnet (MXDGN) ..... 23
1.3.2 Mexico pelagic longline (MXLL) ..... 24
1.3.3 Mexico artisanal (MXART) ..... 24
1.4 Historical and current fisheries in Canadian and international waters. ..... 24
1.5 Management history ..... 24
2. Assessment data ..... 25
2.1 Fishery-dependent data ..... 25
2.1.1 Commercial removals ..... 26
2.1.2 Recreational removals ..... 28
2.1.3 Abundance indices ..... 28
2.1.4 Length composition data ..... 31
2.1.5 Conditional age-at-length data. ..... 33
2.2 Fishery-independent data ..... 33
2.2.1 USA juvenile thresher shark survey index (USJUV0614) ..... 34
2.2.2 Length composition data ..... 34
2.3 Biological parameters ..... 35
2.3.1 Maximum age ..... 35
2.3.2 Natural mortality ..... 35
2.3.3 Maturity and fecundity ..... 35
2.3.4 Weight-length relationship ..... 35
3. Model description ..... 36
3.1 Modeling software platform ..... 36
3.2 General model specifications ..... 36
3.3 Likelihood components ..... 37
3.4 Model parameterization. ..... 37
3.4.1 Life history ..... 37
3.4.2 Stock-recruitment ..... 38
3.4.3 Selectivity ..... 39
3.4.4 Catchability ..... 41
3.4.5 Initial conditions ..... 41
3.5 Data weighting ..... 41
4. Model selection and evaluation ..... 42
4.1 Alternative model configurations ..... 42
4.2 Model convergence ..... 43
4.3 Model fit ..... 43
4.3.1 Fit to abundance indices ..... 43
4.3.2 Fit to size compositions ..... 43
4.3.1 Fit to conditional age-at-lengths ..... 44
4.4 Retrospective analysis ..... 44
4.4 Likelihood profiles on virgin recruitment ( $R_{0}$ profile) ..... 44
4.5 Age-structured production model analysis ..... 45
5. Model results ..... 45
5.1 Model parameter estimates ..... 45
5.1.1 Growth ..... 45
5.1.2 Selectivity ..... 45
5.1.3 Catchability ..... 46
5.1.4 Catch-at-age ..... 46
5.1.5 Sex ratio ..... 46
5.2 Stock assessment results ..... 46
5.2.1 Reproductive capacity and output ..... 46
5.2.2 Recruitment ..... 47
5.2.3 Fishing mortality ..... 47
6. Model uncertainty ..... 48
6.1 Sensitivity analyses ..... 48
6.1.1 Alternative assumptions about fishery removals ..... 48
6.1.2 Alternative assumptions about stock-recruitment ..... 49
6.1.3 Alternative assumptions on life history ..... 50
6.1.4 Alternative data sources and weightings ..... 52
6.1.5 Alternative assumptions on selectivity ..... 53
7. Reference points ..... 54
8. Status of the stock ..... 55
9. Decision table. ..... 55
10. Regional management considerations ..... 56
11. Research and data needs ..... 56
Acknowledgements ..... 58
Literature cited ..... 58
TABLES ..... 63
FIGURES ..... 81
APPENDIX A: Abundance indices for the USA swordfish/shark gillnet fishery ..... 124
APPENDIX B: Abundance indices for the USA nearshore set gillnet and small-mesh drift gillnet fishery ..... 146
APPENDIX C: Abundance index for the USA juvenile thresher shark survey ..... 163
APPENDIX D: Common thresher shark assessment model files ..... 174
Starter file. ..... 174
Forecast file ..... 175
Data file ..... 176
Control file ..... 189

## EXECUTIVE SUMMARY

## Stock

Common thresher sharks (Alopias vulpinus) along the west coast of North America are seasonally distributed in coastal waters from British Columbia, Canada to central Baja California, Mexico. Juvenile common thresher sharks tend to remain in shallow, nearshore areas over the continental shelf, especially within the Southern California Bight (SCB), which is an important nursery area. The distributions of common and bigeye thresher sharks are thought to overlap partially, with bigeye thresher sharks generally exploiting deeper waters. In contrast, there relatively little overlap in the distributions of common and pelagic thresher sharks.

In this assessment, common thresher sharks along the west coast of North America are assumed to be a single, well-mixed stock. This assumption is supported by their genetics, tagging data, and seasonal movements. The mitochondrial genetic sequences of common thresher sharks from California waters are not significantly different from Oregon-Washington waters but both are significantly different from other sampling locations, noting that there have not been any published comparisons with samples from Mexico. There is also no evidence of pupping and nursery grounds outside of the SCB. Tags from common thresher sharks tagged in the SCB have been returned from California, USA, and Baja California, Mexico. There is also unlikely to be substantial interchange of individuals between this stock and other common thresher shark stocks because the geographically closest stock is likely to be along the west coast of Chile.

## Fisheries

The history of fisheries for this stock of common thresher sharks in USA waters is not well known prior to the 1970s but small amounts of catch were recorded by a variety of USA commercial and recreational fisheries. The most important USA commercial fishery for common thresher sharks is the swordfish/shark drift gillnet (USDGN) fishery, which started in 1977 1978. Although the primary targets were initially common thresher and shortfin mako sharks, fishermen soon switched to primarily targeting swordfish because of substantially higher exvessel prices. Fishing operations of the USDGN fishery have been heavily regulated to reduce adverse interactions with other fisheries, fishing mortality of common thresher sharks, and incidental bycatch of marine mammals and sea turtles. Secondarily, nearshore set gillnets and small-mesh drift gillnets (USSN) occasionally catch young-of-year and juvenile common thresher sharks as bycatch. There is also a small USA recreational fishery in Southern California (USREC) that targets adult common thresher sharks but catches are usually relatively low.

The historically most important fishery for common thresher sharks in Mexico waters was the Mexico drift gillnet (MXDGN) fishery, which started in 1986. The fishing gear and operations of this fishery were similar to the USDGN fishery, with swordfish and pelagic sharks as the primary targets. The number of MXDGN vessels began to decline in the mid-1990s as vessels began converting to longline gear. The MXDGN fishery has been prohibited since 2010 by Mexico
federal regulations. The Mexico artisanal (MXART) fishery operates from small boats called pangas, using various nearshore gears that are set and hauled by hand, along the entire Pacific coast of Mexico. The size and history of this fishery is poorly known but it has likely existed since the early $20^{\text {th }}$ century. Only a small portion of pangas are allowed to fish for sharks. For example, there were 50 shark permits for this fishery in Baja California in 1998, representing about 180 out of more than 2000 pangas in total.

There are no historical nor current fisheries along the west coast of Canada that target common thresher sharks and bycatch appears to be rare. There are also no known historical nor current fisheries that target this stock of common thresher sharks in international waters and bycatch is expected to be minimal, given the largely coastal distribution of this population.

## Fishery Removals

Fishery removals by eight fishing fleets based on country, fishing gear, and season were included in this assessment (Table ES.1). These included five USA fleets (F1: USDGN, F2: USDGNs2, F3: USSN, F4: USREC, and F5: USRECs2) and three Mexico fleets (F6: MXDGNLL, F7: MXDGNLLs2, and F8: MXART). The annual estimated removals for the eight fleets are shown in Fig. ES.1.

Estimates of USA commercial landings of common thresher sharks by gear during 1969-1980 and 1981 - 2014 were obtained from the CALCOM (http://calcomfish.ucsc.edu) and PacFIN (http://pacfin.psmfc.org) databases respectively. Several types of net gears in the databases could not be clearly separated into DGN and SN gears. The catch from these unidentified net gears were aggregated and then subdivided into DGN and SN gears based on the seasonal proportion of catch for DGN versus SN gears during representative periods. Some of the commercial landings for common thresher sharks were also likely recorded as unspecified sharks. A correction to the estimated removals by USA fisheries for this misreporting of species was performed by estimating the proportion of unspecified shark landings that was likely to be common thresher sharks. The proportion of common thresher sharks that were discarded at sea as dead fish was also estimated from observer records of the USDGN and USSN fisheries and used to expand the removals of the USDGN, USDGNs2, and USSN fleets.

Until recently, shark landings in Mexico were not reported by species. Therefore, the fishery removals for Mexico fisheries were estimated from annual reports of state-specific aggregated shark (Tiburon) landings from the Instituto Nacional de Pesca (INAPESCA) that were available from 1976 through 2013. Subsequently, the proportion of common thresher sharks in the aggregated shark catch of the Pacific coast of Baja California was estimated for specific periods since 1976. The estimated common thresher shark catches were then separated into seasonal catches by the MXDGN, MXLL, and MXART fisheries. The estimated removals from 1976 2013 for each fleet were extrapolated to the 1969 - 1975 period and 2014 in order to match the 1969-2014 assessment period. All common thresher sharks caught were assumed to be retained by the Mexico fisheries.

Table ES.1. Description of fleets and abundance indices in the base case model.

| Fleet ID | Short name | Fleet description |
| :---: | :---: | :---: |
|  |  | Fleets with remova |
| F1 | USDGN | USA swordfish/shark pelagic drift gillnet fishery for seasons 1, 3, and 4. Removals from USA miscellaneous fisheries for these seasons were included into this fleet. |
| F2 | USDGNs2 | USA swordfish/shark pelagic drift gillnet fishery for season 2. Removals from USA miscellaneous fisheries for season 2 were included into this fleet. |
| F3 | USSN | USA nearshore set gillnet and small-mesh drift gillnet fishery for all 4 seasons. |
| F4 | USREC | USA recreational fishery for seasons 1,3 , and 4 . Catch units in number of fish. |
| F5 | USRECs2 | USA recreational fishery for season 2. Catch units in number of fish. |
| F6 | MXDGNLL | Mexico swordfish/shark pelagic drift gillnet fishery for seasons 1, 3, and 4. Removals from the Mexico pelagic longline fishery for these seasons were included in this fleet. |
| F7 | MXDGNLLs2 | Mexico swordfish/shark pelagic drift gillnet fishery for season 2. Removals from the Mexico pelagic longline fishery for this season were included in this fleet. |
| F8 | MXART | Mexico coastal artisanal fishery with mixed gillnet and longline gears. Also known as the panga fishery. |
|  |  | Abundance indices inputted as surveys |
| S1 | USDGN8284 | Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA |
| S2 | USDGN9200 | swordfish/shark pelagic drift gillnet fishery during 1982 - 1984. Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA |
| S3 | USDGN0113 | swordfish/shark pelagic drift gillnet fishery during 1992-2000. Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA swordfish/shark pelagic drift gillnet fishery during 2001-2013. |
| S4 | USSN8593 | Standardized annual index of relative abundance of primarily age-0 common thresher sharks based on logbooks from the USA nearshore set gillnet and small-mesh drift gillnet fishery during 1985-1993. |
| S5 | USSN9414 | Standardized annual index of relative abundance of primarily age-0 common thresher sharks based on logbooks from the USA nearshore set gillnet and small-mesh drift gillnet fishery during 1994 - 2014. |
| S6 | USJUV0614 | Standardized annual index of relative abundance of juvenile common thresher sharks from a coastal longline survey conducted by the Southwest Fishery Science Center during 2006-2014. |



Figure ES.1. Estimated annual fishery removals by fleet. See Table ES. 1 for a description of the fleets.

## Data and Assessment

This is the first stock assessment of common thresher sharks along the west coast of North America that incorporates information from all fisheries exploiting the population. The Stock Synthesis modeling platform (v3.24U) was used to conduct the analysis and estimate management quantities. The base case model began in 1969, assuming that the stock was at equilibrium prior to 1969 in a near unfished state, and ended in 2014, which was the last year that data were available. Each fishing year was divided into 4 seasons (1: Feb-Apr; 2: May-Jul; 3: Aug-Oct; and 4: Nov-Jan). The assessment model was sex-specific due to differences in biology between genders and assumed that the sex ratio at birth was $1: 1$. Sex-specific growth was estimated within the model. A low fecundity stock-recruitment relationship was used in the model because common thresher sharks produce only a few pups per litter, with relatively little variability in litter size, and pups are born at a relatively large size, which suggested that common thresher sharks have lower potential productivity and a more direct connection between stock size and recruitment than for teleosts. The shape parameter, $\beta$, of the stock-recruitment relationship was also estimated within the model.

The model included eight fishing fleets that operated in USA and Mexico waters (see above in Fishery Removals and Table ES.1). Five abundance indices from fishery-dependent fisheries and one abundance index from a fishery-independent survey were available (Table ES.1). However, the survey abundance index (USJUV0614) was not fit in the base case model. Length composition data were available for the majority of the fleets and were fit in the base case model, with the exception of the MXDGNLL fleet. Conditional age-at-length data from two USA fleets (USDGN and USSN) were also fit in the base case model.

A large number of alternative model configurations were investigated to develop the base case model, which provided a realistic but parsimonious description of common thresher shark population dynamics based on the best available scientific information. The base case model reflected the best aspects of these exploratory models. Overall, the base case model appeared to
have converged to a global minimum; while fitting the observed data well, with plausible model processes and parameters that were within reasonable bounds.

## Reproductive Capacity and Output

In this assessment, the reproductive capacity of the population was calculated as the number of mature female sharks (i.e., spawning abundance) rather than spawning biomass, because the size of mature female sharks did not appear to affect the number of pups produced (i.e., larger female sharks did not produce more pups). The reproductive output of the stock (i.e., the number of pups produced by the stock) was calculated using four pups produced per year per mature female shark.

In the base case model, the estimated number of mature female common thresher sharks under unfished conditions was 88,200 sharks ( $95 \%$ CI: $69,500-107,000$ sharks) with a reproductive output of 352,900 pups ( $95 \%$ CI: 278,000 - 427,800 pups) (Fig. ES.2). The start of targeted commercial fishing in 1977 - 1978 was quickly followed by a large increase in fishery removals, peaking in the early 1980s (Fig. ES.1). These relatively large removals resulted in the number of mature female sharks declining quickly to approximately 35,200 sharks (95\% CI: 21,300 49,100 sharks) in 1985 . Over the next decade, the number of mature female sharks continued to decline but at a substantially slower rate, likely due to the management of the USDGN fishery during this period. The historical low estimate occurred in 1995, with 26,800 mature female sharks ( $95 \%$ CI: 15,000 - 38,600 sharks). After 1995, the reproductive capacity gradually increased over the past two decades. In 2014, the terminal year of the assessment model, the estimated number of mature female sharks reached 83,300 sharks (95\% CI: 49,500 - 117,100 sharks) with a reproductive output of 333,100 pups ( $95 \%$ CI: 198,000 $-468,300$ pups) (Table ES.2).


Figure ES.2. Estimated number of mature female sharks in Q2 (Feb Apr). Dashed lines indicate 95\% confidence intervals; and closed circle and error bar indicate estimated quantities and $95 \%$ confidence intervals under unfished conditions, respectively.

Depletion of the stock was estimated as the number of mature females in the second quarter ( $S$ ) for a specific year divided by the number of mature females under unfished conditions ( $S_{0}$ ) because the reproductive output of the stock (i.e., number of pups produced) was dependent on the number of mature females and not on the biomass of the female sharks. Therefore, the estimated depletion followed the same trajectory as the number of mature female sharks, albeit scaled to $S_{0}$ (Fig. ES.3).


Figure ES.3. Estimated depletion of the stock $\left(\mathrm{S} / \mathrm{S}_{0}\right)$. Dashed lines indicate 95\% confidence intervals.

Table ES.2. Recent estimates of total biomass (Q1, age-1+), biomass and number of mature female sharks in Q2, depletion ( $\mathrm{S} / \mathrm{S}_{0}$ ), recruitment, and fishing intensity (1-SPR) estimated in the base case model. Reproductive output in number of pups is: 4 * number of mature females.

| Year | Total <br> biomass <br> age-1+(t) | Biomass of <br> mature <br> female <br> sharks (t) | Number of <br> mature female <br> sharks (1000s) | Depletion <br> $\left(\mathbf{S} / \mathbf{S}_{\mathbf{0}}\right)$ | Number of <br> recruits <br> $(\mathbf{1 0 0 0 s})$ | Fishing <br> intensity <br> $(\mathbf{1 - S P R )}$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 2005 | 16041.0 | 4753.2 | 46.1 | 0.523 | 49.50 | 0.262 |
| 2006 | 16216.0 | 5274.6 | 52.1 | 0.591 | 150.51 | 0.256 |
| 2007 | 17630.4 | 5808.1 | 57.0 | 0.646 | 125.69 | 0.291 |
| 2008 | 18960.3 | 5788.9 | 54.4 | 0.616 | 87.62 | 0.264 |
| 2009 | 19996.8 | 5750.0 | 52.5 | 0.595 | 113.05 | 0.161 |
| 2010 | 21518.0 | 5794.9 | 51.9 | 0.588 | 119.32 | 0.120 |
| 2011 | 23198.6 | 6402.2 | 60.3 | 0.683 | 86.68 | 0.138 |
| 2012 | 24346.1 | 7481.2 | 73.2 | 0.830 | 126.48 | 0.080 |
| 2013 | 25985.6 | 8158.4 | 78.9 | 0.894 | 46.49 | 0.084 |
| 2014 | 26499.2 | 8707.9 | 83.3 | 0.944 | 88.47 | 0.076 |

## Recruitment

The estimated recruitment and stock-recruitment relationship were generally consistent with the biology of the stock and assumptions in the base case model. Unfished recruitment was estimated to be 77,100 sharks $\left(\log \left(R_{0}\right)=4.345\right)$. The estimated recruitment fluctuated
substantially during the assessment period (1969 - 2014), ranging from a low of 40,700 sharks ( $95 \%$ CI: 23,300 - 58,100 fish) in 1989 to a high of 150,500 sharks ( $95 \%$ CI: $86,400-214,600$ fish) in 2006 (Fig. ES.4). Overall average recruitment during the assessment period was approximately 73,700 sharks but there appeared to be a period of relatively low recruitment from 1985 - 1995, with average recruitment at 56,700 sharks. In contrast, a more recent period from 2006 - 2012 had substantially higher recruitment, averaging approximately 115,600 sharks.


Figure ES.4. Estimated recruitment time series in the base case model. Error bars indicate 95\% confidence intervals; and closed circle indicates recruitment under unfished conditions, respectively.

## Reference Points

The current USA fishery management plan for USA West Coast fisheries associated with highly migratory species uses status determination criteria (SDC) for common thresher sharks that are based on maximum sustainable yield (MSY), with overfishing occurring if the estimated current fishing mortality or a reasonable proxy exceeds the maximum fishing mortality threshold (MFMT) defined as F $_{\text {MSY }}$ or a reasonable proxy; and the stock declared in an overfished condition if current spawning biomass is less than the minimum stock size threshold (MSST) defined as ( $1-\mathrm{M}$ )* $\mathrm{B}_{\mathrm{MSY}}$, when $\mathrm{M} \leq 0.5$ and M is the instantaneous rate of natural mortality. Based on an unpublished assessment of the USA portion of the stock, a harvest guideline of 340 t was established using the alternative optimum yield (OY) control rule for vulnerable species (i.e., $0.75 * \mathrm{MSY}$ ).

For the base case model of this assessment, the estimated MSY for this stock was 806.5 t ( $95 \%$ CI: 614.7 - 998.3 t ), and the number of mature female sharks at MSY was estimated to be 43,500 sharks ( $95 \%$ CI: $34,600-52,400$ sharks), with a reproductive output of 174,000 pups ( $95 \% \mathrm{CI}$ : $138,300-209,700$ pups) (Table ES.3). The fishing intensity (1-SPR; where SPR is the spawning potential ratio) corresponding to MSY was estimated at 0.39 ( $95 \%$ CI: $0.37-0.40$ ). Based on these estimates, the MFMT was 0.39 (using $1-$ SPR $_{\text {MSY }}$ as a proxy for $\mathrm{F}_{\text {MSY }}$ ) and the MSST was 35,700 mature female sharks.

Table ES.3. Estimated reference points for the base case model.

|  | Estimate (95\% CI) | Units |
| :---: | :---: | :---: |
| Unfished conditions |  |  |
| Number of mature female sharks (spawning abundance) ( $\mathrm{S}_{0}$ ) | 88.2 (69.5-107.0) | 1000s of sharks |
| Reproductive output | 352.9 (278.0-427.8) | 1000s of pups |
| Summary biomass at age-1+ ( $\mathrm{B}_{0}$ ) | 28,096 (21,768-34,424) | Metric tons |
| Recruitment at age-0 ( $\mathrm{R}_{0}$ ) | 77.1 (60.7-93.5) | 1000s of sharks |
| MSY-based reference points |  |  |
| MSY | 806.5 (614.7-998.3) | Metric tons |
| Number of mature female sharks at MSY (spawning abundance) ( $\mathrm{S}_{\mathrm{MSY}}$ ) | 43.5 (34.6-52.4) | 1000s of sharks |
| Minimum stock size threshold (MSST) (1-M)* $\mathrm{S}_{\text {MSY }}$ | 35.7 (28.4-43.0) | 1000s of sharks |
| Reproductive output at MSY | 174.0 (138.3-209.7) | 1000s of pups |
| Fishing intensity at MSY (1-SPR ${ }_{\text {MSY }}$ ) | 0.39 (0.37-0.40) | NA |

## Status of the Stock

The estimated fishing intensity (1-SPR) on common thresher sharks off the west coast of North America is currently relatively low at 0.08 (average of 2012 - 2014) and substantially below the estimated overfishing threshold (MFMT), with (1-SPR $\left.{ }_{1214}\right) /\left(1-\right.$ SPR $\left._{\text {MSY }}\right)$ at 0.21 (Table ES. 4 and Fig. ES.5). Similarly, the estimated number of mature female sharks in 2014 (S2014) for this stock is at $94 \%$ of its unexploited level and is substantially larger than the estimated MSST, with $\mathrm{S}_{2014} / \mathrm{MSST}$ at 2.33 (Table ES. 4 and Fig. ES.5). Thus, this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing.

The stock experienced a relatively large and quick decline in the late 1970s and early 1980s, soon after the onset of the USA swordfish/shark drift gillnet fishery, with spawning depletion dropping to 0.4 in 1985. The population appeared to have stabilized in the mid-1980s after substantial regulations were imposed. Over the past 15 years, the stock began recovering relatively quickly and is currently close to an unexploited level.

## Uncertainty

This assessment explicitly estimated the model uncertainty due to uncertainty in parameter estimates, which were reported as confidence intervals for key parameters and management quantities. In addition, a suite of sensitivity runs were used to explore the uncertainty associated with alternative model specifications and examine the sensitivity of important model outputs to different model assumptions. These included alternative assumptions about fishery removals, initial conditions, stock-recruitment, life history like natural mortality, growth, maturity, and fecundity; and alternative data sources and weightings. The most important sources of uncertainty were related to the reproductive biology and stock-recruitment of the stock.

Besides the base case model, the status of the stock was also examined under three alternative states of nature, based on alternative reproductive biology and two alternative stock-recruitment
relationships. These alternative states of nature addressed the most important sources of uncertainty identified in the sensitivity analysis. The estimated management quantities from models assuming these alternative states of nature all indicated that this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing (Table ES. 4 and Fig. ES.6).

## Decision Table

The same four states of nature used to examine stock status were also used in model projections: the base case model; alternative reproductive biology; and two alternative stock-recruitment relationships.

Ten-year forecasts for each state of nature were calculated based on three future removal scenarios: 1) average catch for 2012 - 2014 in the base case model; 2) 2 * the average catch for 2012 - 2014 in the base case model; and 3) total annual catch of USA swordfish/shark drift gillnet and recreational fisheries at the 340 t PFMC harvest guideline and remaining fisheries at their average catch for 2012 - 2014.

A decision table with these future removal scenarios and alternative states of nature is provided in Table ES.5. For all states of nature and removal scenarios, the adult population is expected to continue increasing and stock depletion is expected to continue improving over the next several years. For the base case and alternative stock-recruitment states of nature, the adult population starts to decline after several years because the fisheries on common thresher sharks primarily catch juvenile and sub-adult sharks and a lag of several years is needed before changes are evident in the adult population. For the alternative reproductive biology model, a lag longer than 10 years (timespan of the forecasts) is needed before changes in the adult population are evident, given the older median age-at-maturity.

## Research and Data Needs

In this stock assessment, several critical assumptions were made based on limited supporting data and research. There are several research and data needs that if satisfied could improve future assessments, including:

1. The reproductive biology of this stock of common thresher sharks requires further research.
2. The survey design and protocols of the USA juvenile thresher shark survey should be reexamined and improved.
3. Catch and catch-at-size estimates from USA fisheries, especially the USA recreational fishery, should be improved.
4. Catch and catch-at-size estimates from Mexico fisheries should be improved.
5. The use of the low fecundity stock recruitment relationship requires further research.

Table ES.4. Summary of reference points and management quantities for the base case and three alternative states of nature. $\mathrm{C}_{2014}$ is the estimated fishery removals in metric tons in 2014. 1$\mathrm{SPR}_{1214}$ is the average of the estimated fishing intensity (1-SPR) from 2012 through 2014. Key management quantities for the USA fishery management plan are in bold. Under the current USA fishery management plan, this stock is considered to be in an overfished state if $\mathrm{S}_{2014} / \mathrm{MSST}$ is $<1$. Overfishing is considered to be occurring if (1-SPR 1214 )/(1-SPR ${ }_{\text {MSY }}$ ) is $>1$.

|  | Base case | Alternative reproductive biology (12years median age-of maturity; biennial; $\mathrm{M}=\mathbf{0 . 0 7 5 7}$ ) | Alternative stockrecruitment $\left(z_{\text {frac }}=0.4\right)$ | Alternative stockrecruitment $\left(Z_{f r a c}=0.8\right)$ |
| :---: | :---: | :---: | :---: | :---: |
| MSY (t) | 806.5 | 773.8 | 911.1 | 833.7 |
| Number of mature female sharks at MSY (S $\mathrm{S}_{\text {MSY }}$ ) (1000s of sharks) | 43.5 | 33.9 | 71.6 | 32.0 |
| Number of mature female sharks under virgin conditions ( $\mathrm{SB}_{0}$ ) (1000s of sharks) | 88.2 | 67.4 | 134.3 | 70.6 |
| Minimum stock size threshold (MSST) | 35.7 | 27.9 | 58.8 | 26.3 |
| (1-M)* $\mathrm{S}_{\text {MSY }}$ |  |  |  |  |
| Fishing intensity at MSY (1$\mathrm{SPR}_{\text {MSY }}$ ) | 0.39 | 0.39 | 0.34 | 0.45 |
| $\mathrm{C}_{2014} / \mathrm{MSY}$ | 0.20 | 0.21 | 0.17 | 0.19 |
| $\mathrm{S}_{2014} / \mathrm{S}_{\mathrm{MSY}}$ | 1.91 | 1.44 | 1.81 | 2.13 |
| $\mathrm{S}_{2014} / \mathrm{S}_{0}$ | 0.94 | 0.72 | 0.97 | 0.97 |
| $\mathrm{S}_{2014} / \mathrm{MSST}$ | 2.33 | 1.75 | 2.21 | 2.59 |
| (1-SPR $\left._{1214}\right) /\left(1-\right.$ SPR $_{\text {MSY }}$ ) | 0.21 | 0.20 | 0.16 | 0.21 |

Table ES.5. Decision table of 10-year projections for the base case and three alternative states of nature based on two major axes of uncertainty: 1) reproductive biology and 2) stock-recruitment relationship; and three future catch scenarios: 1) average catch for 2012 - 2014; 2) 2 * average catch for 2012 - 2014; and 3) total annual catch of USA swordfish/shark drift gillnet and recreational fishery at the 340 t PFMC harvest guideline and remaining fisheries at average catch for 2012 - 2014. Note that the total removals shown for scenario 1 and 2 are approximate ( $\pm 4 \mathrm{t}$ ) because catches by the USA recreational fishery are in numbers of fish and conversion to catch in weight depends on the estimated growth for each model.

| Forecast catch scenario (see legend) | Year | Total removals <br> (t) | Base model |  | Alternative reproductive biology (12-years median age-of maturity; biennial; $\mathrm{M}=0.0757$ ) |  | Alternative stockrecruitment$\left(Z_{f r a c}=0.4\right)$ |  | Alternative stockrecruitment$\left(z_{\text {frac }}=0.8\right)$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Number of mature females (1000s of fish) | Depletion | Number <br> of <br> mature females (1000s of fish) | Depletion | Number of mature females (1000s of fish) | Depletion | Number of mature females (1000s of fish) | Depletion |
| Average | 2015 | 182.5 | 89.8 | 1.02 | 98.0 | 0.73 | 138.4 | 1.03 | 74.2 | 1.05 |
| catch | 2016 | 183.2 | 92.7 | 1.05 | 97.7 | 0.72 | 141.7 | 1.06 | 76.9 | 1.09 |
| 2012-14 | 2017 | 183.7 | 96.2 | 1.09 | 97.9 | 0.73 | 146.2 | 1.09 | 80.1 | 1.13 |
|  | 2018 | 184.1 | 94.6 | 1.07 | 105.1 | 0.78 | 143.4 | 1.07 | 78.9 | 1.12 |
|  | 2019 | 184.3 | 90.9 | 1.03 | 117.1 | 0.87 | 137.5 | 1.02 | 75.6 | 1.07 |
|  | 2020 | 184.2 | 89.3 | 1.01 | 124.0 | 0.92 | 135.1 | 1.01 | 73.6 | 1.04 |
|  | 2021 | 183.7 | 86.2 | 0.98 | 129.8 | 0.96 | 130.8 | 0.97 | 69.9 | 0.99 |
|  | 2022 | 183.2 | 82.9 | 0.94 | 137.7 | 1.02 | 126.1 | 0.94 | 66.2 | 0.94 |
|  | 2023 | 182.6 | 80.1 | 0.91 | 142.9 | 1.06 | 122.4 | 0.91 | 63.0 | 0.89 |
|  | 2024 | 182.0 | 78.7 | 0.89 | 148.5 | 1.10 | 120.9 | 0.90 | 61.0 | 0.86 |
| 2X | 2015 | 365.5 | 89.7 | 1.02 | 98.0 | 0.73 | 138.3 | 1.03 | 74.1 | 1.05 |
| average | 2016 | 367.1 | 92.0 | 1.04 | 97.6 | 0.72 | 141.0 | 1.05 | 76.2 | 1.08 |
| catch | 2017 | 368.1 | 94.9 | 1.08 | 97.8 | 0.73 | 145.0 | 1.08 | 78.8 | 1.12 |
| 2012-14 | 2018 | 368.9 | 92.7 | 1.05 | 104.9 | 0.78 | 141.5 | 1.05 | 76.9 | 1.09 |
|  | 2019 | 369.0 | 88.3 | 1.00 | 116.9 | 0.87 | 134.9 | 1.00 | 73.0 | 1.03 |
|  | 2020 | 368.4 | 85.9 | 0.97 | 123.5 | 0.92 | 131.7 | 0.98 | 70.1 | 0.99 |
|  | 2021 | 367.2 | 82.2 | 0.93 | 129.2 | 0.96 | 126.7 | 0.94 | 65.8 | 0.93 |
|  | 2022 | 365.8 | 78.5 | 0.89 | 136.7 | 1.01 | 121.8 | 0.91 | 61.7 | 0.87 |
|  | 2023 | 364.5 | 75.6 | 0.86 | 141.5 | 1.05 | 118.0 | 0.88 | 58.4 | 0.83 |
|  | 2024 | 363.4 | 74.3 | 0.84 | 146.7 | 1.09 | 116.6 | 0.87 | 56.6 | 0.80 |
| Harvest | 2015 | 440.7 | 89.8 | 1.02 | 98.0 | 0.73 | 138.4 | 1.03 | 74.1 | 1.05 |
| guideline | 2016 | 440.7 | 91.6 | 1.04 | 97.6 | 0.72 | 140.6 | 1.05 | 75.8 | 1.07 |
| 340 t | 2017 | 440.7 | 94.0 | 1.07 | 97.8 | 0.73 | 144.0 | 1.07 | 77.9 | 1.10 |
| for | 2018 | 440.7 | 91.3 | 1.04 | 104.8 | 0.78 | 140.1 | 1.04 | 75.6 | 1.07 |
| F1, F2, | 2019 | 440.7 | 86.8 | 0.98 | 116.6 | 0.87 | 133.3 | 0.99 | 71.5 | 1.01 |
| F4 \& F5 | 2020 | 440.7 | 84.5 | 0.96 | 123.2 | 0.91 | 130.2 | 0.97 | 68.8 | 0.97 |
|  | 2021 | 440.7 | 80.9 | 0.92 | 128.6 | 0.95 | 125.4 | 0.93 | 64.7 | 0.92 |
|  | 2022 | 440.7 | 77.6 | 0.88 | 135.9 | 1.01 | 120.8 | 0.90 | 60.9 | 0.86 |
|  | 2023 | 440.7 | 75.1 | 0.85 | 140.4 | 1.04 | 117.5 | 0.87 | 58.0 | 0.82 |
|  | 2024 | 440.7 | 74.2 | 0.84 | 145.2 | 1.08 | 116.6 | 0.87 | 56.6 | 0.80 |



Figure ES.5. Kobe time series plot of the ratio of spawning abundance (S; number of mature female sharks) relative to the minimum stock size threshold reference point (MSST; (1$\mathrm{M}) * \mathrm{~S}_{\mathrm{MSY}}$ ) and ratio of the fishing intensity (1-SPR) relative to the maximum fishing mortality threshold (MFMT; 1-SPR ${ }_{\text {MSY }}$ ) for the base case model. Values for the start (1969) and end (2014) years are indicated by blue triangle and white circle, respectively. White lines indicate the 95\% confidence intervals. Grey numbers indicate selected years.


Figure ES.6. Kobe plot of the ratio of spawning abundance (S; number of mature female sharks) relative to the minimum stock size threshold reference point (MSST; (1-M)*SMSY) and ratio of the fishing intensity (1-SPR) relative to the maximum fishing mortality threshold (MFMT; 1SPR $_{\text {MSY }}$ ) for the end year (2014) of the base case model (white circle) and three alternative states of nature: 1) alternative reproductive biology with a biennial reproductive cycle, 12 years median age-at-maturity, and natural mortality of 0.0757 (white square); 2 ) alternative stock-recruitment with $Z_{\text {frac }}$ of 0.4 (blue triangle); and 3 ) alternative stock-recruitment with $z_{\text {frac }}$ of 0.8 (blue diamond). White and blue lines indicate the respective $95 \%$ confidence intervals.

## 1. Introduction

There are three recognized species of thresher sharks around the world's oceans: 1) common (Alopias vulpinus); 2) bigeye (A. superciliosus); and 3) pelagic (A. pelagicus) thresher sharks. These three species are distinguished by the highly elongated dorsal lobe of their caudal fins, which approaches their body length (Compagno 1984). Thresher sharks typically feed on schooling fishes and squids (Preti et al. 2012), and use their long caudal fin as a whip to stun and kill prey (Aalbers et al. 2010). All three species are caught by various international and USA fisheries, and are highly regarded for human consumption.

Common thresher sharks can be easily distinguished from bigeye thresher sharks but pelagic thresher sharks have been misidentified as common thresher sharks (Smith et al. 2008a). Bigeye thresher sharks are distinguished by very large eyes that have orbits that expand onto the dorsal surface of the head, and a deep horizontal groove on the side of the head (Compagno 1984). Common thresher sharks are distinguished by labial folds around the mouth, and a difference in skin color above the base of the pectoral fin (Compagno 1984).

All three species of thresher sharks are large pelagic sharks but exhibit differences in distribution, and are thought to have different ecological niches (Smith et al. 2008a). Common and bigeye thresher sharks are distributed circumglobally in the Atlantic, Indian, and Pacific Oceans and the Mediterranean Sea, while pelagic thresher sharks are restricted to the Indian and Pacific Oceans (Gruber and Compagno 1981; Compagno 1984). Compared to bigeye and pelagic thresher sharks, common thresher sharks are relatively more coastal, occurring primarily within 40-75 miles of land, over continental and insular shelves and slopes, and occupy cooler, more temperate waters (Compango 1984; Smith et al. 2008a). Pelagic thresher sharks are distributed primarily in warmer, oceanic waters but misidentification of pelagic thresher sharks as common thresher sharks have resulted in less reliable habitat distribution information (Smith et al. 2008a). Bigeye thresher sharks are thought to exploit deeper waters in warm temperate and tropical areas, making forays into mesopelagic depths to at least 500 m (Smith et al. 2008a).

This is the first stock assessment of common thresher sharks along the west coast of North America that incorporates information from all fisheries exploiting the population throughout its distribution. Previously, an unpublished population growth rate (PGR) analysis of common thresher sharks, using only data from USA fisheries, resulted in an estimated local maximum sustainable yield (LMSY) of 450 t (PFMC 2003). However, the LMSY was considered to be a minimal estimate because the analysis did not include any information from Mexico fisheries exploiting the same population (PFMC 2003). The PGR analysis was dependent on estimates of the intrinsic rate of increase for common thresher sharks, which indicated that common thresher sharks were likely to be moderately productive with productivity similar to blue and shortfin mako sharks (Smith et al. 2008b). The PGR analysis also assumed that the population was at an unfished state in 1981 (start of the CPUE series) even though the largest commercial fishery for this stock of common thresher shark began in 1977 - 1978 (Hanan et al. 1993). Given the
drawbacks of the previous analysis, a collaboration was initiated between scientists from the USA and Mexico to conduct a stock assessment of this common thresher shark population throughout its entire distribution along the west coast of North America.

### 1.1 Distribution, biology, and life history

### 1.1.1 Distribution and seasonal movements

Along the west coast of North America, common thresher sharks are seasonally distributed in coastal waters from British Columbia, Canada to central Baja California, Mexico. The highest concentration of common thresher sharks occur in the Southern California Bight (SCB), which extends from Point Conception, California to Cabo Colonet, Mexico (Hanan et al. 1993; Smith et al. 2008a). The distributions of common and bigeye thresher sharks are thought to overlap partially, with bigeye thresher sharks generally exploiting deeper waters (Smith et al. 2008a). In contrast, there relatively little overlap in the distributions of common and pelagic thresher sharks, except for El Nino years, when the distribution of pelagic thresher sharks shift northwards (Smith et al. 2008a).

Seasonal movements of common thresher sharks are not well known but they are thought to move northward from Baja California into Southern California in early spring (Hanan et al. 1993). Large, adult sharks are then hypothesized to continue northwards to as far north as British Columbia, with the reverse movement occurring in winter (Hanan et al. 1993). Juvenile sharks tend to remain in shallow, nearshore areas over the continental shelf, especially within the SCB, which is an important nursery area (Holts and Bedford 1989; Cartamil et al. 2010).

### 1.1.2 Stock structure

In this assessment, common thresher sharks along the west coast of North America are assumed to be a single, well mixed stock, which is supported by their genetics and seasonal movements. Trejo (2005) analyzed a $1,082 \mathrm{bp}$ segment of the mitochondrial DNA control region and found that common thresher sharks from California waters were not significantly different from sharks in Oregon-Washington waters but both were significantly different from all other common thresher shark stocks, noting that there were no samples from Mexico. In addition, there is no evidence of pupping and nursery grounds outside of the SCB and common thresher sharks migrate seasonally along the coastal waters from Baja California to as far north as British Columbia, Canada (Smith et al. 2008a). Limited tagging data also supports the assumption that this is a local population of common thresher sharks limited to the coastal waters of the west coast of North America (Cartamil et al. 2010; Cartamil et al. 2011a). There is also unlikely to be substantial interchange of individuals between this stock and other common thresher shark stocks because the geographically closest stock is likely to be along the west coast of Chile. Due to species misidentification, thresher sharks previously reported as common thresher sharks from many other parts of the Pacific Ocean have turned out to be pelagic thresher sharks after using genetic tools to identify the species (J. Hyde, Southwest Fisheries Science Center, NOAA Fisheries, personal communication; Velez-Zuazo et al. 2015).

### 1.1.3 Reproductive biology

Common thresher sharks are ovoviviparous, where after the absorption of the yolk sac, developing fetuses consume eggs still developing in the uterus (Smith et al. 2008a). The reproductive cycle is seasonal, with mating thought to occur in summer and pupping occurring in spring after a gestation period lasting 9 months (Smith et al. 2008a). Common thresher sharks have small litter sizes, usually giving birth to two to four pups (Gubanov 1978; Cailliet et al. 1983; Bedford 1992; Natanson and Gervelis 2013) but litter sizes of up to seven have been recorded off Spain (Moreno et al. 1989).

Previous studies on the reproductive biology of common thresher sharks have resulted in inconsistent conclusions about their fecundity, which may reflect differences between stocks. Smith et al. (2008b) thought that common thresher sharks in the eastern North Pacific produced two female pups per year (i.e., an annual reproductive cycle with four pups per litter, assuming an equal sex ratio at birth), when they estimated intrinsic rates of increase for several pelagic shark species. This was supported by Castro (2009), who suggested that thresher sharks exhibited an annual reproductive cycle based on concurrent vitellogensis and gestation coupled with continuous ovulation. However, Natanson and Gervelis (2013) suggested that common thresher sharks in the western North Atlantic had at least a biennial reproductive cycle with an average litter size of 3.7 pups.

There also appear to be substantial differences in the estimated median age of maturity between common thresher sharks in the eastern North Pacific and the western North Atlantic. Smith et al. (2008a) estimated that the female common thresher sharks in the Pacific reach maturity at about 5.3 years of age ( $\sim 160 \mathrm{~cm}$ FL). However, Natanson and Gervelis (2013) estimated that the median age of maturity for female common thresher sharks in the western North Atlantic was 12 years of age ( $\sim 216 \mathrm{~cm} \mathrm{FL}$ ).

### 1.1.4 Growth

Common thresher sharks are large pelagic sharks with sexually dimorphic growth and intermediate to relatively rapid growth rates (Cailliet et al. 1983; Smith et al. 2008a; Gervelis and Natanson 2013). Sharks are aged by examining band pairs consisting of one opaque and one translucent band in vertebral cross-sections (Cailliet et al. 1983). There have been three studies on the growth of common thresher sharks, with two in the eastern North Pacific (Cailliet et al. 1983; Smith et al. 2008a) and one in the western North Atlantic (Gervelis and Natanson 2013). The initial growth curves by Cailliet et al. (1983) lacked older, larger samples and resulted in high estimates of asymptotic length. Smith et al. (2008a) fitted additional age-length data to a von Bertalanffy growth curve and estimated the following parameters for male and female common thresher sharks - Male: $\mathrm{L}_{\infty}=221.5 \mathrm{~cm}, \mathrm{~K}=0.189 \mathrm{y}^{-1}$, and $\mathrm{t}_{0}=-2.08 \mathrm{y}$; Female: $\mathrm{L}_{\infty}=$ $247.3 \mathrm{~cm}, \mathrm{~K}=0.124 \mathrm{y}^{-1}$, and $\mathrm{t}_{0}=-3.35 \mathrm{y}$, where $\mathrm{L}_{\infty}$ is the asymptotic length in fork length, K is the rate coefficient, and $\mathrm{t}_{0}$ is the theoretical age at length 0 . Common thresher sharks in the western North Atlantic appeared to follow a relatively similar growth curve albeit with slightly higher asymptotic lengths (Gervelis and Natanson 2013).

### 1.2 Historical and current fisheries in USA waters

The history of common thresher shark fisheries along the west coast of the USA is not well known prior to the 1970s but small amounts of catch were recorded by the California Department of Fish and Game (CDFG) prior to the 1970s (Pearson et al. 2008). Prior to the 1970s, some species of shark were exploited in the USA for food, vitamin-rich liver oil, pet food, leather, curios, and reduction to protein and fertilizer but common thresher sharks do not appear to have been heavily exploited prior to the 1970s (Holts 1988).

Demand for common thresher sharks as food began to increase in the mid-1970s on the west coast of the USA, together with other shark species like Pacific angel and shortfin mako sharks (Holts 1988). Ex-vessel prices for shark meat rose sharply due to this demand and common thresher sharks became one of several shark species with important west coast fisheries. For example, ex-vessel prices for thresher sharks rose five-fold between 1977 ( $\$ 0.29$ per pound; $\$ 1.13$ per pound in 2014 dollars) and 1986 ( $\$ 1.60$ per pound; $\$ 3.46$ per pound in 2014 dollars) (Holts 1988), which is substantially higher than the average price in 2014 ( $\$ 0.82$ per pound) (PFMC 2015).

The most important USA commercial fishery for common thresher sharks is the swordfish/shark drift gillnet (USDGN) fishery. Secondarily, nearshore set gillnets and small-mesh drift gillnets (USSN) occasionally catch young-of-year and juvenile common thresher sharks as bycatch. Common thresher sharks are also occasionally caught as bycatch by a variety of miscellaneous gears like purse seine and harpoon but catches are usually minimal. Some recreational fishermen in Southern California target adult common thresher sharks but catches are usually relatively low (PFMC 2015).

### 1.2.1 USA swordfish/shark drift gillnet (USDGN)

The most important commercial fishery for common thresher sharks is the USDGN fishery, which began in 1977 - 1978 (Hanan et al. 1993). The drift gillnet gear was inspired by the occasional catch of pelagic sharks in nearshore gillnets used to target barracuda and white seabass. The nets used by the USDGN fishery have larger mesh size than the nearshore gillnets, and regulations have required a minimum mesh size of 14 inches since 1982 (Hanan et al. 1993).

The USDGN fishery began with about 15 vessels in Southern California but the number of vessels grew rapidly (Hanan et al. 1993). By 1985, the number of California permits for the fishery totaled about 265, with about 35 of those permits limited to areas north of Point Arguello, California (PFMC 2003). Although the initial primary targets were common thresher and shortfin mako sharks, fishermen soon discovered that they could efficiently catch swordfish with the same gear, and switched to primarily targeting swordfish because of substantially higher exvessel prices (Hanan et al. 1993). Since those early days, the primary target of the USDGN fishery has been swordfish, with common thresher and shortfin mako sharks being secondary targets.

The USDGN fishery expanded into Oregon and Washington in 1983, when these states began issuing experimental permits for a thresher shark fishery (PFMC 2003). Thresher shark landings for Oregon and Washington remained relatively low until 1986, when 37 vessels landed 293 t dressed weight of common thresher sharks. However, Oregon and Washington closed the experimental fishery in 1989 due to concern over the observed incidental bycatch of marine mammals and sea turtles (PFMC 2003).

Landings of common thresher sharks by the USDGN fishery peaked in 1982 at 1711 t (PFMC 2011a) and have declined since, dropping to approximately 10 t in 2014 (PFMC 2015). The number of USDGN vessels landing fish have also declined from 297 in 1985 (PFMC 2011a) to only 18 vessels by 2014 (PFMC 2015).

Fishing operations of the USDGN fishery have been heavily regulated to reduce adverse interactions with other fisheries, fishing mortality of common thresher sharks, and incidental bycatch of marine mammals and sea turtles (Hanan et al. 1993; PFMC 2003). The timeline of major changes in regulations and operations for the USDGN fishery can be found in Table 1.1. Details of current and historical regulations are provided by Hanan et al. (1993), PFMC (2003), and PFMC (2015). There appeared to be three major periods of fishery operations and regulations: 1) $1977-1991$; 2) 1992 - 2000; and 3) 2001 - 2014. The first period (1977-1991) encompassed the initial expansion of the fishery and the switch from primarily targeting pelagic sharks to swordfish. There were also early attempts at regulating the fishery, which resulted in frequent changes in regulations that included gear restrictions, swordfish catch, swordfish to shark catch ratios, seasonal closures, and time-area closures (Table 1.1). In particular, time-area closures in California were enacted or modified in 1982, 1985, and 1989, which likely affected the catch-per-unit-effort (CPUE) of sharks for this fishery (Urbisci et al. in review). Washington and Oregon also closed their drift gillnet fisheries in 1989. The time-area closures for the USDGN fishery were relatively stable during the second period (1992 - 2000), after the closure period for California was changed to May 1 through August 14 in 1992 (Table 1.1). The second period was a period of decline in the USDGN fishery, with the number of vessels landing fish declining from 119 in 1992 to 72 in 2000 (PFMC 2015). This decline continued in the third period (2001 - 2014), which was marked by the enactment of a large time-area closure in 2001 to protect leatherback turtles (Table 1.1). 1The number of vessels in the USDGN fishery landing fish declined from 61 in 2001 to 18 in 2014 (PFMC 2015).
1.2.2 USA nearshore set gillnet and small-mesh drift gillnet (USSN) A secondary USA commercial fishery that catches common thresher sharks is the nearshore set gillnet and small-mesh drift gillnet (USSN) fishery in nearshore waters that target species like barracuda, white seabass, and halibut. The key differences between this fishery and the USDGN fishery are that the USSN fishery uses nets with smaller mesh size (typically $<10$ inches) and fishes in shallow, nearshore waters. Most of the catch and effort of the USSN fishery centers around the SCB but some parts of the fishery operates in nearshore areas as far north as Mendocino, California.

The USSN fishery does not target common thresher sharks but occasionally catches common thresher sharks as bycatch. The USSN fishery predominantly catches young-of-year common thresher sharks because the continental shelf of the SCB is a known nursery area for common thresher sharks (Cartamil et al. 2010).

In 1994, the California Marine Resources Protection Act of 1990 began prohibiting all gillnets and trammel nets within 3 nm of the California mainland and within 1 nm (or waters $<70$ fathoms deep) of the Channel Islands (Table 1.1). This resulted in the USSN fishery fishing in slightly deeper waters from 1994.

### 1.2.3 USA recreational (USREC)

Common thresher sharks are a target of the USA recreational fishery, especially in Southern California (Holts et al. 1998). Recreational fishing directed at large pelagic species, including sharks, come from anglers on Commercial Passenger Fishing Vessels (CPFVs) (Hill and Schneider 1999), as well as private vessels departing from sportfishing landings, marinas, and boat ramps. The vast majority of recreationally caught common thresher sharks are caught by anglers on private vessels (>99 \%) rather than CPFVs. Captains of CPFVs are required to submit logbooks but not private vessels. Information on recreational fishing from private vessels is obtained using surveys, which are available in a comprehensive coastwide marine recreational fishery database (RecFIN; http://www.recfin.org). Information on common thresher sharks caught by anglers on private vessels is highly limited.

### 1.3 Historical and current fisheries in Mexico waters

Subsistence fishing for sharks has historically been an important resource for rural communities along the Pacific coast of Mexico but commercial shark fishing in the Gulf of California developed during World War II to provide shark liver oil to the USA (Holts et al. 1998). Three Mexico fisheries have historically been or currently are important fisheries for common thresher sharks: 1) Mexico swordfish/shark drift gillnet (MXDGN); 2) Mexico pelagic longline (MXLL); and 3) Mexico artisanal (MXART) fisheries.

### 1.3.1 Mexico swordfish/shark drift gillnet (MXDGN)

The historically most important fishery for common thresher sharks in Mexico waters was the MXDGN fishery. A small fleet of MXDGN vessels began fishing for swordfish from Ensenada, Mexico in 1986, and the fleet increased to 31 vessels by 1993 (Holts and Sosa-Nishizaki 1998). Soon after that, the number MXDGN vessels began to decline as vessels began converting to longline gear in the mid-1990s. The MXDGN fishery has been prohibited since 2010 by federal regulations in Mexico (Sosa-Nishizaki 2013). Similar to the USDGN fishery, the primary and secondary targets were swordfish and pelagic sharks respectively (Holts et al. 1998). The fishing gear and operations of this fishery were also similar to the USDGN fishery, except that nets in Mexico could extend to 4.8 km in length whereas nets in the USA were limited to 1 nm ( 1.8 km ). A 50 nm sportsfishing-only zone was established along the Mexico coast in 1983 but commercial fishing operations for sharks continued to be routinely conducted in this zone (Holts et al. 1998).
1.3.2 Mexico pelagic longline (MXLL)

Mexico and international pelagic longline fisheries have operated within 200 nm of the Mexico coast during various periods. From 1967 to 1976, Mexico issued permits to Japanese pelagic longline vessels to fish for swordfish, billfish, and tunas (Holts and Sosa-Nishizaki 1998). After Mexico established its Exclusive Economic Zone (EEZ) in 1976, all longline permits were withheld until 1980. From 1980 to 1990, a Mexico/Japan joint venture program for the longline fishery was established, which targeted swordfish, billfish and tunas (Holts and Sosa-Nishizaki 1998). After the cessation of that program in 1990, no pelagic longline fishing occurred until the mid-1990s, when MXDGN vessels began converting to longline gear. Like the MXDGN fishery, the primary and secondary targets of the current MXLL fishery are swordfish and pelagic sharks respectively. However, the pelagic sharks targeted are primarily blue and shortfin mako sharks instead of common thresher sharks.

### 1.3.3 Mexico artisanal (MXART)

The MXART fishery operates along the entire Pacific coast of Mexico, and fishes from small boats called pangas, which are small, open boats approximately 7-9 m long powered by an outboard engine (Holts et al. 1998). Hence, the artisanal fishery is also often called the panga fishery. The size and history of this fishery is largely unknown but it has likely existed throughout the $20^{\text {th }}$ century and thought to have exceeded 2000 pangas by the late 1990s (Holts et al. 1998). Only a small portion of the pangas are permitted to fish for sharks. For example, Holts et al. (1998) stated that in the Mexican state of Baja California, there were 50 shark permits for this fishery in 1998, representing about 180 pangas. Pangas can range up to 40 km but usually fish closer to shore. A variety of gears are used, including gillnets and longlines, but the fishing gears are limited by the need to set and haul by hand. The MXART fishery is highly mobile and the pangas can be easily trailered to other locations with better fishing or market prices. Given the nature of the MXART fishery, it is generally difficult to obtain data from this fishery.

### 1.4 Historical and current fisheries in Canadian and international waters

 There are no historical nor current fisheries along the west coast of Canada that target common thresher sharks and bycatch of common thresher sharks appear to be rare (McFarlane et al. 2010). McFarlane et al. (2010) reported some bycatch of bigeye thresher sharks, which may have been misidentified common thresher sharks. However, further enquiry indicated that these reports of bigeye thresher shark bycatch were erroneous due to miscoded unidentified shark species (J. R. King, pers. comm.). There are also no known historical nor current fisheries that target this stock of common thresher sharks in international waters and bycatch is expected to be minimal, given the largely coastal distribution of this population.
### 1.5 Management history

Common thresher sharks have been managed in USA waters under the fishery management plan (FMP) for highly migratory species (HMS) by the Pacific Fishery Management Council (PFMC)
(PFMC 2003; PFMC 2011b). A summary of major changes in the management history is shown in Table 1.1 and described in more detail in sections 1.2 and 1.3. Most important for this assessment is the implementation and changes to various time-area closures for the USDGN fishery in 1982, 1985, 1989, 1992, and 2001, and the USSN fishery in 1994, which likely affected the catchability and selectivity of these fisheries. Changes in the management and fishing operations of the Mexico fisheries probably also affected their catchability and selectivity but the lack of information on these fisheries, other than catch, during these periods precluded modeling such effects.

A harvest guideline of 340 t is currently in place for common thresher sharks in USA waters, based on an estimate of LMSY from an unpublished analysis (PFMC 2003). Since common thresher sharks are considered a vulnerable species with relatively low productivity, the harvest guideline is derived from the optimum yield (OY) for vulnerable species, which is defined as $0.75 * \mathrm{~F}_{\mathrm{MSY}} * \mathrm{~B}_{\mathrm{MSY}}$, or the respective maximum sustainable yield (MSY) proxies. The maximum fishing mortality threshold (MFMT) for common thresher sharks is the ratio $\mathrm{F}_{\mathrm{MFMT}} / \mathrm{F}_{\mathrm{MSY}}=1.0$, or the appropriate MSY proxy. Therefore, the stock is considered to be experiencing overfishing if $\mathrm{F}_{\text {current }} / \mathrm{F}_{\text {MSY }}>1.0$. The maximum stock size threshold (MSST) is the minimum biomass at which recovery measures are to begin. Since common thresher shark has natural mortality (M) of $<0.5, \mathrm{~B}_{\text {MSST }}=(1-\mathrm{M}) * \mathrm{~B}_{\mathrm{MSY}}$, or the appropriate MSY proxy. Therefore, the stock is considered to be overfished if $\mathrm{B}_{\text {current }}<(1-\mathrm{M}) * \mathrm{~B}_{\text {MSY }}$ or $\mathrm{B}_{\text {current }}(1-\mathrm{M}) * \mathrm{~B}_{\text {MSY }}<1.0$. Landings of common thresher sharks by fisheries along the west coast of the USA have been less than the harvest guideline of 340 t since 1992 (PFMC 2015).

## 2. Assessment data

The data used for this assessment are summarized in Figure 2.1, and included both fisherydependent and fishery-independent data. The time period of this assessment was 1969 - 2014 because recorded landings for USA fisheries were unreliable before 1969. In addition, total landings from 1969 through 1976 were relatively minimal before the development of the USDGN fishery. The data were divided into fishing years, which were defined as February 1 to January 31 because fishing operations for the USDGN fishery end on January 31. Each fishing year was further subdivided into four seasons of three months each (1: Feb-Apr; 2: May-Jul; 3: Aug-Oct; and 4: Nov-Jan). Data for the assessment included fishery removals (i.e., catch), abundance indices, length composition, and conditional age-at-length data. The fleet structure of the assessment model consisted of eight fleets based on country, fishing gear, and season; and six abundance indices. See subsections in this section and Table 2.1 for details on the fleet structure and nomenclature.

### 2.1 Fishery-dependent data

The USA fleets in the assessment model were based on the USDGN, USSN, and USREC fisheries. The catch from a variety of miscellaneous gears like purse seine and harpoon were added to that of the USDGN fishery because the catch was minimal and the size composition of
the catch was assumed to be similar to the USDGN fishery. The USDGN and USREC fisheries were further subdivided into separate fleets for season 2 , and seasons 1,3 , and 4 because preliminary examination of the size composition data indicated that large adult common threshers were caught by these fisheries in season 2, which is the pupping season. Therefore, the assessment model contained five USA fleets: F1: USDGN; F2: USDGN season 2 (USDGNs2); F3: USSN; F4: USREC; and F5: USREC season 2 (USRECs2) (Table 2.1).

The Mexico fleets in the assessment model were based on the MXDGN, MXLL, and MXART fisheries. However, the catches from the MXLL and MXDGN fisheries were combined because the only data available for the MXLL fishery was catch and anecdotal evidence suggested similar sized common thresher sharks were caught by these fisheries. Similar to the USDGN fishery, the MXDGN fishery was subdivided into separate fleets for season 2 , and seasons 1, 3, and 4. Therefore, the assessment model contained three Mexico fleets: F6: Mexico drift gillnet and longline (MXDGNLL); F7: MXDGNLL season 2 (MXDGNLLs2); and F8: MXART (Table 2.1).

### 2.1.1 Commercial removals

The estimated removals for the eight USA and Mexico fleets are shown in Table 2.2 and Figure 2.2.

### 2.1.1.1 USA fisheries

Estimates of commercial landings of common thresher sharks from 1981 through 2014 were obtained from the Pacific Fisheries Information Network (PacFIN), a regional fisheries database that manages fishery-dependent information in cooperation with USA West Coast state agencies, and NOAA Fisheries (http://pacfin.psmfc.org). Catch data were extracted by gear type and assigned to the fishing fleets used in the assessment. Several types of net gear recorded in PacFIN could not be clearly separated into USDGN and USSN gears. The catch from these net gears were aggregated and then subdivided into USDGN and USSN gears based on the seasonal proportion of catch for USDGN versus USSN fisheries during three periods (1981-1985; 19861993; and 1994-2014). The largest amount of catch for these unknown net gears was 281 t for 1985 season 2, and the amount of catch for these unknown net gears was negligible after 1994. The catch from miscellaneous gears was added to the USDGN (F1) and USDGNs2 (F2) fleets.

Estimates of commercial landings of common thresher sharks from 1969 through 1980 were obtained from the CALCOM database (Pearson et al. 2008; http://calcomfish.ucsc.edu). The CALCOM database is the repository for commercial groundfish market sample data managed by the California Cooperative Groundfish Survey (CCGS). Since there were no commercial fisheries for common thresher sharks in Oregon and Washington prior to 1983, relying only on catch data from California for this early period is adequate for the assessment. The landings recorded in the CALCOM database were based on dressed weight, which were converted into round weights using the PacFIN conversion factor. The gear types in the CALCOM database (Net; Hook-and-Line; and Other) do not differentiate between USDGN and USSN fisheries. The
seasonal proportions of catch for USDGN vs USSN fisheries during 1981-1985 were used to split the net catch for 1969-1980 into USDGN and USSN catch. The catch data from the hook-and-line and other gears were added to the USDGN (F1) and USDGNs2 (F2) fleets.

Some of the commercial landings for common thresher sharks were likely recorded as unspecified sharks (Pearson et al. 2008). A correction to the estimated removals by USA fisheries for this likely misrecording of species was performed by estimating the proportion of unspecified shark landings that was likely to be common thresher sharks. We assumed that the proportion of common thresher sharks in the unspecified shark landings was the same as that for the specified sharks, and added the estimated amount of common thresher sharks in the unspecified shark catch to the estimated removals of the USDGN (F1), USDGNs2 (F2), and USSN (F3) fleets. In addition, we estimated the proportion of common thresher sharks that were discarded at sea as dead fish from observer records of the USDGN and USSN fisheries and used that to expand the removals of USDGN, USDGNs2, and USSN fleets to include dead discards.

### 2.1.1.2 Mexico fisheries

Until recently, shark landings in Mexico were not reported by species. Instead, shark landings were divided into two groups, "Tiburon" and "Cazon", based on length. Sharks larger than 150 cm TL were considered tiburon while sharks smaller than 150 cm TL were classified as cazon. Thresher sharks (or "zorro" in Spanish) are generally classified as tiburon. Since 2006, speciesspecific landings reports have been publicly available from the Mexican fisheries agency, Comision Nacional de Acuacultura y Pesca (CONAPESCA), through a website (http://www.conapesca.sagarpa.gob.mx/wb/cona/consulta_especifica_por_produccion) but all three species of thresher sharks are combined into a single category (Zorro).

For this assessment, the fishery removals for Mexican fisheries were therefore estimated from annual reports of state-specific aggregated shark (Tiburon) landings from the Instituto Nacional de Pesca (INAPESCA) that were available from 1976 through 2013. The southern extent of the distribution of common thresher sharks coincides approximately with the border between the Mexican states of Baja California and Baja California Sur, so catch data from only Baja California were used to estimate removals. Since common thresher sharks are only landed on the Pacific coast, the proportion of aggregated shark catch that comes from the Pacific coast of Baja California was estimated using statistics from the Mexican fisheries agency office in Ensenada, Mexico, and then used to estimate aggregated shark catches for the Pacific coast of Baja California.

Based on the work of Sosa-Nishizaki et al. (2002), Sosa-Nishizaki et al. (2008), and Cartamil et al. (2011a), we estimated the proportion of common thresher sharks in the aggregated shark catch of the Pacific coast of Baja California for specific periods since 1976. The estimated proportion of common thresher shark catch ranged from 0.06 in 1976 to a high of 0.2 in the mid1980s, when the MXDGN fishery developed, before declining as the MXDGN fishery changed gradually to longline gear and was eventually prohibited. The estimated common thresher shark
catch was then separated into monthly catch by the MXDGN, MXLL and MXART fisheries based on the work of Sosa-Nishizaki et al. (2002), Sosa-Nishizaki et al. (2008), and Cartamil et al. (2011a). The estimated monthly catch was then aggregated into seasonal removals by the MXDGNLL (F6), MXDGNLLs2 (F7), and MXART (F8) fleets for the assessment.

The estimated removals from 1976 - 2013 for each fleet were extrapolated to the 1969 - 1975 period and 2014 in order to match the 1969 - 2014 assessment period. The 2014 seasonal catch was assumed to be the average of the 2011 - 2013 seasonal catch. The 1969 - 1975 seasonal catch was assumed to be the average of the 1976 - 1978 seasonal catch.

### 2.1.2 Recreational removals

Estimated removals of common thresher sharks by USA private vessel recreational anglers from 1981 through 2014 were obtained from the Recreational Fisheries Information Network (RecFIN) (http://www.recfin.org), which is a recreational fisheries database maintained by the Pacific States Marine Fisheries Commission. The RecFIN removal estimates are based on angler surveys in California, Oregon, and Washington. From 1980 through 2003, the angler survey data were provided in "waves", which were bimonthly periods (i.e., Jan-Feb; Mar-Apr). Since the definition of seasons for this assessment were not consistent with these bimonthly periods, it was assumed that the removals within a bimonthly period were split equally between the two months in a single wave. Survey data from 2004 were provided on a monthly basis and did not require this assumption.

Estimates of common thresher shark removals by USA recreational anglers on CPFVs from 1969 through 2014 were obtained from the CPFV logbook database maintained by CDFG. The logbook data contained the daily species-specific catch of the CPFVs (Hill and Schneider 1999).

The seasonal removals by recreational anglers on private vessels and CPFVs were summed into the USREC (F4) and USRECs2 (F5) fleets. It should be noted that estimated removals for the USREC (F4) and USRECs2 (F5) fleets were in 1000s of fish rather than the metric tons for all other fleets.

### 2.1.3 Abundance indices

Indices of relative abundance were derived from logbook data of the USDGN and USSN fisheries using generalized linear models (GLMs). Details and diagnostics of the GLMs used to derive the abundance indices for the USDGN and USSN fisheries can be found in Appendices A and B respectively. A delta-lognormal approach (Lo et al. 1992) was taken to explicitly account for proportion of sets having zero versus non-zero catch. A binomial GLM was used to estimate the expected probability of non-zero catch for a given set and a lognormal GLM was used to estimate the expected catch for a given set with non-zero common thresher shark catch. The binomial and lognormal GLMs were independent and the explanatory variables used in each GLM were not necessarily the same, except for the year factor, which was present in every GLM. A stepwise model selection process using Akaike's Information Criteria (AIC) as the
selection criteria was used. Uncertainty in each index was estimated by jack-knifing the data used to calculate the index. The abundance indices and corresponding uncertainty are shown in Table 2.3.

### 2.1.3.1 USA swordfish/shark drift gillnet fishery

The USDGN fishery is the most important fishery in this assessment, and primarily catches subadult and adult sharks. The abundance indices from this fishery are therefore expected to be the most important indices for this assessment.

Three indices representing different regulatory and operational periods were developed for the USDGN fishery: 1) 1982 - 1984 (S1); 2) 1992 - 2000 (S2); 3): 2001 - 2013 (S3). Changes in the regulations and fishery operations of this fishery have likely affected the catchability of this fishery (Urbisci et al. in review). The most important regulatory changes occurred in 1982, 1985, 1989, 1992, and 2001, when time-area closures were implemented or changed. For this assessment, we did not attempt to account for the effect of these time-area closures in our GLMs. Instead, we developed shorter time series within the periods when regulatory changes were likely less important. Logbook data for 2014 were also not available by the time that development of abundance indices was completed. An abundance index was not developed for the 1985 - 1991 period because of changing regulations and fishery operations. In addition, preliminary examination of the logbook data indicated that the CPUE rapidly increased and decreased several fold during this period, which indicated that changing regulations and fishing operations likely resulted in the exploitation of some local areas of high abundance.

Regulatory changes over the years have also affected the start of the fishing season. Therefore, only data from seasons 3 and 4 (i.e., Aug - Oct and Nov - Jan) were used for the abundance indices because fishing consistently occurred during these seasons. Three bimonthly periods within the six month period were used as factors in the GLMs to account for changes in thresher CPUE due to time of year.

The annual decile rank of swordfish catch of a given set was included in the GLMs to account for changes in the targeting of the fishery from pelagic sharks to swordfish. In the initial development of the fishery, the primary target of the fishery changed from pelagic sharks to swordfish because of higher market prices. However, the targeting switch was constrained by regulations restricting the total amount of monthly swordfish landings and requirements to land equal amounts of shark (Table 1.1). Even after regulations restricting swordfish catch were removed, USDGN vessels likely switched between swordfish and pelagic sharks depending on availability and market prices. The annual decile rank of swordfish catch was determined by ranking the swordfish catch from all sets within a given year, and then splitting the ranks into deciles (e.g., 0-10\%, 10-20\%).

Additional initial uncertainty was estimated and assigned to each USDGN index in addition to the data uncertainty estimated using a jackknife procedure. Since the USDGN indices
represented the relative changes in the stock abundance of sub-adult and adult sharks, changes in the indices over time should be relatively smooth. Therefore, variability in the indices above and beyond that expected by the uncertainty in the data (i.e., estimated from the jackknife procedure) and a smoothly changing adult population, is largely due to variability in the catchability of fishery. In this assessment, we model the variability in catchability with additional uncertainty. The USDGN indices were fit to a loess curve and the coefficient of variation (CV) of the index relative to the loess curve was calculated. If this CV was greater than the mean CV calculated with the jackknife procedure, the additional uncertainty added was the difference in the CVs. Otherwise, no additional uncertainty was added unless the mean CV from the jackknife procedure was $<0.2$. In that case, additional uncertainty was added to the index until the mean CV was equal to 0.2. The estimated additional CVs for the three indices were: S1: 0.000 ; S2: 0.123 ; and S3: 0.392 . These additional CVs were only included as initial inputs into the assessment model and were adjusted based on model fit to the indices (Section 3.5).

The S1 index (1982-1984) showed a general decline but being a short time series was not expected to be strongly influential (Table 2.3). The S2 index generally increased from 1992 through 2000 (Table 2.3). However, the S3 index exhibited a high variability in the index from year to year during 2001 through 2013 (Table 2.3). This was caused by the substantial reduction in the number of vessels in the USDGN fishery and consequently, a large reduction in effort.

### 2.1.3.2 USA set net fishery

The USSN fishery primarily catches age- 0 common thresher sharks. The abundance indices from this fishery can therefore be considered as recruitment indices.

Two indices representing different regulatory and operational periods were developed for the USSN fishery: 1) 1986 - 1993 (S4); and 2) 1994 - 2014 (S5). In 1994, the California Marine Resources Protection Act prohibited all gillnets and trammel nets within 3 nm of the California mainland and 1 nm of the Channel Islands. Since age- 0 common thresher sharks are known to be distributed close to shore (Cartamil et al. 2010), this regulatory change may have affected the catchability of the USSN fishery on common thresher sharks.

Logbook data from the USSN fishery were available from 1981 through 1985 but the data from this period were not used to develop abundance indices because the USSN data were mixed with the USDGN data and could not be easily separated. After 1985, when the USDGN fishery moved out of the 75 nm zone due to regulations, it became easier to separate the USSN fishery data from that of the USDGN fishery because the operations of the two fisheries became very different.

Unlike the USDGN indices, data from all four seasons were used in the USSN indices. In addition, it was not necessary to correct for the USSN fishery targeting swordfish instead of pelagic sharks because neither swordfish nor pelagic sharks are targets of the fishery.

No additional CVs were assigned to the USSN indices in addition to the data uncertainty estimated using a jackknife procedure. The USSN indices were not fit to a loess curve because we expected these recruitment indices to be highly variable unlike the USDGN indices. A minimum CV of 0.2 was assumed for all indices but the mean CVs from the jackknife procedure for both indices were $>0.2$.

### 2.1.4 Length composition data

In both the USA and Mexico, the sampling programs used to sample the length composition of the catch varied over time, depending on country and fishery. This resulted in changes in the types of length data collected (alternate versus fork lengths), availability of sex composition data, and sample sizes.

Common thresher sharks were predominantly landed as "trunks", without heads and tails (this practice has recently been prohibited by USA regulations). This practice made it impossible for port samplers to measure the fork lengths of landed sharks. They therefore measured alternate lengths instead, which is the distance between the origins of the first and second dorsal fins (Childers and Halko 1994). However, onboard observers were able to measure the fork length of the sharks. It was therefore necessary to use a relationship between alternate and fork lengths to convert alternate lengths to fork lengths. Based on 3043 samples, Kohin et al. (pers, comm.) estimated the relationship as: $\mathrm{FL}=2.3627 \times \mathrm{AL}+16.82$ (Fig. 2.3), where FL and AL were the fork lengths and alternate lengths in cm, respectively. Using such a relationship resulted in aliasing of the length composition data. Preliminary analysis indicated that using 7 cm bins reduced aliasing to negligible levels for this relationship. We therefore used 7 cm bins for length composition data that were derived from measured alternate lengths. Smaller bins of 2 cm were used for data that were derived from measured fork lengths.

The genders of individual size samples were collected at the same time for some sampling programs. In general, port samples had very few and inconsistent number of length samples with associated sex information. However, onboard observers often collected sex information with their size samples.

A summary of the annual sampling effort by fleet, length type, and year used to generate the seasonal length frequency distributions are shown in Table 2.4. The initial input sample sizes ( $\mathrm{N}_{\text {input }}$ ) for the length composition data by season were the number of trips sampled, if available. For USA commercial fisheries, seasonal length frequency distributions with $\mathrm{N}_{\text {input }}<5$ were not used in the assessment, which eliminated 5 out of 69,7 out of 18 , and 22 out of 42 seasons of length composition data available for the USDGN (F1), USDGNs2 (F2), and USSN (F3) fleets respectively. Mexico fisheries had much poorer sampling effort, so the minimal $\mathrm{N}_{\text {input }}$ required for seasonal length frequency distributions to be used in the assessment was 2, which eliminated 0 out of 3 seasons of length composition data available for the MXDGNLL (F6) fleet. The ranges of $N_{\text {input }}$ for USA and Mexico commercial fisheries were 5-124 and $2-3$ respectively.

### 2.1.4. 1 USA fisheries

Length composition data from California port sampling and onboard observer programs were available for the USDGN and USSN fisheries. From 1981 through 1990, CDFG's port samplers collected length information from common thresher sharks landed by the USDGN and USSN fisheries (Childers and Halko 1994). These length samples were in alternate lengths rather than fork lengths, and were therefore converted to fork lengths for use in this assessment (Fig. 2.3). There was a negligible number of port samples with associated sex information but the sex composition data from these samples were not used in this assessment. In contrast, the onboard observer program (1990 - present) for these two fisheries recorded sex information on almost all of their length samples, which were measured as fork lengths. The sex composition data from the onboard observer program were incorporated into this assessment.

No length composition data were available for the USREC and miscellaneous fisheries. Based on anecdotal evidence, we assumed that the size of common thresher sharks caught by these fisheries were similar to the USDGN fishery.

### 2.1.4.2 Mexico fisheries

Length composition data from Mexico fisheries were much sparser than for the USA fisheries (Table 2.4). Scientists from Mexico sampled the lengths of common thresher sharks landed by the MXDGN and MXLL fisheries over several fishing trips during 2007 and 2008. These length composition data were in alternate lengths and were mostly unsexed. The MXART fishery was sampled over a period of time from 2006 till the present by scientists visiting fishing camps along the Baja California coast (Cartamil et al. 2011b). These length data were in fork lengths and were a mixture of sex and unsexed samples. However, the number of fishing trips from which the samples were taken was unknown.

Preliminary examination of the length composition data from the MXART fishery suggested that the size of sharks taken was different from the USSN fishery. Given the lack of sample size information, uncertainty in the sampling period, and the sparse data, we used a "super-year" approach when using the data in the assessment model. This approach combined all the length data from the fishery into a single length composition and assumed that was the average length composition for the entire time period.

Preliminary model runs fitting the length composition data from the MXGDNLL (F6) fleet resulted in highly uncertain and variable selectivity, and poor fits to the length composition data because of the sparse and variable length composition data. Examination of the data suggested that the overall size of common thresher sharks caught by the MXDGNLL (F6) fleet was similar to the USDGN (F1) fleet, which was likely due to their similar gear and fishing operations. Therefore, the length composition data from the MXDGNLL (F6) fleet were not fit in the base case model. Instead, the MXDGNLL (F6) and MXDGNLLs2 (F7) fleets were assumed to have the same selectivities as the USDGN (F1) and USDGNs2 (F2) fleets respectively.

### 2.1.5 Conditional age-at-length data

Sex-specific conditional age-at-length data from the age and growth study by Smith et al. (2008a) were used in this assessment. Most of the samples came from the USDGN (F1) fleet ( $\mathrm{N}=183$ ) and one sample came from the USSN (F3) fleet. These vertebral samples were aged by three independent readers at SWFSC using the techniques described in Cailliet et al. (1983).

Aging imprecision was estimated with the method described by Punt et al. (2008), using the R package "nwfscAgeingError" (Thorson et al. 2012). Each reader was assumed to be unbiased in turn, and the aging imprecision and bias (for the other two readers) were estimated. The best fitting model, based on AIC, suggested that the age readings by the lead reader (S. E. Smith) were unbiased and had a constant CV (0.176). The age readings and associated uncertainty were incorporated into the base case assessment model and all sensitivity runs with estimated growth.

### 2.2 Fishery-independent data

This assessment used fishery-independent data from a longline juvenile thresher shark survey conducted in nearshore waters of the SCB by NOAA Fisheries’ Southwest Fisheries Science Center (SWFSC). Overall catch and effort from the survey can be found in Table C. 1 in Appendix C. The SWFSC juvenile thresher shark survey was conducted annually in September from 2006 through 2014. This survey was developed after an initial study on the common thresher shark nursery grounds (Smith 2005). The study indicated that longline gear in nearshore waters would be successful in catching age-0 and juvenile common thresher sharks.

The basic survey design consisted of 12 area blocks and a minimum of three longline sets were required for each block (Fig. C. 1 in Appendix C). Each longline set consisted of a one mile long anchored monofilament longline with 100 hooks deployed from a small commercial longline vessel. The hooks were expected to fish approximately $6-8 \mathrm{~m}$ below the surface and were baited with primarily sardines but mackerels were sometimes used when sardines were not available. The longline sets were deployed in areas where bottom depth was $<25$ fathoms ( $\sim 45$ $\mathrm{m})$. Sharks were tagged and released alive, if possible.

Several operational factors of this survey impacted how the survey data were utilized in this assessment. Most importantly, the location and timing of each set was determined by the captain of the vessel, within the constraints set by SWFSC scientists. The sets were in effect targeted at common thresher sharks and were somewhat similar to commercial longline sets. In addition, after the initial three sets within a block were completed and there was time available, the captain was free to set again in the same area. Therefore, the first three sets in an area were possibly used as learning sets, providing information on where it was more likely to encounter threshers in subsequent sets in the same block. Preliminary analysis of the CPUE indicated that sets after the first three sets do have a significant positive effect on encountering non-zero thresher catch.

Another important factor was that soak times of sets were inconsistent and varied substantially. When relatively large numbers of sharks were caught, soak times were sometimes cut to reduce
shark mortality and possible hook saturation. Therefore, we included soak time as part of the fishing effort. Occasionally on some sets in the past, if a shark was seen hooked, the shark would be brought aboard and released, and the hook was then rebaited and put back into the water. This practice was considered inappropriate and has since been discontinued.

Other secondary factors likely impacting the CPUE of the survey were Marine Protected Areas (MPAs) and consumption of baits by sea lions. In 2012, several areas within survey blocks became unavailable to the survey due to MPAs being implemented. Preliminary analysis indicated that sets within those areas before they became MPAs had higher CPUEs. Sea lions would also occasionally consume the baits on the longlines, making the longlines less effective in catching fish. If the survey data indicated that baits were consumed by sea lions, the data from the set would be discarded before further analysis.
2.2.1 USA juvenile thresher shark survey index (USJUV0614)

A similar approach to the USDGN and USSN indices was used to derive an index of relative abundance for the juvenile thresher shark survey. Details and diagnostics of the GLMs used to derive the abundance index can be found in Appendix C. A delta-lognormal approach was taken, using binomial and lognormal GLMs (Lo et al. 1992). The effects of a set being in one of the first three sets within a block or within an MPA were accounted for by incorporating those factors as candidate factors in the GLMs. An AIC-based stepwise model selection process was used to select the final GLMs used to derive the index. Uncertainty in the index was estimated by jack-knifing the data.

Based on the size composition data, the juvenile thresher shark survey catches a mixture of age-0 and juvenile thresher sharks. This index should therefore be considered as a recruitment index. The estimated abundance index and uncertainty are shown in Table 2.3.

Additional CVs were not assigned to this index because the estimated CVs from the jackknife procedure were relatively high, with a mean CV of 0.485 . The high CVs were due to the highly patchy distribution of juvenile thresher sharks and relatively low number of longline sets in the survey. In addition, we expect a recruitment index to have relatively high variability unlike the indices based on the USDGN fishery.

No obvious trends were observed in the estimated index because of the highly variable index and high estimated CVs. The large estimated CVs resulted in this index being uninformative in preliminary models. The juvenile thresher shark survey index was therefore not fit in the base case model, and was instead used in a sensitivity analysis (Section 6.1.4).

### 2.2.2 Length composition data

Common thresher sharks caught by the juvenile thresher shark survey were measured (fork length) and sexed. The length and sex composition data from the survey were fit in the base case model. The number of sets and fish used to generate the seasonal length frequency distributions
are shown in Table 2.4. The initial input sample sizes ( $\mathrm{N}_{\mathrm{input}}$ ) for the length composition data by season were the number of sets sampled.

### 2.3 Biological parameters

Several biological parameters used in this assessment were fixed at externally determined values, which were obtained from published sources.

### 2.3.1 Maximum age

Based on previous biological studies, the maximum age of this stock of common thresher sharks was assumed to be 25 years for both sexes (Smith et al. 2008a; Smith et al. 2008b). With a natural mortality of $0.179 \mathrm{y}^{-1}$, approximately $1 \%$ of a cohort was expected to reach the age-25+ plus group, without fishery removals. This was consistent with previous analyses of this common thresher shark stock (PFMC 2003; Smith et al. 2008b).

### 2.3.2 Natural mortality

The instantaneous rate of natural mortality ( $M$ ) was assumed to be a constant $0.179 \mathrm{y}^{-1}$ for both sexes of this common thresher shark stock. This $M$ was estimated by Smith et al. (2008b), based on a maximum age of 25 years using the relationship: $\ln M=1.44-0.982 \ln w$, where $M$ was natural mortality and $w$ was maximum age (Hoenig 1983). The natural mortality used in this assessment was consistent with previous analyses of this stock (PFMC 2003; Smith et al. 2008b). A sensitivity analysis was performed to examine model results with respect to alternative assumptions for $M$ (Section 6.1.3.1)

### 2.3.3 Maturity and fecundity

The females of this common thresher shark stock were assumed to be $50 \%$ mature at age- 5 and $100 \%$ mature at age-6+, based on Smith et al. (2008a). This was consistent with previous analyses of this stock (PFMC 2003; Smith et al. 2008b). However, recent work on the western North Atlantic stock of common thresher sharks suggested a median age of maturity of 12 years (Natanson and Gervelis 2013). A sensitivity analysis was performed to determine the effect of an age of $50 \%$ maturity of 12 years (Section 6.1.3.3).

Following the analyses of PFMC (2003) and Smith et al. (2008b), we assumed that this stock of common thresher sharks produced four pups per year and there was no change in fecundity with respect to female size or age. However, Natanson and Gervelis (2013) suggested that the western North Atlantic stock had at least a biennial reproductive cycle with litter sizes of 3.7 pups. A sensitivity analysis was performed to determine the effect of a biennial reproductive cycle by halving the fecundity to two pups per year (Section 6.1.3.3).

### 2.3.4 Weight-length relationship

The weight-length relationship used in this assessment followed the relationship estimated by Kohler et al (1995): $W T=1.8821 \times 10^{-4} F L^{2.5188}$, where $W T$ was the weight in kg and $F L$ was the fork length in cm. This relationship was based on data from the western North Atlantic stock but
visual examination of limited weight-length data suggested that this weight-length relationship was representative of this stock as well (S. Kohin, personal communication). Male and female sharks were assumed to have the same weight-length relationship.

## 3. Model description

The base case model used for this assessment is described below.

### 3.1 Modeling software platform

The assessment model was developed using the 3.24U version of the Stock Synthesis (SS) modeling platform (Methot and Wetzel 2013).

### 3.2 General model specifications

This assessment incorporated information from the entire distribution of common thresher sharks along the west coast of North America, from Baja California, Mexico to British Columbia, Canada. Based on currently available evidence, we assumed that this was a single, well-mixed stock (Section 1.1).

The start year of the base case model was 1969, which was the earliest year of reliable information on fishery removals, and the terminal year was 2014, which was the last year of available data. Each fishing year was divided into four seasons (1: Feb-Apr; 2: May-Jul; 3: AugOct; and 4: Nov-Jan) (Section 2). The model was sex-specific due to differences in biology between genders, and the sex ratio at birth was assumed to be 1:1. The configuration and nomenclature of the eight fleets and six abundance indices in the base case model can be found in Table 2.1. Fishery removals were divided among 8 fleets (Section 2.1 and Table 2.2). Six indices of relative abundance were available for the model but only 5 were fit in the base case model (section 2.2). For convenience, abundance indices were inputted into the model as surveys and named accordingly (e.g., S1, S2). A summary of the data can be found in Fig. 2.1.

The length frequency distributions were based on fork lengths (cm) divided among $1302-\mathrm{cm}$ bins ( $40-300 \mathrm{~cm}$ ) for measured fork lengths, and $387-\mathrm{cm}$ bins for measured alternate lengths converted into fork lengths. However, length frequency distributions for the USSN fleet required a modification to this length bin structure. Preliminary models indicated that length compositions of age-0 fish from the USSN fleet were poorly fit in all preliminary model configurations and also tended to degrade the fit to other fleets with age-0 observations. Visual examination of the length compositions of the USSN fleet suggested that the quality of the length observations of age-0 sharks in this fleet was relatively poor compared to the length observations from the juvenile thresher survey. Given that most of the common thresher sharks ( $>95 \%$ in number) caught by the USSN fleet were age-0, the bins from $40-93 \mathrm{~cm}$ were aggregated into a single bin to approximate the age- 0 size classes, and an age selectivity process was used to represent the selectivity of the USSN fleet. Doing so resulted in better fits to the data from this and other fleets. A sensitivity analysis was performed to illustrate the sensitivity of model results to this structural change coupled with a length selectivity process (Section 6.1.5.2).

### 3.3 Likelihood components

In the assessment model, likelihoods for the various data components were obtained by comparing the expected values from the model with the observations in the data based on 'goodness of fit' procedures for the appropriate likelihood distribution for the data component. The main likelihood components in the model included: 1) abundance indices (lognormal); 2) fleet and survey length frequency compositions (multinomial); and 3) conditional age-at-length data (multinomial).

### 3.4 Model parameterization

Four main types of parameters were in the assessment model: 1) life history; 2) stockrecruitment; 3) selectivity; and 4) initial conditions. These parameters were either fixed or estimated within the model. Reasonable bounds were specified for all parameters. Catchability was estimated for each index of abundance without any prior assumptions.

### 3.4.1 Life history

Except for growth, all other life history parameters were fixed in the model, including natural mortality, weight-length relationship, maturity-at-age, and fecundity. These fixed parameters were derived from data available or published literature (Section 2.3 and Fig. 3.1). Sensitivity of the model to the natural mortality, maturity-at-age, and fecundity parameters was analyzed (Section 6.1.3).

### 3.4.1.1 Growth

In this assessment, growth was estimated within the model, assuming that growth was sexspecific and time-invariant. Preliminary models using fixed growth parameters from a previous study on this stock (Smith et al. 2008a) (Section 1.1.4) had poor fits to the size compositions of age-0 fish from the USSN fishery and the USA juvenile thresher shark survey because age-0 fish in the data were substantially smaller and did not show the sex-specific differences in size expected by the fixed growth models. The age-0 size composition data could have been better fit if the selectivity of male and female age- 0 sharks were very different but this was considered to be unlikely because the behavior of age-0 sharks did not appear to be sex-specific and the sex ratio of age- 0 sharks caught in the USA juvenile thresher shark survey was approximately $1: 1$ in the same area. It was considered more likely that the estimated size at age- 0 from the published studies were unrepresentative due to limited samples from age-0 fish. Estimating growth within the model substantially improved the fits to the size composition and conditional age-at-length data. Growth of male and female sharks were modeled separately because all previous studies on common thresher shark growth indicated that these sharks exhibited sex-specific growth (Cailliet et al. 1983; Smith et al. 2008a; Gervelis and Natanson 2013).

A von Bertalanffy growth function, as parameterized by Schnute (1981), was used to model the relationship between fork length (cm) and age:

$$
L=L_{\infty}+\left(L_{1}-L_{\infty}\right) e^{-K\left(A-A_{1}\right)}
$$

where $L_{1}$ and $L$ were the sizes associated with ages $A_{1}$ and $A$ respectively, $L_{\infty}$ was the asymptotic length, and $K$ was the growth coefficient. The $L_{1}, K$, and $L_{\infty}$ parameters were estimated for both male and female common thresher sharks and $A_{1}$ was set at 0.125 . The coefficients of variation (CVs) of size-at-age for $L_{1}\left(C V_{1}\right)$ and $L_{\infty}\left(C V_{2}\right)$ were fixed at 0.08 and 0.05 for both sexes, based on an estimate of the overall CV for age- 0 fish caught by the USA juvenile thresher shark survey and estimated from preliminary model runs respectively.

Sensitivity of the model to the estimated growth model was analyzed by performing alternative model runs with growth parameters fixed at the values estimated by Smith et al. (2008a) (Section 6.1.3.2).

### 3.4.2 Stock-recruitment

Common thresher sharks produce only a few pups per litter, with relatively little variability in litter size between individuals. In addition, the pups are born at a relatively large size. This suggests that common thresher sharks have lower potential productivity than teleosts producing millions of eggs and there is likely a more direct connection between spawning abundance and recruitment than for teleosts.

Therefore, the stock-recruitment relationship was modeled using a relatively new functional form developed by Taylor et al. (2013) for low fecundity fish that explicitly modeled the pre-recruit survival during the period from pupping to recruitment at age- 0 . The survival of pre-recruit sharks, $\mathrm{S}_{0}$, was calculated as,

$$
S_{0}=\frac{R_{0}}{B_{0}}
$$

where $R_{0}$ was the recruitment at equilibrium without fishing, and $B_{0}$ was the equilibrium number of pups produced under unfished conditions, in number of animals, which was equal to the number of mature females multiplied by the number of pups per female (i.e., 4 in the base case model). Expected recruitment, based on the number of pups produced, for each year in the time series was then calculated as,

$$
R_{y}=S_{y} B_{y}
$$

where $B_{y}$ was the spawning population in year $y$, and $S_{y}$ is the pre-recruitment survival given by,

$$
S_{y}=\exp \left[-z_{0}+\left(z_{0}-z_{\min }\right)\left(1-\left(\frac{B_{y}}{B_{0}}\right)^{\beta}\right)\right]
$$

where $z_{0}$ was the pre-recruitment mortality rate at equilibrium calculated as $-\log \left(S_{0}\right) ; z_{\text {min }}$ was the limit of the pre-recruitment mortality as depletion approaches 0 calculated as $z_{0}\left(1-z_{f r a c}\right)$, and $z_{\text {frac }}$ represented the reduction in mortality as a fraction of $z_{0}$ ( $z_{\text {frac }}$ therefore ranged from 0 to

1 ); and $\beta$ was the shape parameter of the density dependence between the spawning population and pre-recruitment survival.

The steepness, $h$, of the spawner-recruit curve (i.e., expected recruitment relative to $R_{0}$ at a spawning depletion of 0.2 ) can be derived from the parameters using,

$$
h=0.2 \exp \left[z_{0} z_{f r a c}\left(1-0.2^{\beta}\right)\right]
$$

A suite of preliminary simulations, with model structures consistent with this assessment, were performed to examine if the $\beta$ and/or $Z_{\text {frac }}$ parameters were estimable given the model structure and available data. Results from the simulations indicated that the available data were likely to be informative on the $\beta$ parameter but not the $z_{\text {frac }}$ parameter. Therefore, based on these simulation results, we fixed $z_{f r a c}$ in the middle of a reasonable range for the base case model (base case: 0.6 ; range: $0.3-0.9$ ) and estimated $\beta$. Sensitivity analyses were performed to evaluate the sensitivity of the model to the range of $z_{\text {frac }}$ (Section 6.1.2.1). In addition, we also conducted sensitivity analyses using a Beverton-Holt stock-recruitment relationship with similar steepness to the low fecundity stock-recruitment relationship (Section 6.1.2.2).

Annual deviations in recruitment were modeled by replacing the $B_{y}$ with,

$$
B_{y} \exp \left[-0.5 b_{y} \sigma_{R}^{2}+\tilde{R}_{y}\right], \tilde{R}_{y} \sim N\left(0, \sigma_{R}^{2}\right)
$$

where $b_{y}$ was the bias adjustment fraction applied for year $y, \sigma_{R}$ was the standard deviation of the recruitment deviations in log space, and $\tilde{R}_{y}$ was the lognormal recruitment deviation for year y. The bias adjustment factor ensured that estimated recruitment during even 'data poor' eras, when the estimated $\tilde{R}_{y}$ was near 0, was unbiased (Methot and Taylor 2011). The bias adjustments for the base case and sensitivity analysis models were performed by estimating the expected bias adjustments using the R package 'r4ss' (v1.23.5) and then re-running the model again with the new bias adjustments. This bias adjustment procedure was performed once or twice depending on whether the estimated and expected bias adjustments were well matched after a single pass.

In this assessment, $\sigma_{R}$ was assumed to be 0.5 , which was consistent with the expected variability. A sensitivity analysis was conducted assuming a lower $\sigma_{R}$ of 0.3 (Section 6.1.2.3).

### 3.4.3 Selectivity

The assessment model had a sex-specific structure, with sex-specific growth curves. However, we assumed that male and female common thresher sharks have identical selectivity for each fleet because the size composition data were adequately fit with this assumption, sex-specific size composition data were not available prior to 1990, and there was no available information that suggested selectivity differed by sex.

The USSN fleet (F3) was assumed to have an age-based selectivity because preliminary models using size-based selectivity fit the size composition data poorly and degraded the fit of other
fleets with age-0 observations (Section 3.2). Using an age selectivity process together with a size bin structure that approximately aggregated age-0 observations resulted in better fits to the data. The selectivity of each age class from age-0 through age-2 was freely estimated, and the selectivity of ages $>2$ was assumed to be negligible for this fleet. A sensitivity analysis was performed to examine the sensitivity of model results to using size selectivity for this fleet rather than age selectivity (Section 6.1.5.2).

All other fleets were assumed to have size-based selectivity processes. Size selectivities were estimated for four fleets with size composition data (F1, F2, F8, and S6) and the size selectivities of other fleets were mirrored to one of these fleets (Table 3.1). The MXDGNLL (F6) fleet had several size composition observations in 2007 - 2008 (Table 2.4) but preliminary models indicated that the low sample sizes and variability of these observations resulted in the model poorly fitting these observations. Given that the size of common thresher sharks caught by this fleet was similar to the USDGN fleets (F1 and F2), we assumed that their size selectivities were also similar. Visual examination of the expected and observed size composition of the removals suggested that this assumption was adequate. A sensitivity analysis was performed that fit to the size observations from the MXDGNLL (F6) fleet (Section 6.1.5.3).

The selectivity curves for the USDGN (F1) and MXART (F8) fleets, and the USJUV0614 (S6) index were assumed to be dome-shaped and parameterized as double-normal curves (Table 3.1). Each double normal selectivity curve had six parameters: 1) peak, the initial length at which the fish is fully selected; 2) width of the plateau at the top; 3) width of the ascending limb of the curve; 4) width of the descending limb of the curve; 5) selectivity of the first size bin; and 6) selectivity of the last size bin. The parameters for peak, width of ascending limb, and width of descending limb were estimated for all three double-normal curves. In addition, the selectivity of the first size bin was estimated for the USDGN (F1) fleet but assumed to be controlled by the width of the ascending limb for the other two fleets and therefore not estimated. The selectivity of the final size bin was assumed to be controlled by the width of the descending limb and therefore not estimated for all three selectivity curves. The width of the plateau was assumed to be negligible and fixed at a very small value for all three selectivity curves because preliminary models indicated that this parameter was always estimated to be a very small value and at the lower bound for all three curves.

The size selectivity curves of the USDGNs2 (F2) fleet were parameterized as cubic splines with four knots because of bimodal size composition data. Preliminary models indicated that cubic splines with four knots at $75,125,175$, and 225 cm allowed for flexible selectivity curves that adequately fit the size composition data. Sensitivity analysis on the location of the final knot was performed because that affected the selectivity at the final size bin, which can influence the estimated scale of the population (Section 6.1.5.4).

Selectivities of the USDGN (F1), USDGNs2 (F2), and USSN (F3) fleets were allowed to vary through time. The selectivities of these fleets were likely affected by major regulatory changes
(Table 1.1), which forced the fleets to change their fishery operations. Therefore, the selectivities of these fleets were grouped into blocks of time when their regulations and fishery operations were relatively consistent (Table 3.1). A sensitivity analysis was performed to examine the effect of alternative time blocks of selectivity (Section 6.1.5.1).

### 3.4.4 Catchability

Catchability, $q$, was estimated assuming that the abundance indices were proportional to vulnerable biomass with a scaling factor of $q$. It was assumed that $q$ was constant over time for each index.

### 3.4.5 Initial conditions

In this assessment, we started the main population dynamics of the model in 1969, which was prior to the start of targeted commercial fishing in 1977 - 1978. Although there was some low level of exploitation of this stock prior to 1969, the level of exploitation was substantially lower than during the period of targeted fishing. It was therefore assumed that the population was relatively close to equilibrium in a near unfished state. The level of pre-1969 equilibrium catch was assumed to be the average of 1969 - 1971, and grouped into three fleets based on the approximate size and unit of catch: 1) the USDGN (F1 and F2) and MXDGNLL (F6 and F7) fleets for all seasons; 2) USREC (F4 and F5) for all fleets; and 3) the USSN (F3) and MXART (F8) fleets. The initial fishing mortality rates that remove these equilibrium catches were estimated to allow the model to start at an appropriate depletion level, albeit near an unfished condition. No early recruitment deviations (i.e. recruitment deviations prior to 1969) were estimated because the earliest size composition and abundance index observations were from 1981 and 1982 respectively, and the recruitment deviations during the period from 1969 to 1980 acted like early recruitment deviations, which allowed the model to develop a non-equilibrium age structure when the main observations started. A sensitivity run was used to examine the effect of starting the model in an unfished condition (Section 6.1.1.2).

### 3.5 Data weighting

Statistical stock assessment models fit a variety of data components, including abundance indices and size composition data. The results of these models can depend substantially on the relative weighting between different data components (Francis 2011). In this assessment, we use the method proposed by Francis (2011) (Method TA1.8) to weight the size composition data, using the SSMethod.TA1.8 function in the 'r4ss' package (v1.23.5). All estimated Francis weights of the size composition for all fleets were $>1$, which suggested that the size composition data did not have to be down-weighted. A $R_{0}$ profile of the data components (Lee et al. 2015) also suggested that the size composition data were relatively consistent with abundance indices with respect to estimated population scale (Section 4.4). Visual examination of the residual patterns of the size composition data suggested that the size composition data were relatively well fit and the scale of the Pearson's residuals for each data component were consistent with the statistical assumptions (i.e., approximately $95 \%$ of the residuals were within $\pm 2$ standard deviations) except
for the 2 cm bin data for the USDGN (F1) and USSN (F3) fleets. The larger than expected residuals for these two data components were due to large spikes in single bins, which were primarily attributed to noisy data and small sample sizes. Therefore, no adjustments were made to the input sample size ( $N_{\text {input }}$ ) for the size composition data for all fleets.

Sensitivity analyses were performed where the variance adjustment factors for $N_{\text {input }}$ followed the estimated Francis weights and were allowed to exceed 1.0; and where the $N_{\text {input }}$ were downweighted in turn using likelihood component weighting factors (i.e., lambda factors) of 0.2 (Section 6.1.4).

A similar data weighting process was performed for the conditional age-at-length data. Estimated Francis weights of the conditional age-at-length data using the SSMethod.Cond.TA1.8 function in the ' $r 4 s s$ ' package were $>1$, which indicated that the conditional age-at-length data did not have to be down-weighted. However, preliminary $R_{0}$ profiles suggested that the conditional age-at-length data were inconsistent with the abundance indices in terms of estimated population scale. We decided to down-weight the influence of the conditional age-at-length data because the data were intended to provide information on the growth of the fish but not to influence estimates of population scale, which was better represented by abundance indices. In the base case model, the contribution of the overall likelihood by the conditional age-at-length component was downweighted by a lambda weighting factor of 0.2

Input variances of the abundance indices were adjusted to make them consistent with the statistical assumptions of the model. The initial input coefficients of variance ( $C V_{\text {input }}$ ) of the abundance indices were the sum of the estimated observation error and variance adjustment factors based on the estimated additional process errors (USDGN indices only) (Section 2.1.3). After the initial model was run, the estimated root-mean-square errors of the model fit to the abundance indices were used to adjust the variance adjustment factors to allow the total expected errors to be consistent with the estimated errors. The minimum value allowed for variance adjustment factors was 0.0 , in order to limit the minimum expected error to the observation errors estimated by jack-knifing the data.

## 4. Model selection and evaluation

### 4.1 Alternative model configurations

A large number of alternative model configurations were explored to develop the base case model, which provided a realistic but parsimonious description of common thresher shark population dynamics based on the best available scientific information. The alternative models were evaluated on overall model fit and convergence criteria, as well as consideration of whether model assumptions, structural choices, estimated parameters, and outputs were reasonable and consistent with available information for the stock. The base case model reflected the best aspects of these exploratory models. Overall, the base case model fit the observed data well, with plausible model processes and estimated parameters were within reasonable bounds.

Several models that describe alternative states of nature are described in the sensitivity analyses section (Section 6.1). These include alternative assumptions on growth, reproductive biology, natural mortality, stock-recruitment relationship, total removals, data weighting, and selectivity.

### 4.2 Model convergence

Convergence of the base case model was indicated by all of the tests that were conducted. The base case model had a maximum gradient component that was very close to zero (2.20974E-5), a positive definite Hessian matrix, and all estimated parameters were within reasonable bounds. We also explored the likelihood surface of the model using 50 runs with different phasing and initial values. Total negative log-likelihood from the model run using the phasing and initial parameters from the base case model was the lowest (i.e., best) among these runs, and 33 out of 50 runs also obtained the same total negative log-likelihood (Fig. 4.1). In addition, the estimated virgin recruitment in log-scale $\left[\ln \left(R_{0}\right)\right]$ was similar from runs with similar likelihoods to the base case model (Fig. 4.1).

### 4.3 Model fit

The fit of the base case model to observations were determined by examining the residuals of the abundance indices, size compositions, and conditional age-at-length data.

### 4.3.1 Fit to abundance indices

The base case model was able to adequately capture the trends indicated by the sub-adult/adult (S1, S2, and S3) and recruitment (S4 and S5) abundance indices that were fit (Fig. 4.2). Importantly, the base case model results were consistent with the population decline observed by the S1 index during 1982 - 1984, and the increasing population trend observed by the S2 index during 1992 - 2000. However, we note that the observed trends during these two periods were steeper than expected. The lack of contrast and large uncertainties of the observations for S3 during 2001-2013 made it difficult to ascertain how well the base case model matched the observed population trends during that period. The base case model captured the trends in recruitment observed by the S4 and S5 indices.

Overall, the model fits to the sub-adult/adult indices (S1, S2, and S3) were poorer than the recruitment indices ( S 4 and S 5 ) but were considered to be adequately representative of abundance trends and consistent with model input CVs. The RMSEs of the S1, S2, and S3 indices were $0.157,0.391$, and 0.545 respectively while the RMSEs of the S 4 and S 5 indices were 0.176 and 0.178 (Table 4.1). The RMSEs of the S1, S4, and S5 indices were smaller than their input CVs based on observation errors while the RMSEs of the S2 and S3 indices were approximately equivalent to the sum of their input CVs and variance adjustments after tuning.

### 4.3.2 Fit to size compositions

Base case model fits to the size composition data were generally good. Overall, the model predicted size compositions that matched observations well (Fig. 4.3-4.5). Examination of the input sample size (input N ) and model estimated effective sample size (eff $N$ ) also showed
reasonably good model fits (Table 4.2). A higher eff $N$ indicates better model fit, with a mean $e f f N>30$ indicating good model fit. In addition, ratios of the harmonic mean of the eff $N$ to mean input N were all $\geq 1$, which indicated that the base case input N did not assume less error than was evident in the model fits.

Pearson residuals of the model fit to the size composition data did not reveal substantial patterns in the residuals (Fig. 4.6 - 4.7). In addition, the scale of the residuals were generally small, with most lying within $\pm 2$ standard deviations. Exceptions to this occurred in the USDGN (F1) and USSN (F3) fleets when 2-cm bins were used because of several large spikes in the size compositions, which could not be fit with reasonable model processes.

### 4.3.1 Fit to conditional age-at-lengths

Base case model fits to the conditional age-at-length data were generally good. Overall, the model predictions matched observations well although some large fish appeared to have been aged at unreasonably young ages (Fig. 4.8). The ratios of the harmonic mean of the eff $N$ to mean input N were all $\geq 1$, which indicated that the base case input N did not assume less error than was evident in the model fits (Table 4.3).

### 4.4 Retrospective analysis

Retrospective analysis did not reveal any pattern in the estimates of female spawning abundance and fishing intensity (1-SPR) with successive elimination of up to five years of terminal year data (Fig. 4.9).

### 4.4 Likelihood profiles on virgin recruitment ( $R_{0}$ profile)

Results of the likelihood profiling on virgin recruitment, $R_{0}$, for the abundance indices and size composition data components of the model are shown in Fig. 4.10. Changes in the likelihood of each data component are a measure of how informative that data component is to the overall estimated population scale and what that scale is. Ideally, catch and abundance indices should be the primary sources of information on the population scale in a model (Lee et al. 2015).

In the base case model, the abundance indices appeared to be the primary sources of information on $R_{0}$. The USDGN9200 (S2) and USSN9414 (S5) indices had the largest influences on $R_{0}$ but the other three indices had negligible information on $R_{0}$. This was because both S 2 and S 5 indices had good contrast coupled with moderate amounts of observations and/or uncertainty. The maximum likelihood estimates of $R_{0}$ for the S 2 and S 5 indices were also relatively consistent with each other and the overall $R_{0}$ estimate. In comparison, the USDGN8284 (S1), USDGN0113 (S3), and USSN8593 (S4) indices had some combination of small number of observations, large uncertainties and/or limited contrast.

The size composition data also influenced the $R_{0}$ estimate but appeared to be relatively consistent with the information from the abundance indices. The USDGN (F1) fleet had the largest influence among all the fleets with size compositions, which was expected because the F1 fleet
had the largest number of size composition observations. None of the size composition data from other fleets had major influences on $R_{0}$. Given that the $R_{0}$ profiles of the size composition data were consistent with the abundance indices, we considered the scale of the population to be adequately estimated by the base case model.
4.5 Age-structured production model analysis

Following the proposal by Maunder and Piner (2015), the base case model was modified into an age-structured production model to identify if the catch and sub-adult/adult abundance indices were consistent with the estimated scale and trends in the population. Maunder and Piner (2015) stated that "When catch does explain indices with good contrast (e.g., declining and increasing trends), it suggests that a production function is apparent in the data, therefore providing evidence that the index is a reasonable proxy of stock trend". In this assessment, the base case model was modified by fixing the stock-recruitment relationship, sex-specific growth curves, and selectivities of all fleets to those estimated in the base case model, not estimating annual recruitment deviates so that recruitment follows the stock recruitment curve, and not fitting to the size composition and conditional age-at-length data.

The age-structured production model had similar scale and populations trends to the base case model (Fig. 4.11). Model fits to the sub-adult/adult abundance indices (S1, S2, and S3) were also similar to the base case model (Fig. 4.11), which suggested that the sub-adult/adult indices were reasonable proxies of stock trend and the productivity of the stock was estimated reasonably well.

## 5. Model results

### 5.1 Model parameter estimates

The estimated or fixed values of the explicit parameters used in the base case model are shown in Table 5.1. All estimated parameters except initial fishing mortality were estimated within reasonable bounds. The initial fishing mortalities were estimated very close to the lower bounds (i.e., very close to 0 ), which is reasonable because the stock was close to being in an unfished condition at the start of the model.

### 5.1.1 Growth

Growth parameters of female and male common thresher sharks were estimated within the model and were consistent with what we know of the species (Fig. 5.1). Female sharks were slightly larger than male sharks for each age. However, the size difference between sexes appeared to be smaller than previously estimated. In addition, the size at age-0 appeared to be smaller than previously estimated.

### 5.1.2 Selectivity

Estimated selectivity curves are shown in Figures 5.2 - 5.4. Selectivity parameters were well estimated and selectivity curves were consistent with the known fishery operations of the fleets.

Higher selectivities for smaller fish were estimated for the USSN (F3), and MXART (F8) fleets, and the USJUV0614 survey (S6), which catch predominantly small, juvenile common thresher sharks. The peak parameters for F8 and S6 were $<85 \mathrm{~cm}$ and selectivity of age-0 sharks for F3 was substantially higher than age-1 and 2 sharks (Table 5.1). In contrast, the selectivity curves of the USDGN (F1) and USDGNs2 (F2) fleets, which catch primarily sub-adult and adult sharks, had peak selectivities closer to 150 cm . A clear bimodal selectivity pattern was estimated for the USDGNs2 (F2) fleet during 1985-1988 because a large number of large sharks >200 cm were caught during this period (Fig. 5.5), which may have been due to time-area closures affecting fishing operations.

### 5.1.3 Catchability

The catchability coefficient $(q)$ was solved analytically in the base case model as a single value for each index (Table 4.1). Catchability was allowed to vary through time by separating the abundance index from a single fishery into multiple time series based on an examination of the fishery operations of the fishery.

### 5.1.4 Catch-at-age

Juvenile and sub-adult common thresher sharks (ages-0 to 4) formed the largest component of the catch (Fig. 5.6), even during the peak of the USDGN fishery in 1982. This is because the selectivity of all fleets select for a substantial proportion of juvenile and sub-adult sharks.

### 5.1.5 Sex ratio

The sex ratio (male/female) estimated in the base case model was close to $1: 1$ because the estimated female growth curve was similar to the male growth curve, and selectivity was assumed to be non sex-specific (Fig. 5.7).

### 5.2 Stock assessment results

### 5.2.1 Reproductive capacity and output

In this assessment, the reproductive capacity of the population was calculated as the number of mature female sharks (i.e., spawning abundance) rather than spawning biomass, because the size of mature female sharks did not appear to affect the number of pups produced (i.e., larger female sharks did not produce more pups). The reproductive output of the stock (i.e., the number of pups produced by the stock) was calculated using four pups produced per year per mature female shark.

In the base case model, the estimated number of mature female common thresher sharks under unfished conditions was 88,200 sharks ( $95 \%$ CI: $69,500-107,000$ sharks) with a reproductive output of 352,900 pups ( $95 \%$ CI: 278,000 - 427,800 pups) (Table 5.2 and Fig. 5.8). Prior to the start of targeted commercial fishing in 1977 - 1978, the estimated reproductive capacity was 93,000 mature female sharks ( $95 \%$ CI: 74,200 - 111,800 sharks) in the early 1970s. The start of targeted commercial fishing in 1977 - 1978 was quickly followed by a large increase in fishery removals, peaking in the early 1980s (Fig. 2.2). These relatively large removals resulted in the
number of mature female sharks declining quickly to approximately 35,200 sharks ( $95 \% \mathrm{CI}$ : $21,300-49,100$ sharks) in 1985 . Over the next decade, the number of mature female sharks continued to decline but at a substantially slower rate, likely due to the management of the USDGN fishery during this period. The historical low estimate occurred in 1995, with 26,800 mature female sharks ( $95 \%$ CI: 15,000 - 38,600 sharks). After 1995, the reproductive capacity gradually increased over the past two decades. In 2014, the terminal year of the assessment model, the estimated number of mature female sharks reached 83,300 sharks (95\% CI: 49,500 117,100 sharks) with a reproductive output of 333,100 pups ( $95 \%$ CI: $198,000-468,300$ pups) (Table 5.2).

Depletion of the stock was estimated as the number of mature females in the second quarter ( $S$ ) for a specific year divided by the number of mature females under unfished conditions ( $S_{0}$ ) because the reproductive output of the stock (i.e., number of pups produced) was dependent on the number of mature females and not on the weight of the female sharks. Therefore, the estimated depletion followed the same trajectory as the number of mature female sharks, albeit scaled to $S_{0}$ (Table 5.2 and Fig. 5.8). The total (age-1+) and mature female biomass were both less important than the number of mature females as an indicator of the stock, but both also showed similar trends (Table 5.2 and Fig. 5.8).

### 5.2.2 Recruitment

The estimated recruitment and stock-recruitment relationship were generally consistent with the biology of the stock and assumptions in the base case model. Conditional on a fixed $z_{\text {frac }}$ of 0.6 , the base case model estimated a shape parameter, $\beta$, of 3.059 , which indicated that the stockrecruitment relationship had a moderate curvature (Table 5.1 and Fig. 5.9). Unfished recruitment was estimated to be 77,100 sharks $\left(\log \left(R_{0}\right)=4.345\right)($ Table 5.1). The estimated recruitment deviations from the expected spawner-recruit curve appeared to be relatively well estimated and consistent with the expected distribution of recruitment deviations ( $\sigma_{R}=0.5$ ), but there appeared to be a small amount of autocorrelation in the time series that was unaccounted for in the base case model (Fig. 5.9). The change in recruitment bias was consistent with expectations and accounted for in the base case model (Fig. 5.9).

The estimated recruitment fluctuated substantially during the assessment period (1969 - 2014), ranging from a low of 40,700 sharks ( $95 \%$ CI: 23,300 - 58,100 fish) in 1989 to a high of 150,500 sharks ( $95 \%$ CI: 86,400 - 214,600 fish) in 2006 (Table 5.2 and Fig. 5.9). Overall average recruitment during the assessment period was approximately 73,700 sharks but there appeared to be a period of relatively low recruitment from 1985 - 1995, with average recruitment at 56,700 sharks. In contrast, a more recent period from 2006 - 2012 had substantially higher recruitment, averaging approximately 115,600 sharks.

### 5.2.3 Fishing mortality

Fishing mortality-at-age (F-at-age) was estimated for female and male common thresher sharks in the base case model (Fig. 5.10). The fishing mortality was highest on the sub-adult and adult
sharks during the peak of the swordfish/shark drift gillnet fishery. In recent years, the declining catch and effort from this and other fisheries have resulted in substantially lower fishing mortality for all ages. There did not appear to be substantial differences in the fishing mortality between female and male sharks.

Female spawning potential ratio (SPR) was used to describe the fishing intensity on the stock. The SPR of a population is the ratio of spawning output per recruit under fishing to the spawning output per recruit under unfished conditions (Goodyear 1993). Therefore, 1-SPR is the reduction in the spawning output per recruit due to fishing and can be used to describe fishing intensity on a fish stock. The fishing intensity (1-SPR) on this common thresher shark stock ranged from a low of 0.067 in 1971, prior to the start of targeted commercial fishing, to a high of 0.831 in 1982 during the peak of the swordfish/shark drift gillnet fishery (Table 5.2 and Fig. 5.11).

## 6. Model uncertainty

The assessment explicitly estimated the model uncertainty due to uncertainty in parameter estimates. These uncertainties were reported as confidence intervals for key parameters and management quantities (Table 6.1). These confidence intervals captured the uncertainty in the model fits to the data sources in the assessment but did not include uncertainty in model specification and fixed parameters. We used a suite of sensitivity runs to explore the uncertainty associated with alternative model specification and examine the sensitivity of important model outputs to different model assumptions.

### 6.1 Sensitivity analyses

A large number of alternative model specifications were used to examine the sensitivity of model results to different model assumptions. Only the most important ones are reported here.
Summarized results of these sensitivity runs can be found in Table 6.1 and Figs. 6.1-6.17. Unless otherwise stated, input variances of abundance indices in the sensitivity runs were adjusted to make them consistent with the statistical assumptions of the model, and recruitment bias adjustments were performed. In addition, all sensitivity runs except for the run described in Section 6.1.4.2, used a data weighting approach that was consistent with the base case model. Essentially, a maximum weighting factor of 1 for all size composition data was used for the sensitivity runs and since estimated Francis weights of size composition data were all $>1$, all size composition weighting factors were set to 1 unless otherwise specified.

### 6.1.1 Alternative assumptions about fishery removals

### 6.1.1.1 High and low catch

Commercial landings of common thresher sharks by the USA West Coast commercial fisheries were relatively well known due to the CALCOM and PacFIN databases. However, there was uncertainty associated with potential misidentification of common thresher sharks as unspecified sharks (Pearson et al. 2008) or other less common species of thresher sharks (i.e., pelagic and bigeye thresher sharks). The commercial landings from Mexico fisheries were less well known
but we assumed that the uncertainty associated with our estimates of removals by the Mexico drift gillnet, longline, and artisanal fisheries were approximately $\pm 30 \%$.

To explore the sensitivity of model output to the uncertainty in fishery removals, we developed two alternative fishery removal time series: 1) high catch, and 2) low catch. The high catch scenario was based on including all landings of unspecified sharks, and pelagic and bigeye thresher sharks by the USA West Coast commercial fisheries as landings of common thresher sharks, and setting the Mexico commercial landings to base case $+30 \%$. Conversely, the low catch scenario was based on excluding all landings of unspecified sharks, and pelagic and bigeye thresher sharks by the USA West Coast commercial fisheries, and setting the Mexico commercial landings to base case - $30 \%$. The dead discard rates for USA commercial fisheries were assumed to be the same for the base case model and both alternative catch scenarios. The removals by the USA recreational fishery were relatively minor compared to the commercial fisheries and were not adjusted for either catch scenario. However, the initial equilibrium catches for the high and low catch scenarios were adjusted accordingly to be the average of 1969 - 1971 for their respective scenario.

Although the absolute scale of the estimated unfished and current reproductive output changed, the trends in the estimated depletion levels as well as the status of the stock relative to reference points differed only slightly (Table 6.1 and Fig. 6.1).

### 6.1.1.2 Unfished initial conditions

In the base case model, we assumed that the level of pre-1969 equilibrium catch was the average of 1969 - 1971, and the initial fishing mortality was estimated from that initial catch. However, the population could have been in an unfished state at the start of the model. Therefore, we explored the effect of starting the model in an unfished state by fixing the initial fishing mortality to zero for all fleets and not fitting to the initial catch. The absolute scale of the unfished reproductive output was slightly lower if the model was started under unfished conditions but the trends in reproductive capacity were highly similar (Table 6.1 and Fig. 6.2).

### 6.1.2 Alternative assumptions about stock-recruitment

### 6.1.2.1 Alternative $z_{\text {frac }}$ values

A $z_{\text {frac }}$ value of 0.6 was assumed for the base case model. However, it was unclear what $z_{\text {frac }}$ values were appropriate for common thresher sharks, and preliminary models and simulations suggested that $Z_{\text {frac }}$ could not be reliably estimated with the available data. A large range of $Z_{\text {frac }}$ values ( $0.3-0.9$ ) were used in sensitivity runs to explore the effects of assumed $z_{\text {frac }}$ values on model results. The shape parameter, $\beta$, of the stock-recruitment relationship was estimated for these sensitivity runs.

Assuming different $z_{\text {frac }}$ resulted in relatively large changes to the estimated management quantities. Both estimated unfished recruitment and $\beta$ became lower as $z_{\text {frac }}$ was changed from 0.3 to 0.9 (Fig. 6.3). As a result, pup survival curves were flatter and lower at low $Z_{\text {frac }}$ values. At
low $Z_{\text {frac }}$ values, the expected recruitments were generally higher but with recruitment maxima occurring at higher stock levels. The general trends in the estimated number of mature female sharks, spawning depletion, and fishing intensity were similar for all $z_{\text {frac }}$ values but there were substantial differences in scale, especially at low $Z_{\text {frac }}$ values (Fig. 6.4). For example, the estimated number of mature females in the terminal year, 2014, was substantially higher at a $Z_{\text {frac }}$ of 0.3 (202,100 sharks) than for the base case $\left(z_{\text {frac }}=0.6 ; 83,300\right.$ sharks $)$ and at a $z_{\text {frac }}$ of 0.9 (64,100 sharks) (Table 6.1). The estimated MSY had a bowl-shaped response to the range of $Z_{\text {frac }}$ used, with the MSY at a minimum for the base case model $\left(z_{\text {frac }}=0.6\right)($ Table 6.1).

### 6.1.2.2 Beverton-Holt stock-recruitment

The base case model used the relatively new stock-recruitment relationship developed by Taylor et al. (2013) for low fecundity fish like common thresher sharks (Section 3.4.2). However, common thresher sharks may instead have a Beverton-Holt stock-recruitment relationship. Therefore, we explored the effect of using a Beverton-Holt stock-recruitment relationship at several levels of steepness (h): 1) $h=0.495$ (equivalent to steepness in base case model; Section 3.4.2); 2) $h=0.4$; 3) $h=0.6$; and 4) estimated $h$.

The use of Beverton-Holt stock-recruitment relationships resulted in similar trends in the estimated number of mature females, recruitment, depletion, and fishing intensity (Fig. 6.5). However, the recovery of the stock was slower when Beverton-Holt stock-recruitment relationships were used, resulting in lower $\mathrm{S}_{2014} / \mathrm{S}_{0}$ ratios (Table 6.1 and Fig. 6.5).

### 6.1.2.3 Recruitment variability (sigma-R)

The expected recruitment variability in the base case model was set at a moderate level ( $\sigma_{R}=$ 0.5 ) that was consistent with estimated recruitment deviates for the base case model. The recruitment variability for sharks born at a moderately large size like common thresher sharks could conceivably be smaller than a $\sigma_{\mathrm{R}}$ of 0.5 . The effects of using a $\sigma_{\mathrm{R}}$ of 0.3 were examined.

As expected, the estimated recruitment was slightly less variable when a $\sigma_{\mathrm{R}}$ of 0.3 was used, with lower recruitment since 2000 (Fig. 6.6). However, the trends in the estimated number of mature females, depletion, and fishing intensity were highly similar. The estimated recruitment deviates when using a $\sigma_{R}$ of 0.3 were less variable than the base case model but many estimated deviates approached 0.5 , suggesting that the base case model parameterization was likely more consistent with the data.

### 6.1.3 Alternative assumptions on life history

### 6.1.3.1 Alternative natural mortality

In the base case model, we assumed an instantaneous rate of natural mortality of $0.179 \mathrm{y}^{-1}$ based on a maximum age of 25 years and Hoenig's relationship between maximum age and natural mortality (Hoenig 1983). Given that natural mortality was a highly uncertain parameter, we examined the effect of three alternative rates of natural mortality: 1) $50 \%$ of base case; 2 ) $75 \%$ of
base case, and 3) $125 \%$ of base case. A fourth sensitivity run at $150 \%$ of base case was performed but the model did not converge and was therefore discarded.

The trends of estimated number of mature females, spawning depletion, and fishing intensity were relatively similar for all levels of natural mortality but differed in the estimated scale, especially for estimated fishing intensity (Table 6.1 and Fig. 6.7). As expected, the estimated scale of the population increased with increasing natural mortality, while the estimated fishing intensity decreased.

### 6.1.3.2 Alternative growth parameterization

Sex-specific growth was estimated in the base case model but growth of this stock was previously estimated by Smith et al. (2008a). In this sensitivity run, we fixed the growth of male and female sharks to the Smith et al. (2008a) estimates and did not fit to the conditional age-atlength data. The estimated number of mature female sharks, spawning depletion, and fishing intensity of the sensitivity run were highly similar to the base case model (Table 6.1 and Fig. 6.8). However, the model fit of the size compositions of age-0 female sharks caught by the USA juvenile thresher shark survey (S6) was substantially better in the base case model than the sensitivity run (Fig. 6.8).

### 6.1.3.3 Alternative assumptions on maturity and fecundity

The base case model used biological parameters from Smith et al. (2008a, b) because those studies were based on the same population of common thresher sharks as this assessment. However, a recent study on the reproductive biology of the western North Atlantic stock of common thresher sharks (Natanson and Gervelis 2013) demonstrated a much higher median age of maturity for female sharks (12 vs 5 years) and longer reproductive cycle (biennial or triennial vs annual cycle). Therefore, a series of sensitivity runs were performed to examine the effects of these differences in maturity and fecundity. Preliminary models with an age-12 median age of maturity did not converge. It was therefore assumed that maximum age was proportional to the age of maturity [i.e., maximum age of 60 years ( $\frac{12}{5} \mathrm{X} 25$ years $)$ ] and a corresponding natural mortality rate of 0.0757 (Section 2.3.2). Lower natural mortality rates allowed the models with an age-12 median age-of-maturity to converge. Preliminary models with triennial reproductive cycles did not converge (even with lower natural mortality rates) and were therefore discarded.

Changing the maturity and fecundity schedules resulted in substantial differences in the trend and scale of the estimated population dynamics (Table 6.1 and Fig. 6.9). Assuming a biennial reproductive cycle is identical to halving the fecundity from four to two pups per female, which resulted in an approximate doubling of the estimated number of mature females to maintain the reproductive output (i.e., number of pups produced) of the stock at about the same level. This increase in the population size also resulted in a substantial increase in the estimated MSY (Table 6.1). Increasing the median age-of-maturity to 12 years appeared to slow the initial decline and subsequent recovery in the estimated number of mature females, even though the peak fishing intensities were highest for these runs. The slower initial decline was due to the
dome-shaped selectivity of the primary commercial fisheries, which reduced the availability of mature females to these fisheries as age-of-maturity increased. However, the female sharks also took a longer time to mature, which resulted in a relatively slow recovery (Fig. 6.9). With an age of maturity of 12 years, the population was estimated to be in a substantially poorer condition in $2014\left(\mathrm{~S}_{2014} / \mathrm{S}_{0}: 0.636\right)$ than the base case model ( $\mathrm{S}_{2014} / \mathrm{S}_{0}: 0.944$ ). If both the maturity and fecundity schedules of the population were changed, the estimated number of mature females had a similar trend to the age-12 median age-of-maturity model but with a higher population scale due to the lower fecundity (Fig. 6.9).

### 6.1.4 Alternative data sources and weightings

6.1.4.1 Including S6 as juvenile index

In the base case model, abundance indices based on the USDGN (S1, S2, and S3) and USSN (S4 and S5) fisheries were used to represent the sub-adult/adult and recruitment population trends respectively. In addition, an abundance index from the USA juvenile thresher survey (S6) was available but not used in the base case model (Section 2.2). The effect of fitting to the S6 index was investigated in this sensitivity run. There were negligible differences in the estimated population dynamics between the base case model and including the S6 index (Table 6.1 and Fig. 6.10). The negligible influence of S 6 was expected because of the large input CVs (mean input $C V=0.485$ ) that were estimated by jack-knifing the data set.

### 6.1.4.2 Maximum weighting factors $>1$

In the base case model, the variance adjustment factors of the size composition and conditional age-at-length data were based on estimated Francis (2011) weights but were also limited to a maximum of 1 in order to limit the influence of these data on estimated population scale (Maunder and Piner 2015). However, such a procedure may lead to the under-weighting of these data, and result in potential bias and inappropriate uncertainty. In this sensitivity analysis, we allow the weighting factors of the size composition and conditional age-at-length data to be $>1$. Reweighting with estimated Francis weights were performed twice.

Preliminary model runs with weighting factors $>1$ for the size composition data of the USA juvenile thresher survey (S6) and the USSN (F3) fleet did not converge with positive definite Hessian matrices. Therefore, we also performed a run with the weighting factors for the size composition data of the S6 survey and the F3 fleet set at 1 while the other size composition data were allowed to have weighting factors $>1$.

The effect of allowing the maximum weighting factors to be $>1$ were limited (Table 6.1 and Fig. 6.11). The trend and scale of the estimated population dynamics in the sensitivity runs were highly similar to the base case model. However, the estimated $95 \%$ confidence intervals were slightly smaller in the sensitivity runs.
6.1.4.3 Down-weighting size composition data

Inappropriate weighting, especially over-weighting, of size composition data can result in biased results (Francis 2011; Maunder and Piner 2015). A series of sensitivity runs were performed to examine the influence of size composition data from each fleet on the estimated population dynamics. The size composition data from each fleet (F1, F2, F3, F8, S6) were down-weighted by a weighting factor of 0.2 in turn. Down-weighting the size composition data resulted in similar estimated population dynamics to the base case model (Table 6.1 and Fig. 6.12). The size composition data from the USDGN (F1) fleet had the largest influence because it had the largest amount of size composition data. Down-weighting the size composition data of the USSN (F3) fleet resulted in a non-positive definite Hessian matrix.

### 6.1.4.3 Up-weight conditional age-at-length data

The conditional age-at-length data in the base case model were down-weighted by a weighting factor of 0.2 to reduce the influence of these data on the estimated population dynamics while maintaining the ability to estimate growth inside the model. Here, we examined the sensitivity of model results to this decision by allowing the data to be fully weighted (i.e., weighting factor of 1). Model results were largely insensitive to this change in data weighting (Table 6.1 and Fig. 6.13). However, the estimated growth for female sharks were different from the base case model. If the conditional age-at-length were fully weighted, the estimated $L_{\infty}$ was larger than the base case model ( 269.9 cm vs 251.9 cm ) and a concomitantly smaller $K\left(0.1145 \mathrm{y}^{-1}\right.$ vs $\left.0.1286 \mathrm{y}^{-1}\right)$. Differences in the estimated growth of male sharks were smaller than for female sharks.

### 6.1.5 Alternative assumptions on selectivity

### 6.1.5.1 Alternative time blocks

Regulatory changes, especially different time-area closures, likely affected the fishing operations of the USDGN and USSN fisheries, and hence changed the selectivities of the F1, F2, and F3 fleets over time. In the base case model, we accounted for this by allowing selectivities of these three fleets to vary over time in time blocks defined by regulatory changes. However, alternative time periods may be used to define the selectivity time blocks. In this sensitivity model, we simplified the selectivity time blocks for the F1 (1969-1984, 1985 - 2000, and 2001-2014) and F2 (1969 - 1984, and 1985 - 2014) fleets (cf. Table 3.1). The estimated scale of the population dynamics for this sensitivity model were highly similar to the base case model. However, the population trajectories of the two models differed during a middle period from the mid-1980s to the mid-2000s. In this sensitivity model, the population reached a lower level in the mid-1980s but began to recover from that point. In contrast, the base case model population stabilized at that point in time but did not begin increasing consistently till about 2000. Over the last 10 years of the time series, both models exhibited highly similar trends with minimal differences.

### 6.1.5.2 Size selectivity for F3

In the base case model, the USSN (F3) fleet was assumed to have an age-based selectivity and used an aggregated age-0 size bin because of the difficulty in fitting the size composition data
with a reasonable size-based selectivity process. In this sensitivity run, the effect of this decision was explored by using a size-based selectivity process for the F3 fleet and not aggregating the age-0 size bins into a single bin. The estimated selectivity and model fits indicated relatively poor model fit to the data in the sensitivity run (Fig. 6.15). However, the effect on the estimated population dynamics was relatively minor, with only a period between the mid-1980s to the mid1990s showing any obvious differences. Differences in other periods appeared to be negligible.
6.1.5.3 Estimate F6 selectivity

The selectivity of the MXDGN (F6) fleet was assumed to be the same as the USDGN (F1) fleet in the base case model because of difficulty in fitting the limited size composition data in preliminary models and similarities in fishing gear and operations for both fleets. In this sensitivity run, the selectivity of the F6 fleet was estimated and we examined the effect of doing so on the estimated population dynamics. The estimated selectivity for F6 was highly similar to that of F1, albeit without any time blocks due to the limited size composition data, and there were minimal differences in the estimated population dynamics (Fig. 6.16).

### 6.1.5.4 Alternative spline parameterization for F2

The size selectivity of the USDGNs2 (F2) fleet was parameterized as a spline with knots at four fixed locations in the base case model (Table 5.1). However, preliminary models indicated that the estimated selectivity could be sensitive to the location of the knots, especially the final knot. In these sensitivity runs, the location of the final knot was shifted from 225 cm to 215 and 235 cm to examine the effects on the estimated population dynamics. The most important effect appeared to be on the estimated selectivity for the 1985-1988 time block but had negligible effects on the estimated population dynamics (Fig. 6.17).

## 7. Reference points

The current USA fishery management plan for USA West Coast fisheries associated with highly migratory species (PFMC 2011b) uses status determination criteria (SDC) for common thresher shark that are based on MSY, with overfishing occurring if the estimated current fishing mortality or a reasonable proxy exceeds the maximum fishing mortality threshold (MFMT) defined as $\mathrm{F}_{\text {MSY }}$ or a reasonable proxy; and the stock declared in an overfished condition if current spawning biomass is less than the minimum stock size threshold (MSST) defined as (1$\mathrm{M}) * \mathrm{~B}_{\mathrm{MSY}}$, when $\mathrm{M} \leq 0.5$ and M is the instantaneous rate of natural mortality. Based on an unpublished assessment of the USA portion of the stock, a harvest guideline of 340 t was established using the alternative optimum yield (OY) control rule for vulnerable species (i.e., 0.75*MSY) (PFMC 2011b).

For the base case model of this assessment, the estimated MSY for this stock was 806.5 t (95\% CI: 614.7 - 998.3 t ), and the number of mature female sharks at MSY was estimated to be 43,500 sharks ( $95 \%$ CI: $34,600-52,400$ sharks), with a reproductive output of 174,000 pups ( $95 \% \mathrm{CI}$ : $138,300-209,700$ pups) (Table 7.1). The fishing intensity (1-SPR) corresponding to MSY was
estimated at 0.39 ( $95 \%$ CI: $0.37-0.40$ ). Based on these estimates, the MFMT was 0.39 (using 1 - SPR $_{\text {MSY }}$ as a proxy for $\mathrm{F}_{\text {MSY }}$ ) and the MSST was 35,700 mature female sharks (Table 7.1).

## 8. Status of the stock

The estimated fishing intensity (1-SPR) on the common thresher sharks off the west coast of North America is currently relatively low at 0.08 (average of 2012 - 2014) (Table 5.2) and substantially below the estimated overfishing threshold (MFMT), with (1-SPR $\left.{ }_{1214}\right) /\left(1-\mathrm{SPR}_{\mathrm{MSY}}\right)$ at 0.21 (Table 8.1 and Fig.8.1). Similarly, the estimated number of mature female sharks in 2014 ( $\mathrm{S}_{2014}$ ) for this stock is at $94 \%$ of its unexploited level and is substantially larger than the estimated MSST, with $\mathrm{S}_{2014} / \mathrm{MSST}$ at 2.33 (Table 8.1 and Fig.8.1). Thus, this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing.

The stock experienced a relatively large and quick decline in the late 1970s and early 1980s, soon after the onset of the USA swordfish/shark drift gillnet fishery, with spawning depletion dropping to 0.4 in 1985 (Table 5.2 and Fig. 5.8). The population appeared to have stabilized in the mid-1980s after substantial regulations were imposed. Over the past 15 years, the stock began recovering relatively quickly and is currently close to an unexploited level.

Besides the base case model, the status of the stock was also examined under three alternative states of nature, based on alternative reproductive biology and stock-recruitment assumptions: 1) alternative reproductive biology with a biennial reproductive cycle, 12 years median age-atmaturity, and natural mortality of 0.0757 ; 2) alternative stock-recruitment with $z_{\text {frac }}$ of 0.4 ; and 3 ) alternative stock-recruitment with $z_{\text {frac }}$ of 0.8 (Table 8.1). These alternative states of nature addressed the most important sources of uncertainty identified in the sensitivity analysis (Sections 6.1.2.1 and 6.1.3.3). The estimated management quantities from models assuming these alternative states of nature all indicated that this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing (Table 8.1 and Fig. 8.2).

## 9. Decision table

The same four states of nature used to examine stock status were also used in model projections: 1) the base case model; 2) alternative reproductive biology with a biennial reproductive cycle, 12 years median age-at-maturity, and natural mortality of 0.0757 ; 3 ) alternative stock-recruitment with $z_{\text {frac }}$ of 0.4 ; and 4 ) alternative stock-recruitment with $z_{f r a c}$ of 0.8 (Table 9.1). These alternative states of nature addressed the most important sources of uncertainty identified in the sensitivity analysis (Sections 6.1.2.1 and 6.1.3.3).

Ten-year forecasts for each state of nature were calculated based on three future removal scenarios: 1) average catch for 2012 - 2014 in the base case model; 2) 2 * the average catch for 2012 - 2014 in the base case model; and 3) total annual catch of USA swordfish/shark drift gillnet and recreational fisheries (i.e., F1, F2, F4, and F5) at the 340 t PFMC harvest guideline and remaining fisheries at their average catch for 2012 - 2014.

A decision table with these future removal scenarios and alternative states of nature is provided in Table 9.1. For all states of nature and removal scenarios, the adult population is expected to continue increasing and stock depletion is expected to continue improving over the next several years. For the base case and alternative stock-recruitment states of nature, the adult population starts to decline after several years because the fisheries on common thresher sharks primarily catch juvenile and sub-adult sharks and a lag of several years is needed before changes are evident in the adult population. For the alternative reproductive biology model, a lag longer than 10 years (timespan of the forecasts) is needed before changes in the adult population are evident because of the older median age-at-maturity.

## 10. Regional management considerations

Common thresher sharks are migratory, large pelagic sharks and this stock along the west coast of North America is abundant from Baja California, Mexico to Washington, USA. This stock assessment included data from both USA and Mexico waters, encompassing the predominant range of the stock. Small numbers of common thresher sharks are caught by Canada fisheries but the catch is small enough to be negligible. Although this stock assessment encompasses the entire stock, management of this stock is dependent on the domestic regulations of the USA and Mexico, which are largely uncoordinated. However, catch and effort from both USA and Mexico fisheries have been relatively low in recent years compared to historical catch and effort.

## 11. Research and data needs

In this stock assessment, several critical assumptions were made based on limited supporting data and research. There are several research and data needs that if satisfied could improve future assessments, including:

1. The reproductive biology of this stock of common thresher sharks requires further research. Previous research on the reproductive biology of this common thresher shark stock suggested that the median age of maturity for female sharks was 5 years of age and that common thresher sharks had an annual reproductive cycle (Smith et al. 2008a,b). However, a recent study on the reproductive biology of the western North Atlantic stock of common thresher sharks (Natanson and Gervelis 2013) demonstrated a much higher median age of maturity for female sharks (age-12) and longer reproductive cycle (biennial or triennial cycle) for that stock. Sensitivity model runs indicated that changing the maturity and fecundity schedules resulted in substantial differences in the estimated trend and scale of the estimated population dynamics, and was one of the most important assumptions in this assessment. Therefore, it is important that research be conducted to re-examine the maturity ogive and reproductive schedule of this stock. A comparative study between this and the western North Atlantic stock should also be conducted to examine and explain major observed differences in reproductive biology.
2. The survey design and protocols of the USA juvenile thresher shark survey should be reexamined and improved. In this stock assessment, the abundance index derived from the

USA juvenile thresher shark survey was not fit in the base case model because: 1) current protocols resulted in fishing operations that resembled commercial fishing operations with variable effort and catchability; 2) spatial coverage of the survey was relatively limited and likely covered only a small portion of the juvenile range; and 3) fishing effort of the survey was relatively low and the patchy distribution of common thresher sharks resulted in highly variable abundance index estimates (i.e., high CV). The design and protocols of the USA juvenile thresher shark survey should be re-examined to reduce these current drawbacks.
3. Catch and catch-at-size estimates from USA fisheries, especially the USA recreational fishery, should be improved. The USA recreational fishery on this stock of common thresher sharks consists mostly of private vessels, which are poorly sampled. Besides the usual difficulties in estimating the catch, there is also virtually no data on the size composition of the catch. In this assessment, the size of fish caught by the recreational fishery was assumed to be similar to that caught by the USDGN fishery but this assumption may be inappropriate. Therefore, some effort should be put into sampling the recreational catch in the near future. In addition, size composition data from the USSN fishery have also been lacking in recent years.
4. Catch and catch-at-size estimates from Mexico fisheries should be improved. The catch of common thresher shark from Mexico fisheries were estimated for this assessment because of the lack of historical species-specific catch data for sharks. In addition, the collection of size composition data for common thresher shark from Mexico fisheries was ad hoc and opportunistic. Improving future data collection from Mexico fisheries will be difficult but likely to result in improvements to future stock assessments.
5. The use of the low fecundity stock recruitment relationship requires further research. The low fecundity stock recruitment relationship has only been developed recently and has not been thoroughly investigated. In this assessment, we assumed a fixed level for $Z_{\text {frac }}$ and estimated the shape parameter. Preliminary model simulations suggested that the data in the assessment was adequate to estimate the shape parameter but more thorough examination of the use of this stock recruitment relationship is required.

## Acknowledgements

The authors would like to acknowledge and thank everyone who contributed to the development of this assessment and provided the data. Special thanks goes out to Paul Crone (SWFSC), Kevin Hill (SWFSC), Hui-Hua Lee (SWFSC), Mark Maunder (IATTC), Carolina Minte-Vera (IATTC), Kevin Piner (SWFSC), and Tim Sippel (SWFSC) for very useful discussions on preliminary models during a thresher shark assessment meeting held at the SWFSC, La Jolla on June 4 - 5, 2015; James Wraith (SWFSC) and Suzy Kohin (SWFSC) for providing information on the USA juvenile thresher shark survey (including survey data and maps), and discussions on thresher shark biology; Don Pearson (SWFSC), Yuhong Gu (SWFSC), and John Childers (SWFSC) for providing USA fisheries data; Dan Cartamil (SIO) and Dovi Kacev (SWFSC) for discussions and data on the Mexico artisanal fishery; John Hyde (SWFSC) for discussions on the genetics and stock structure of thresher sharks. The authors also thank Paul Crone (SWFSC) and Tim Sippel (SWFSC) for reviewing this document.

## Literature cited

Aalbers, S. A., D. Bernal, and C. A. Sepulveda. 2010. The functional role of the caudal fin in the feeding ecology of the common thresher shark Alopias vulpinus. Journal of Fish Biology, 76: 1863-1868.

Bedford, D. 1992. Thresher shark. In W. S. Leet, C. M. Dewees, and C. W. Haugen, eds. California’s Living Marine Resources and Their Utilization. California Sea Grant Publication UCSGEP-92-12, p 49-51.

Cailliet, G. M., L. K. Martin, J. T. Martin, J. T. Harvey, D. Kusher, and B. A. Welden. 1983. Preliminary studies on the age and growth of the blue, Prionace glauca, common thresher, Alopias vulpinus, and shortfin mako, Isurus oxyrinchus, sharks from California waters. In D. Prince, and L. M. Pulos eds. Proceedings of the International Workshop on Age Determination of Oceanic Pelagic Fishes. NOAA Technical Report NMFS 8. NOAA/NMFS, Silver Spring, Maryland, p 1-17.

Cartamil, D., N. C. Wegner, D. Kacev, N. Ben-aderet, S. Kohin, and J. B. Graham. 2010. Movement patterns and nursery habitat of juvenile thresher sharks Alopias vulpinus in the Southern California Bight. Marine Ecology Progress Series, 404: 249-258.

Cartamil, D. P., C. A. Sepulveda, N. C. Wegner, S. A. Aalbers, A. Baquero, and J. B. Graham. 2011a. Archival tagging of sub-adult and adult common thresher sharks (Alopias vulpinus) off the coast of Southern California. Marine Biology, 158: 935-944.

Cartamil, D., O. Santana-Morales, M. Escobedo-Olvera, D. Kacev, L. Castillo-Geniz, J. B. Graham, R. D. Rubin, and O. Sosa-Nishizaki. 2011b. The artisanal elasmobranch fishery of the Pacific coast of Baja California, Mexico. Fish. Res. 108:393-403.

Castro, J. I. 2009. Observations on the reproductive cycles of some viviparous North American sharks. Aqua, International Journal of Ichthyology, 15:205-222.

Childers, J. and L. Halko. 1994. Length-frequency database description: California Department of Fish and Game gill net market samples. NOAA Fisheries Southwest Fisheries Science Center Administrative Report LJ-94-01. 46 p.

Compagno, L. J. V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the World: An Annotated and Illustrated Catalogue of Shark Species Known to Date. Part 1. Hexanchiformes to Lamniformes. FAO Fisheries Synopsis 125, Vol 4, Part 1. FAO, Rome, Italy. 249 p.

Francis, R. I. C. C. 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences, 68: 1124-1138.

Gervelis, B. J., and L. J. Natanson. 2013. Age and growth of the common thresher shark in the western North Atlantic Ocean. Transactions of the American Fisheries Society, 142:15351545.

Goodyear, C. P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. In S. J. Smith, J. J. Hunt, and D. Rivard (eds.) Risk evaluation and biological reference points for fisheries management. Canadian Special Publications of Fisheries and Aquatic Science, 120: 67-81.

Gruber, S. H., and L. J. V. Compagno. 1981. Taxonomic status and biology of the bigeye thresher, Alopias superciliosus. Fishery Bulletin. 79: 617-640.

Gubanov, Y. P. 1978. The reproduction of some species of pelagic sharks from the equatorial zone of the Indian Ocean. Journal of Ichthyology, 12: 591-600.

Hanan, D. A., D. B. Holts, and A. L. Coan Jr. 1993. The California drift gill net fishery for sharks and swordfish, 1981-82 through 1990-91. California Department of Fish and Game Fish Bulletin 175. 95 p.

Hill, K. T., and N. Schneider. 1999. Historical logbook databases from California's Commercial Passenger Fishing Vessel (Partyboat) Fishery, 1936-1997. Scripps Institution of Oceanography Reference Series, 99-19. 63 p.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin, 81: 898-903.

Holts, D. B. 1988. Review of U.S. West Coast Commercial Shark Fisheries. Marine Fisheries Review, 50: 1-8.

Holts, D. B., and D. Bedford. 1989. Report of the assessment methods workshop for sharks, March 14-15, 1989. NOAA Fisheries Southwest Fisheries Science Center Administrative Report LJ-89-11. 20 p.

Holts, D. B., and O. Sosa-Nishizaki. 1998. Swordfish, Xiphias gladius, fisheries of the eastern North Pacific Ocean. In I. Barrett, O. Sosa-Nishizaki, and N. Bartoo eds. Biology and Fisheries of Swordfish, Xiphias gladius: Papers from the International Symposium on Pacific Swordfish, Ensenada, Mexico, 11 - 14 December 1994. NOAA Technical Report NMFS 142: 65-76.

Holts, D. B., A. Julian, O. Sosa-Nishizaki, and N. W. Bartoo. 1998. Pelagic shark fisheries along the west coast of the United States and Baja California, Mexico. Fisheries Research, 39: 115-125.

Kohler, N. E., J. G. Casey, and P. A. Turner. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. Fishery Bulletin, 93: 412-418.

Lee, H. H., K. R. Piner, R. D. Methot Jr, and M. N. Maunder. 2015. Use of likelihood profiling over a global scaling parameter to structure the population dynamics model: An example using blue marlin in the Pacific Ocean. Fisheries Research, 158: 138-146.

Lo, N. C., L. D. Jacobson, J. L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Canadian Journal of Fisheries and Aquatic Science, 49: 2515-2516.

Maunder, M. N, and K. R. Piner. 2015. Contemporary fisheries stock assessment: many issues still remain. ICES Journal of Marine Science, 72: 1-6.

McFarlane, G. A., R. P. McPhie, and J. R. King. 2010. Distribution and life history parameters of elasmobranch species in British Columbia waters. Canadian Technical Report of Fisheries and Aquatic Sciences 2908. Fisheries and Oceans Canada. 143p.

Methot, R. D., and I. G. Taylor. 2011. Adjusting for bias due to variability of estimated recruitments in fishery assessment methods. Canadian Journal of Fisheries and Aquatic Sciences, 68: 1744-1760.

Methot, R. D., and C. R. Wetzel. 2013. Stock Synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research, 142: 86-99.

Moreno, J. A., J. I. Parajúa, and J. Morón. 1989. Biología reproductiva y fenología de Alopias vulpinus (Bonnaterre, 1788) (Squaliformes: Alopiidae) en el Atlántico nor-oriental y Mediterráneo occidental. Scientia Marina 53:37-46.

Natanson, L. J., and B. J. Gervelis. 2013. The reproductive biology of the common thresher shark in the western North Atlantic Ocean. Transactions of the American Fisheries Society, 142:1546-1562.

Pacific Fishery Management Council. 2003. Fishery Management Plan and Environmental Impact Statement for U.S. West Coast Fisheries for Highly Migratory Species. http://www.pcouncil.org/wp-content/uploads/HMS_FMP_August2003.pdf

Pacific Fishery Management Council. 2011a. Status of the U.S. West Coast Fisheries for Highly Migratory Species through 2010. http://www.pcouncil.org/wpcontent/uploads/HMS_SAFE_2011_FINAL.pdf

Pacific Fishery Management Council. 2011b. Fishery Management Plan for U.S. West Coast Fisheries for Highly Migratory Species: as amended through Amendment 2. http://www.pcouncil.org/wp-content/uploads/HMS-FMP-Jul11.pdf

Pacific Fishery Management Council. 2015. Status of the U.S. West Coast Fisheries for Highly Migratory Species through 2013. http://www.pcouncil.org/wpcontent/uploads/2014_HMS_SAFE_Report_archive_copy.pdf

Pearson, D. E., B. Erwin, and M. Key. 2008. Reliability of California’s groundfish landing estimates from 1969-2006. NOAA Technical Memorandum NMFS NOAA-TM-NMFS-SWFSC-431. NOAA/NMFS, Southwest Fisheries Science Center, Santa Cruz, California. 134 p.

Preti, A., C. U. Soykan, H. Dewar, R. J. D. Wells, N. Spear, and S. Kohin. 2012. Comparative feeding ecology of shortfin mako, blue and thresher sharks in the California Current. Environmental Biology of Fishes. 95: 127-146.

Punt, A. E., D. C. Smith, K. KrusicGolub, and S. Robertson. 2008. Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Canadian Journal of Fisheries and Aquatic Science, 65: 1991-2005.

Schnute, J. 1981. A versatile growth model with statistically stable parameters. Canadian Journal of Fisheries and Aquatic Sciences, 38: 1128-1140.

Smith, E. S. 2005. First year results: Thresher shark (Alopias vulpinus) nursery ground and prerecruit survey index study, September 2003 - September 2004. NOAA Fisheries Southwest Fisheries Science Center Administrative Report LJ-05-01. 25 p.

Smith, E. S., R. C. Rasmussen, D. A. Ramon, and G. M. Cailliet. 2008a. The biology and ecology of thresher sharks (Alopiidae). In M. D. Camhi, E. K. Pikitch, and E. A. Babcock,
editors; Sharks of the Open Ocean: Biology, Fisheries and Conservation. Blackwell Publishing, Oxford, UK. p 60-68.

Smith, E. S., D. W. Au, C. Show. 2008b. Intrinsic rates of increase in pelagic elasmobranchs. In M. D. Camhi, E. K. Pikitch, and E. A. Babcock, editors; Sharks of the Open Ocean: Biology, Fisheries and Conservation. Blackwell Publishing, Oxford, UK. p 288-297.

Sosa-Nishizaki, O., E. Furlong-Estrada, J.A. Reyes-González, and J.C. Pérez-Jiménez. 2002. Blue shark (Prionace glauca) fishery in Baja California, Mexico: An example of artisanal and middle scale fisheries interactions. NAFO SCR Doc. 02/140. Serial No. N4762.

Sosa-Nishizaki, O., J.F. Márquez-Farias, and C.J. Villavicencio-Garayzar. 2008. Pelagic shark fisheries along the west coast of Mexico. In: Merry D. Camhi, Ellen K. Pikitch and Elizabeth A. Babcock (eds.). Sharks of the Open Oceans. Blackwell Publishing Ltd., Oxford. 275-282 pp.

Sosa-Nishizaki, O. 2013. Unofficial blue shark catch estimates for the Mexican Pacific (19762011). Working document submitted to the ISC Shark Working Group Workshop, 16-24 April, National Research Institute of Far Seas Fisheries, Shizuoka, Japan. http://isc.fra.go.jp/pdf/SHARK/ISC13_SHARK_2/Info1Unoffical\ Mexican\ BS\ report\ to\ ISC\ SHARKWG.pdf

Taylor, I. G., V. Gertseva, R. D. Methot, and M. N. Maunder. 2013. A stock-recruitment relationship based on pre-recruit survival, illustrated with application to spiny dogfish shark. Fisheries Research, 142: 15-21.

Thorson, James T, Stewart, Ian J, and Punt, Andre E. 2012. nwfscAgeingError: a user interface in R for the Punt et al. (2008) method for calculating ageing error and imprecision. Available from:http://github.com/nwfsc-assess/nwfscAgeingError/.

Trejo, T. 2005. Global phylogeography of thresher sharks (Alopias spp.) inferred from mitochondrial DNA control region sequences. MSc. Thesis, California State University Monterey Bay. 80 p.

Urbisci, L. C., S. M. Stohs, and K. R. Piner. In review. From sunrise to sunset in the California drift gillnet fishery: An examination of the effects of time and area closures on the catch and catch rates of pelagic species. Marine Fisheries Review.

Velez-Zuazo, X., J. Alfaro-Shigueto, J. Mangel, R. Papa, and I. Agnarsson. 2015. What barcode sequencing reveals about the shark fishery in Peru. Fisheries Research. 161: 34-41.

## TABLES

Table 1.1. Timeline of major changes in regulations and operations of the USA and Mexico swordfish/shark drift gillnet fisheries (USDGN and MXDGN), USA nearshore set gillnet and small-mesh drift gillnet fishery (USSN), and Mexican pelagic longline fishery (MXLL).

| Year | Regulation or operational change |
| :---: | :---: |
|  | USA swordfish/shark drift gillnet fishery (USDGN) |
| 1977 | Initial development of swordfish/shark drift gillnet fishery in Southern California, initially targeting pelagic sharks. Swordfish landings not authorized. |
| 1980 | Drift gillnet gear restrictions established with minimum mesh size of 8 inches, twine size at \#18, and net length or 6000 feet or less. Nets could be fished only between 2 h before sunset and 2 h after sunrise. Swordfish landings for any given month limited to $25 \%$ of the number of swordfish landed by harpoon fishery for that month. Marlin bycatch limited to $10 \%$ of the number of marlin caught by recreational fishery for any given month. |
| 1982 | Minimum mesh size changed to 14 inches. Limited time-area closure (May 1 through July 31) around Channel Islands and between Channel Islands and mainland (February 1 through April 30). Swordfish ( $25 \%$ of harpoon fishery) and marlin (10\% of recreational fishery) quotas replaced by limits on swordfish landings to no more than the landings of thresher and mako sharks for any permit holder during any given month during May 1 through September 15. |
| 1983 | Initial development of swordfish/shark drift gillnet fishery in Washington and Oregon. Experimental drift gillnet permits issued by Washington and Oregon. |
| 1985 | New time-area closures in California. Drift gillnets were prohibited within 75 nm of the California mainland from 1 June through 14 August, to reduce fishing pressure on thresher sharks; and within 25 nm from 15 December through 31 January to protect gray whales. Equal shark-swordfish landing requirement eliminated. |
| 1986 | California prohibited drift gillnet fishery within 12 nm of the California coast north of Point Arguello and certain areas in the Gulf of the Farallones. First substantial landings of thresher shark in Washington and Oregon ports (~293 mt dressed weight). |
| 1989 | Drift gillnet thresher shark fishery closed in Washington and Oregon. Closure period for 75 nm time-area closure in California (see 1985) changed to May 1 through July 14. |
| 1990 | Mandatory observer program for the USA swordfish/shark drift gillnet fishery began. |
| 1992 | Closure period for 75 nm time-area closure in California (see 1985) changed to May 1 through August 14. |
| 2001 | Additional time-area closures established by the NMFS. The drift gillnet fishery was closed from August 15 through November 15 in an area between Point Conception and $45^{\circ} \mathrm{N}$ to protect leatherback sea turtles. In addition, if an El Nino is occurring, or predicted to occur, the area south of Point Conception will be closed to drift gillnet fishing from August 15 to August 31, and during the entire month of January, to reduce loggerhead sea turtle impacts. |
| 2003 | USA Pacific States Marine Fisheries Commission finalized coastwide thresher shark management plan. Harvest guideline of 340 t established for USA West Coast fisheries. |

Table 1.1. continued.
Year Regulation or operational change
USA nearshore set gillnet and small mesh drift gillnet fisheries
1994 All gillnets and trammel nets prohibited within 3 nm of California mainland and within 1 nm (or waters < 70 fathoms depth) of Channel Islands (California Marine Resources Protection Act, 1990).

Mexico swordfish/shark drift gillnet fishery
198350 nm sportsfishing-only zone along Mexico coast.
1986 Start of fishery.
2010 End of fishery due to Mexico federal regulations.
Mexico pelagic longline fishery

1976 Declaration of Mexico EEZ. All longline permits withdrawn.
1980 Mexico-Japan joint venture longline fishery started.
198350 nm sportsfishing-only zone along Mexican coast.
1990 Mexico-Japan joint venture longline fishery ended.
1997 Mexico DGN vessels begin converting to longline gear.

Table 2.1. Description of fleets and abundance indices in the base case model.

| Fleet ID | Short name | Fleet description |
| :---: | :---: | :---: |
| F1 | USDGN | Fleets with removal |
|  |  | USA swordfish/shark pelagic drift gillnet fishery for seasons 1, 3, and |
|  |  | 4. Removals from USA miscellaneous fisheries for these seasons were included into this fleet. |
| F2 | USDGNs2 | USA swordfish/shark pelagic drift gillnet fishery for season 2. |
|  |  | Removals from USA miscellaneous fisheries for season 2 were included into this fleet. |
| F3 | USSN | USA nearshore set gillnet and small-mesh drift gillnet fishery for all 4 |
|  |  | seasons. |
| F4 | USREC | USA recreational fishery for seasons 1,3 , and 4 . Catch units in number |
| F5 | USRECs2 | USA recreational fishery for season 2. Catch units in number of fish. |
| F6 | MXDGNLL | Mexico swordfish/shark pelagic drift gillnet fishery for seasons 1, 3, and 4. Removals from the Mexico pelagic longline fishery for these seasons were included in this fleet |
| F7 | MXDGNLLs2 | Mexico swordfish/shark pelagic drift gillnet fishery for season 2. |
|  |  | Removals from the Mexico pelagic longline fishery for this season were included in this fleet. |
| F8 | MXART | Mexico coastal artisanal fishery with mixed gillnet and longline gears. <br> Also known as the panga fishery |
|  |  | Abundance indices inputted as surveys |
| S1 | USDGN8284 | Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA |
|  |  | swordfish/shark pelagic drift gillnet fishery during 1982-1984. |
| S2 | USDGN9200 | Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA |
|  |  | swordfish/shark pelagic drift gillnet fishery during 1992-2000. |
| S3 | USDGN0113 | Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA |
|  |  | swordfish/shark pelagic drift gillnet fishery during 2001-2013. |
| S4 | USSN8593 | Standardized annual index of relative abundance of primarily age-0 common thresher sharks based on logbooks from the USA nearshore set gillnet and small-mesh drift gillnet fishery during 1985 - 1993 |
| S5 | USSN9414 | Standardized annual index of relative abundance of primarily age-0 common thresher sharks based on logbooks from the USA nearshore set gillnet and small-mesh drift gillnet fishery during 1994 - 2014. |
| S6 | USJUV0614 | Standardized annual index of relative abundance of juvenile common thresher sharks from a coastal longline survey conducted by the Southwest Fishery Science Center during 2006-2014. |

Table 2.2. Estimated common thresher shark removals by fleet.

| Year | USDGN <br> (t) | USDGNs2 <br> (t) | USSN <br> (t) | $\begin{gathered} \text { USREC } \\ \text { (1000 } \\ \text { fish) } \\ \hline \end{gathered}$ | $\begin{gathered} \hline \text { USRECs2 } \\ \text { (1000 } \\ \text { fish) } \\ \hline \end{gathered}$ | MXDGNLL <br> (t) | MXDGNLLs2 <br> (t) | MXART <br> (t) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1969 | 84.4 | 17.4 | 1.8 | 0.6 | 0.6 | 0.0 | 0.0 | 20.9 |
| 1970 | 87.0 | 32.3 | 2.8 | 0.6 | 0.6 | 0.0 | 0.0 | 20.9 |
| 1971 | 21.4 | 39.8 | 2.4 | 0.6 | 0.6 | 0.0 | 0.0 | 20.9 |
| 1972 | 99.3 | 20.4 | 2.5 | 0.6 | 0.6 | 0.0 | 0.0 | 20.9 |
| 1973 | 42.0 | 70.8 | 1.2 | 0.6 | 0.6 | 0.0 | 0.0 | 20.9 |
| 1974 | 120.9 | 23.4 | 2.5 | 0.6 | 0.6 | 0.0 | 0.0 | 20.9 |
| 1975 | 143.9 | 97.2 | 5.1 | 0.6 | 0.6 | 0.0 | 0.0 | 20.9 |
| 1976 | 263.9 | 133.5 | 7.7 | 0.6 | 0.6 | 0.0 | 0.0 | 29.4 |
| 1977 | 246.1 | 167.0 | 8.9 | 0.6 | 0.6 | 0.0 | 0.0 | 16.8 |
| 1978 | 322.8 | 254.1 | 31.9 | 0.6 | 0.6 | 0.0 | 0.0 | 16.5 |
| 1979 | 745.2 | 380.3 | 55.5 | 0.6 | 0.6 | 0.0 | 0.0 | 21.1 |
| 1980 | 1638.8 | 486.4 | 36.1 | 0.4 | 0.0 | 0.0 | 0.0 | 39.7 |
| 1981 | 842.1 | 747.9 | 74.1 | 0.1 | 0.0 | 0.0 | 0.0 | 54.5 |
| 1982 | 963.0 | 846.7 | 143.4 | 1.9 | 0.2 | 0.0 | 0.0 | 84.7 |
| 1983 | 438.1 | 835.5 | 67.3 | 0.5 | 3.0 | 0.0 | 0.0 | 74.1 |
| 1984 | 447.3 | 754.3 | 102.3 | 0.6 | 0.0 | 0.2 | 0.0 | 47.6 |
| 1985 | 241.8 | 890.7 | 65.9 | 0.2 | 0.2 | 6.6 | 2.7 | 16.6 |
| 1986 | 661.0 | 325.9 | 8.8 | 1.4 | 0.0 | 27.8 | 11.8 | 30.7 |
| 1987 | 303.0 | 285.0 | 15.4 | 0.8 | 4.1 | 88.7 | 40.1 | 38.9 |
| 1988 | 432.6 | 134.5 | 3.7 | 0.0 | 0.9 | 102.5 | 47.0 | 43.6 |
| 1989 | 335.3 | 114.4 | 3.0 | 0.8 | 0.0 | 74.1 | 32.2 | 21.5 |
| 1990 | 337.7 | 104.6 | 3.9 | 0.0 | 0.0 | 174.1 | 79.6 | 32.9 |
| 1991 | 310.0 | 147.7 | 2.8 | 0.0 | 0.0 | 147.5 | 65.4 | 18.9 |
| 1992 | 138.9 | 154.9 | 2.4 | 0.0 | 0.0 | 266.1 | 120.8 | 32.3 |
| 1993 | 237.6 | 38.0 | 3.0 | 1.9 | 0.9 | 280.5 | 127.9 | 20.3 |
| 1994 | 280.5 | 63.5 | 9.3 | 1.9 | 1.7 | 245.9 | 112.8 | 17.7 |
| 1995 | 210.3 | 56.2 | 10.3 | 2.2 | 0.5 | 173.9 | 78.0 | 12.8 |
| 1996 | 278.4 | 84.5 | 10.7 | 0.1 | 0.6 | 248.4 | 112.5 | 18.1 |
| 1997 | 200.8 | 55.0 | 14.8 | 0.3 | 0.1 | 279.3 | 126.1 | 20.6 |
| 1998 | 271.3 | 84.8 | 13.2 | 0.6 | 0.5 | 325.2 | 148.8 | 26.5 |
| 1999 | 194.2 | 110.8 | 19.6 | 0.8 | 0.3 | 185.3 | 81.9 | 18.1 |
| 2000 | 174.6 | 106.1 | 30.7 | 1.5 | 0.8 | 227.8 | 98.9 | 30.9 |
| 2001 | 239.3 | 99.7 | 27.8 | 1.6 | 0.6 | 205.9 | 87.0 | 35.1 |
| 2002 | 266.3 | 88.2 | 22.5 | 0.7 | 1.0 | 197.9 | 83.7 | 33.7 |
| 2003 | 134.9 | 73.0 | 15.8 | 0.5 | 1.7 | 188.8 | 77.9 | 32.6 |
| 2004 | 63.8 | 23.9 | 16.7 | 4.2 | 0.3 | 285.5 | 122.2 | 48.3 |
| 2005 | 155.9 | 29.2 | 9.2 | 0.2 | 0.1 | 181.8 | 76.6 | 31.1 |
| 2006 | 110.0 | 31.4 | 18.4 | 0.2 | 0.8 | 189.2 | 79.5 | 32.4 |
| 2007 | 165.0 | 25.0 | 9.7 | 0.9 | 0.6 | 208.5 | 87.7 | 35.9 |
| 2008 | 117.9 | 19.7 | 12.9 | 0.7 | 0.5 | 208.6 | 87.5 | 42.2 |
| 2009 | 58.4 | 27.9 | 12.8 | 1.5 | 0.4 | 54.4 | 10.1 | 48.5 |
| 2010 | 54.9 | 22.8 | 16.5 | 0.4 | 0.8 | 48.8 | 9.1 | 43.6 |
| 2011 | 82.3 | 4.9 | 9.5 | 1.7 | 0.7 | 41.4 | 7.5 | 36.5 |
| 2012 | 49.0 | 11.2 | 7.4 | 0.3 | 0.1 | 47.3 | 8.6 | 41.9 |
| 2013 | 42.8 | 8.5 | 3.2 | 0.2 | 0.6 | 44.9 | 9.1 | 41.4 |
| 2014 | 12.9 | 19.2 | 5.4 | 0.2 | 0.3 | 44.5 | 8.4 | 39.9 |

Table 2.3. Indices of relative abundance and associated coefficients of variation (CV). Units are number of fish per unit effort.

| Year | $\begin{gathered} \hline \text { USDGN8284 } \\ \text { S1 } \end{gathered}$ |  | USDGN9200S2 |  | $\begin{gathered} \hline \text { USDGN0113 } \\ \text { S3 } \end{gathered}$ |  | $\begin{gathered} \text { USSN8593 } \\ \text { S4 } \end{gathered}$ |  | $\begin{aligned} & \hline \text { USSN9414 } \\ & \text { S5 } \end{aligned}$ |  | $\begin{gathered} \hline \hline \text { USJUV0614 } \\ \text { S6 } \end{gathered}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Index | CV | Index | CV | Index | CV | Index | CV | Index | CV | Index | CV |
| 1981 |  |  |  |  |  |  |  |  |  |  |  |  |
| 1982 | 0.01229 | 0.28035 |  |  |  |  |  |  |  |  |  |  |
| 1983 | 0.00921 | 0.27814 |  |  |  |  |  |  |  |  |  |  |
| 1984 | 0.00763 | 0.27842 |  |  |  |  |  |  |  |  |  |  |
| 1985 |  |  |  |  |  |  | 0.07149 | 0.22246 |  |  |  |  |
| 1986 |  |  |  |  |  |  | 0.05076 | 0.22000 |  |  |  |  |
| 1987 |  |  |  |  |  |  | 0.07998 | 0.23149 |  |  |  |  |
| 1988 |  |  |  |  |  |  | 0.06265 | 0.23024 |  |  |  |  |
| 1989 |  |  |  |  |  |  | 0.04039 | 0.23056 |  |  |  |  |
| 1990 |  |  |  |  |  |  | 0.07087 | 0.23840 |  |  |  |  |
| 1991 |  |  |  |  |  |  | 0.05103 | 0.23477 |  |  |  |  |
| 1992 |  |  | 0.00047 | 0.11681 |  |  | 0.06788 | 0.24198 |  |  |  |  |
| 1993 |  |  | 0.00066 | 0.11289 |  |  | 0.08320 | 0.23061 |  |  |  |  |
| 1994 |  |  | 0.00107 | 0.11289 |  |  |  |  | 0.20827 | 0.25464 |  |  |
| 1995 |  |  | 0.00076 | 0.12739 |  |  |  |  | 0.20266 | 0.23268 |  |  |
| 1996 |  |  | 0.00099 | 0.12568 |  |  |  |  | 0.29486 | 0.21991 |  |  |
| 1997 |  |  | 0.00112 | 0.11994 |  |  |  |  | 0.45911 | 0.19964 |  |  |
| 1998 |  |  | 0.00214 | 0.12047 |  |  |  |  | 0.49911 | 0.20750 |  |  |
| 1999 |  |  | 0.00126 | 0.12996 |  |  |  |  | 0.55780 | 0.19030 |  |  |
| 2000 |  |  | 0.00191 | 0.14880 |  |  |  |  | 0.33207 | 0.20322 |  |  |
| 2001 |  |  |  |  | 0.01269 | 0.19702 |  |  | 0.69024 | 0.21287 |  |  |
| 2002 |  |  |  |  | 0.00631 | 0.20242 |  |  | 0.38927 | 0.22537 |  |  |
| 2003 |  |  |  |  | 0.00575 | 0.21192 |  |  | 0.22220 | 0.20489 |  |  |
| 2004 |  |  |  |  | 0.00518 | 0.21691 |  |  | 0.29735 | 0.20710 |  |  |
| 2005 |  |  |  |  | 0.01830 | 0.20352 |  |  | 0.24872 | 0.22886 |  |  |
| 2006 |  |  |  |  | 0.00687 | 0.19910 |  |  | 1.00752 | 0.19227 | 3.20419 | 0.54869 |
| 2007 |  |  |  |  | 0.02289 | 0.19697 |  |  | 0.69005 | 0.20402 | 1.70947 | 0.51328 |
| 2008 |  |  |  |  | 0.00685 | 0.22096 |  |  | 0.38999 | 0.21220 | 7.64873 | 0.46797 |
| 2009 |  |  |  |  | 0.00391 | 0.22504 |  |  | 0.69659 | 0.19518 | 3.04584 | 0.47143 |
| 2010 |  |  |  |  | 0.01745 | 0.23111 |  |  | 0.76876 | 0.19815 | 5.43268 | 0.43013 |
| 2011 |  |  |  |  | 0.01148 | 0.23021 |  |  | 0.51435 | 0.21067 | 8.82981 | 0.49681 |
| 2012 |  |  |  |  | 0.00711 | 0.22832 |  |  | 0.72856 | 0.19746 | 4.87355 | 0.45691 |
| 2013 |  |  |  |  | 0.01244 | 0.19884 |  |  | 0.21324 | 0.24029 | 5.18471 | 0.45535 |
| 2014 |  |  |  |  |  |  |  |  | 0.81005 | 0.41220 | 1.73476 | 0.52305 |

Table 2.4. Summary of sampling effort used to generate size compositions for the assessment by fleet, length type measured (alternate or fork length), and year. Alternate length samples are shown in italic, while fork length samples are shown in standard type.

| Year | $\begin{aligned} & \hline \hline \text { USDGN } \\ & \text { (F1 \& F2) } \end{aligned}$ |  | $\begin{aligned} & \hline \text { USSN } \\ & \text { (F3) } \end{aligned}$ |  | USJUV0614 <br> (S6) |  | $\begin{aligned} & \text { MXDGN } \\ & \text { (F6 \& F7) } \end{aligned}$ |  | $\begin{aligned} & \text { MXART } \\ & \text { (F8) } \end{aligned}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | N trips | N fish | N trips | N fish | N sets | N fish | N trips | N fish | N trips | N fish |
| 1981 | 64 | 1093 |  |  |  |  |  |  |  |  |
| 1982 | 175 | 1224 |  |  |  |  |  |  |  |  |
| 1983 | 178 | 1528 | 1 | 11 |  |  |  |  |  |  |
| 1984 | 146 | 1292 | 8 | 21 |  |  |  |  |  |  |
| 1985 | 126 | 977 |  |  |  |  |  |  |  |  |
| 1986 | 142 | 802 | 18 | 38 |  |  |  |  |  |  |
| 1987 | 97 | 678 | 14 | 44 |  |  |  |  |  |  |
| 1988 | 168 | 820 | 6 | 34 |  |  |  |  |  |  |
| 1989 | 113 | 1024 | 15 | 98 |  |  |  |  |  |  |
| 1990 | 28 | 221 | 10 | 27 |  |  |  |  |  |  |
| 1991 | 26 | 285 | 30 | 54 |  |  |  |  |  |  |
| 1992 | 28 | 230 | 32 | 87 |  |  |  |  |  |  |
| 1993 | 23 | 286 | 55 | 87 |  |  |  |  |  |  |
| 1994 | 51 | 582 | 8 | 9 |  |  |  |  |  |  |
| 1995 | 23 | 174 |  |  |  |  |  |  |  |  |
| 1996 | 32 | 691 |  |  |  |  |  |  |  |  |
| 1997 | 57 | 516 |  |  |  |  |  |  |  |  |
| 1998 | 51 | 757 |  |  |  |  |  |  |  |  |
| 1999 | 40 | 314 | 11 | 22 |  |  |  |  |  |  |
| 2000 | 42 | 683 | 1 | 1 |  |  |  |  |  |  |
| 2001 | 41 | 611 |  |  |  |  |  |  |  |  |
| 2002 | 33 | 414 |  |  |  |  |  |  |  |  |
| 2003 | 31 | 440 |  |  |  |  |  |  |  |  |
| 2004 | 29 | 162 |  |  |  |  |  |  |  |  |
| 2005 | 37 | 959 |  |  |  |  |  |  |  |  |
| 2006 | 26 | 218 | 2 | 10 | 29 | 236 |  |  |  |  |
| 2007 | 20 | 173 | 3 | 6 | 22 | 129 | 6 | 743 |  |  |
| 2008 | 15 | 165 |  |  | 39 | 280 | 3 | 612 |  |  |
| 2009 | 7 | 50 | 3 | 10 | 32 | 200 |  |  |  |  |
| 2010 | 8 | 1015 | 15 | 32 | 33 | 277 |  |  |  |  |
| 2011 | 17 | 402 | 7 | 15 | 38 | 393 |  |  | NA | 349 |
| 2012 | 6 | 88 | 12 | 51 | 38 | 265 |  |  |  |  |
| 2013 | 20 | 167 | 2 | 3 | 36 | 262 |  |  |  |  |
| 2014 |  |  |  |  | 23 | 138 |  |  |  |  |

Table 3.1. Selectivity patterns used in the base case model. Estimated parameters can be found in Table 5.1.

| Fleet ID | Fleet name | Time periods | Selectivity pattern |
| :---: | :---: | :---: | :---: |
|  | Estimated selectivity |  |  |
| F1 | USDGN | $\begin{aligned} & 1969-1981 \\ & 1982-1984 \\ & 1985-1988 \\ & 1989-1991 \\ & 1992-2000 \\ & 2001-2014 \end{aligned}$ | Double-normal size selectivity |
| F2 | USDGNs2 | $\begin{aligned} & 1969-1981 \\ & 1982-1984 \\ & 1985-1988 \\ & 1989-2014 \end{aligned}$ | 4-knot spline size selectivity |
| F3 | USSN | $\begin{aligned} & 1969-1993 \\ & 1994-2014 \end{aligned}$ | Age selectivity; age- 0 to 2 freely estimated; age- $3+$ at 0 selectivity |
| F8 | MXART | 1969-2014 | Double-normal size selectivity |
| S6 | USJUV0614 | 1969-2014 | Double-normal size selectivity |
| F4 | USREC |  | irrored selectivity Mirrored to F1 |
| F5 | USRECs2 |  | Mirrored to F2 |
| F6 | MXDGNLL |  | Mirrored to F1 |
| F7 | MXDGNLLs2 |  | Mirrored to F2 |
| S1 | USDGN8284 |  | Mirrored to F1 |
| S2 | USDGN9200 |  | Mirrored to F1 |
| S3 | USDGN0113 |  | Mirrored to F1 |
| S4 | USSN8593 |  | Mirrored to F3 |
| S5 | USSN9414 |  | Mirrored to F3 |

Table 4.1. Analytical estimates of catchability, mean input variance, variance adjustment, and model fit (root mean square error, RMSE of expectations to observations) for sub-adult/adult (S1, S2, and S3) and recruitment (S4 and S5) annual abundance indices in the base case model.

| Index | Years | Catchability | Mean <br> input CV | Variance <br> adjustment | Input CV + <br> Var. Adj. | RMSE |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| S1 | $1982-1984$ | $1.27 \mathrm{E}-4$ | 0.279 | 0 | 0.279 | 0.157 |
| S2 | $1992-2000$ | $1.39 \mathrm{E}-5$ | 0.124 | 0.266 | 0.390 | 0.391 |
| S3 | $2001-2013$ | $6.98 \mathrm{E}-5$ | 0.212 | 0.332 | 0.545 | 0.545 |
| S4 | $1985-1993$ | $7.68 \mathrm{E}-4$ | 0.231 | 0 | 0.231 | 0.176 |
| S5 | $1994-2014$ | $5.35 \mathrm{E}-3$ | 0.221 | 0 | 0.221 | 0.178 |

Table 4.2. Mean input variances (input N after variance adjustment) and model estimated mean variance (effN) of the size composition data components of the base case model. Harmonic mean of the eff $N$ and the ratio of the harmonic mean of $e f f N$ to the mean input N are also provided. A higher eff $N$ indicates a better model fit. Number of observations corresponds to the number of quarters in which size composition data were sampled. Number of observations for F8 is not applicable (NA) because a super year was used to aggregate the size compositions for the fleet.

| Fleet | Bin <br> structure | Number of <br> observations | Mean input N <br> after var adj | Mean <br> effN | Harmonic <br> mean effN | Harmonic <br> mean effN/ <br> mean inputN |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| F1 | 2 cm | 43 | 14.9 | 104.2 | 39.0 | 2.6 |
| F1 | 7 cm | 21 | 40.9 | 95.3 | 62.7 | 1.5 |
| F2 | 2 cm | 2 | 7.5 | 107.3 | 96.2 | 12.8 |
| F2 | 7 cm | 9 | 40.3 | 187.3 | 139.2 | 3.5 |
| F3 | Age-0 | 20 | 10.5 | 31.9 | 14.4 | 1.4 |
| F8 | 2 cm | NA | 3.0 | 143.5 | 143.5 | 47.8 |
| S6 | 2 cm | 9 | 32.2 | 284.8 | 256.8 | 8.0 |

Table 4.3. Mean input variances (input N after variance adjustment) and model estimated mean variance (eff $N$ ) of the conditional age-at-length data components of the base case model. Harmonic mean of the eff $N$ and the ratio of the harmonic mean of eff $N$ to the mean input N are also provided. A higher eff $N$ indicates a better model fit. Number of observations corresponds to the number of sharks sampled in a fishery.

| Fleet | Number of <br> observations | Mean input N <br> after var adj | Mean effN | Harmonic <br> mean effN | Harmonic <br> mean effN/ <br> mean inputN |
| :---: | :---: | :---: | :---: | :---: | :---: |
| F1 | 151 | 1.2 | 1.6 | 1.2 | 1.0 |
| F3 | 1 | 1.0 | 9.0 | 9.0 | 9.0 |

Table 5.1. List of parameters used in the base case model. Sex-specific parameters are indicated by having female and male parameters, otherwise parameter values are the same for either gender.

| Parameter | Value | Min | Max | Fixed | Estimation Phase |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Natural Mortality | 0.179 |  |  | X |  |
| Growth |  |  |  |  |  |
| Female L1 | 71.3 | 30 | 100 |  | 5 |
| $L_{\infty}$ | 251.9 | 200 | 300 |  | 5 |
| K | 0.129 | 0 | 0.2 |  | 5 |
| CV1 | 0.08 |  |  | X |  |
| CV2 | 0.05 |  |  | x |  |
| Male Offset from female L1 | $4.43 \mathrm{E}-3$ | -2 | 2 |  | 5 |
| Offset from female $L_{\infty}$ | -0.0118 | -2 | 2 |  | 5 |
| Offset from female K | -0.0233 | -2 | 2 |  | 5 |
| Offset from female CV1 | 0 |  |  | X |  |
| Offset from female CV2 | 0 |  |  | X |  |
| Weight-at-length |  |  |  |  |  |
| Coefficient | $1.88 \mathrm{E}-4$ |  |  | X |  |
| Exponent | 2.519 |  |  | x |  |
| Reproduction |  |  |  |  |  |
| Last age at 0\% maturity | 4 |  |  | x |  |
| Age at 50\% maturity | 5 |  |  | x |  |
| First age at 100\% maturity | 6 |  |  | x |  |
| Fecundity at length intercept | 4 |  |  | X |  |
| Fecundity at length slope | 0 |  |  | x |  |
| Stock-recruitment |  |  |  |  |  |
| $\log \left(\mathrm{R}_{0}\right)$ | 4.345 | 1 | 15 |  | 1 |
| Zfrac | 0.6 |  |  | x |  |
| Beta | 3.059 | 0.4 | 7 |  | 1 |
| Initial fishing mortality |  |  |  |  |  |
| F1 | 0.0238 | 0 | 3 |  | 1 |
| F2 | 0 |  |  | x |  |
| F3 | 0 |  |  | x |  |
| F4 | 0.0222 | 0 | 3 |  | 1 |
| F5 | 0 |  |  | x |  |
| F6 | 0 |  |  | X |  |
| F7 | 0 |  |  | x |  |
| F8 | 0.0445 | 0 | 3 |  | 1 |
| Size selectivity (F1: 1969 - 1981) |  |  |  |  |  |
| Peak | 156.9 | 45 | 250 |  | 2 |
| Top | -4 |  |  | x |  |
| Ascending width | 6.494 | -4 | 12 |  | 3 |
| Descending width | 8.070 | -4 | 12 |  | 3 |
| Selectivity at first bin | -2.248 | -9 | 9 |  | 4 |
| Selectivity at last bin | -1000 |  |  | x |  |

Table 5.1 (continued). List of parameters used in the base case model

| Parameter | Value | Min | Max | Fixed | Estimation Phase |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Size selectivity (F1: 1982-1984) |  |  |  |  |  |
| Peak | 154.3 | 45 | 250 |  | 5 |
| Top | -4 |  |  | x |  |
| Ascending width | 6.369 | -4 | 12 |  | 5 |
| Descending width | 7.438 | -4 | 12 |  | 6 |
| Selectivity at first bin | -2.424 | -9 | 9 |  | 6 |
| Selectivity at last bin | -1000 |  |  | x |  |
| Size selectivity (F1: 1985-1988) |  |  |  |  |  |
| Peak | 137.9 | 45 | 250 |  | 5 |
| Top | -4 |  |  | x |  |
| Ascending width | 6.611 | -4 | 12 |  | 5 |
| Descending width | 7.997 | -4 | 12 |  | 6 |
| Selectivity at first bin | -1.474 | -9 | 9 |  | 6 |
| Selectivity at last bin | -1000 |  |  | x |  |
| Size selectivity (F1: 1989-1991) |  |  |  |  |  |
| Peak | 130.3 | 45 | 250 |  | 5 |
| Top | -4 |  |  | X |  |
| Ascending width | 6.575 | -4 | 12 |  | 5 |
| Descending width | 7.883 | -4 | 12 |  | 6 |
| Selectivity at first bin | 0.236 | -9 | 9 |  | 6 |
| Selectivity at last bin | -1000 |  |  | x |  |
| Size selectivity (F1: 1992 - 2000) |  |  |  |  |  |
| Peak | 160.8 | 45 | 250 |  | 5 |
| Top | -4 |  |  | x |  |
| Ascending width | 6.585 | -4 | 12 |  | 5 |
| Descending width | 7.524 | -4 | 12 |  | 6 |
| Selectivity at first bin | -4.053 | -9 | 9 |  | 6 |
| Selectivity at last bin | -1000 |  |  | x |  |
| Size selectivity (F1: 2001 - 2014) |  |  |  |  |  |
| Peak | 163.6 | 45 | 250 |  | 5 |
| Top | -4 |  |  | x |  |
| Ascending width | 6.756 | -4 | 12 |  | 5 |
| Descending width | 7.279 | -4 | 12 |  | 6 |
| Selectivity at first bin | -3.865 | -9 | 9 |  | 6 |
| Selectivity at last bin | -1000 |  |  | x |  |
| Size selectivity (F2: 1969-1981) |  |  |  |  |  |
| Spline gradient low: all periods | 0.067 | -1 | 1 |  | 3 |
| Spline gradient high: all periods | -0.066 | -1 | 1 |  | 3 |
| Spline knot 1: all periods | 75 |  |  | x |  |
| Spline knot 2: all periods | 125 |  |  | x |  |
| Spline knot 3: all periods | 175 |  |  | X |  |
| Spline knot 4: all periods | 225 |  |  | X |  |

Table 5.1 (continued). List of parameters used in the base case model

| Parameter | Value | Min | Max | Fixed | Estimation Phase |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Size selectivity (F2: 1969 - 1981) continued |  |  |  |  |  |
| Spline value at knot 1 | -3.134 | -9 | 9 |  | 3 |
| Spline value at knot 2 | -0.579 | -9 | 9 |  | 3 |
| Spline value at knot 3: all periods | 0 |  |  | x |  |
| Spline value at knot 4 | -3.100 | -9 | 9 |  | 3 |
| Size selectivity (F2: 1982-1984) |  |  |  |  |  |
| Spline value at knot 1 | -3.260 | -9 | 9 |  | 6 |
| Spline value at knot 2 | -0.739 | -9 | 9 |  | 6 |
| Spline value at knot 4 | -1.934 | -9 | 9 |  | 6 |
| Size selectivity (F2: 1985-1988) |  |  |  |  |  |
| Spline value at knot 1 | -1.091 | -9 | 9 |  | 6 |
| Spline value at knot 2 | -0.101 | -9 | 9 |  | 6 |
| Spline value at knot 4 | 0.078 | -9 | 9 |  | 6 |
| Size selectivity (F2: 1989-2014) |  |  |  |  |  |
| Spline value at knot 1 | -1.720 | -9 | 9 |  | 6 |
| Spline value at knot 2 | 0.980 | -9 | 9 |  | 6 |
| Spline value at knot 4 | -1.285 | -9 | 9 |  | 6 |
| Age selectivity (F3: 1969 - 1993) |  |  |  |  |  |
| Age-0 | 5.825 | -9 | 9 |  | 2 |
| Age-1 | -3.627 | -9 | 9 |  | 2 |
| Age-2 | -4.357 | -9 | 9 |  | 2 |
| Age-3 to age-25: all periods | -99 |  |  | x |  |
| Age selectivity (F3: 1993 - 2014) |  |  |  |  |  |
| Age-0 | 6.981 | -9 | 9 |  | 2 |
| Age-1 | -5.697 | -9 | 9 |  | 2 |
| Age-2 | -5.270 | -9 | 9 |  | 2 |
| Size selectivity (F8) |  |  |  |  |  |
| Peak | 79.6 | 45 | 250 |  | 2 |
| Top | -4 |  |  | x |  |
| Ascending width | 4.135 | -4 | 9 |  | 3 |
| Descending width | 6.733 | -4 | 9 |  | 3 |
| Selectivity at first bin | -1000 |  |  | x |  |
| Selectivity at last bin | -1000 |  |  | x |  |
| Size selectivity (S6) |  |  |  |  |  |
| Peak | 84.7 | 45 | 250 |  | 2 |
| Top | -4 |  |  | x |  |
| Ascending width | 4.135 | -4 | 9 |  | 3 |
| Descending width | 6.733 | -4 | 9 |  | 3 |
| Selectivity at first bin | -1000 |  |  | x |  |
| Selectivity at last bin | -1000 |  |  | x |  |

Table 5.2. Total biomass (Q1, age-1+), biomass and number of mature female sharks (Q2), depletion $\left(\mathrm{S} / \mathrm{S}_{0}\right)$, recruitment, and fishing intensity (1-SPR) estimated in the base case model. Estimated virgin number of mature female sharks ( $\mathrm{S}_{0}$ ) and recruitment were 88,200 and 77,100 fish respectively. Reproductive output in number of pups was 4 * number of mature females.

| Year | Total biomass age-1+ (mt) | Biomass of mature female sharks (mt) | Number of mature female sharks (1000s) | Depletion (S/S ${ }_{0}$ ) | Number of recruits (1000s) | Fishing intensity (1-SPR) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1969 | 29846.6 | 10843.2 | 92.9 | 1.053 | 87.13 | 0.079 |
| 1970 | 29837.1 | 10848.4 | 93.0 | 1.054 | 91.06 | 0.086 |
| 1971 | 29857.8 | 10848.0 | 92.9 | 1.053 | 88.84 | 0.067 |
| 1972 | 29920.9 | 10855.6 | 93.0 | 1.054 | 78.41 | 0.086 |
| 1973 | 29777.9 | 10857.0 | 93.0 | 1.054 | 67.99 | 0.086 |
| 1974 | 29444.4 | 10834.3 | 92.7 | 1.050 | 63.45 | 0.098 |
| 1975 | 28921.9 | 10825.5 | 92.7 | 1.050 | 61.04 | 0.137 |
| 1976 | 28179.3 | 10779.5 | 92.3 | 1.046 | 55.22 | 0.203 |
| 1977 | 27121.6 | 10583.0 | 89.9 | 1.019 | 47.43 | 0.211 |
| 1978 | 25904.8 | 10265.7 | 86.1 | 0.976 | 46.58 | 0.307 |
| 1979 | 24436.7 | 9755.3 | 80.5 | 0.912 | 66.98 | 0.493 |
| 1980 | 22663.1 | 8947.3 | 72.4 | 0.821 | 67.48 | 0.698 |
| 1981 | 20112.0 | 7772.6 | 61.2 | 0.694 | 62.48 | 0.698 |
| 1982 | 18219.0 | 6777.2 | 51.8 | 0.588 | 58.21 | 0.831 |
| 1983 | 15948.4 | 5861.9 | 43.8 | 0.496 | 81.50 | 0.756 |
| 1984 | 14676.3 | 5128.9 | 38.3 | 0.434 | 58.34 | 0.732 |
| 1985 | 13582.5 | 4641.3 | 35.2 | 0.399 | 64.57 | 0.614 |
| 1986 | 12834.1 | 4198.3 | 33.0 | 0.374 | 62.38 | 0.638 |
| 1987 | 12295.8 | 3912.4 | 31.3 | 0.355 | 62.67 | 0.595 |
| 1988 | 11926.5 | 3734.7 | 31.2 | 0.354 | 50.70 | 0.527 |
| 1989 | 11707.5 | 3690.1 | 31.6 | 0.358 | 40.70 | 0.455 |
| 1990 | 11536.8 | 3697.2 | 32.1 | 0.364 | 50.34 | 0.530 |
| 1991 | 11297.1 | 3737.8 | 32.9 | 0.373 | 56.07 | 0.518 |
| 1992 | 11171.6 | 3736.3 | 33.1 | 0.375 | 78.00 | 0.498 |
| 1993 | 11387.4 | 3630.6 | 31.9 | 0.362 | 67.68 | 0.565 |
| 1994 | 11474.0 | 3370.3 | 29.0 | 0.328 | 44.53 | 0.589 |
| 1995 | 11273.8 | 3137.8 | 26.8 | 0.304 | 45.62 | 0.492 |
| 1996 | 11262.7 | 3129.5 | 27.3 | 0.310 | 66.30 | 0.499 |
| 1997 | 11411.5 | 3266.8 | 29.9 | 0.339 | 78.06 | 0.465 |
| 1998 | 11841.7 | 3480.3 | 32.8 | 0.371 | 79.62 | 0.543 |
| 1999 | 12184.8 | 3473.3 | 32.3 | 0.366 | 96.84 | 0.425 |
| 2000 | 13110.6 | 3420.0 | 31.2 | 0.354 | 65.30 | 0.471 |
| 2001 | 13584.6 | 3502.3 | 32.3 | 0.367 | 126.88 | 0.438 |
| 2002 | 14817.7 | 3728.4 | 35.3 | 0.400 | 74.20 | 0.402 |
| 2003 | 15573.7 | 4034.2 | 38.9 | 0.441 | 42.81 | 0.326 |
| 2004 | 15928.4 | 4475.0 | 44.0 | 0.498 | 61.78 | 0.405 |

Table 5.2 (continued). Total biomass (Q1, age-1+), biomass and number of mature female sharks (Q2), depletion ( $\mathrm{S} / \mathrm{S}_{0}$ ), recruitment, and fishing intensity (1-SPR) estimated in the base case model.

| Year | Total biomass age-1+ (mt) | Biomass of mature female sharks (mt) | Number of mature female sharks (1000s) | Depletion ( $\mathrm{S} / \mathrm{S}_{0}$ ) | Number of recruits (1000s) | Fishing intensity (1-SPR) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2005 | 16041.0 | 4753.2 | 46.1 | 0.523 | 49.50 | 0.262 |
| 2006 | 16216.0 | 5274.6 | 52.1 | 0.591 | 150.51 | 0.256 |
| 2007 | 17630.4 | 5808.1 | 57.0 | 0.646 | 125.69 | 0.291 |
| 2008 | 18960.3 | 5788.9 | 54.4 | 0.616 | 87.62 | 0.264 |
| 2009 | 19996.8 | 5750.0 | 52.5 | 0.595 | 113.05 | 0.161 |
| 2010 | 21518.0 | 5794.9 | 51.9 | 0.588 | 119.32 | 0.120 |
| 2011 | 23198.6 | 6402.2 | 60.3 | 0.683 | 86.68 | 0.138 |
| 2012 | 24346.1 | 7481.2 | 73.2 | 0.830 | 126.48 | 0.080 |
| 2013 | 25985.6 | 8158.4 | 78.9 | 0.894 | 46.49 | 0.084 |
| 2014 | 26499.2 | 8707.9 | 83.3 | 0.944 | 88.47 | 0.076 |

Table 6.1. Estimated number of mature females under virgin conditions ( $\mathrm{S}_{0}$ ), and in 2014 ( $\mathrm{S}_{2014}$ ), average fishing intensity (1-SPR) in 2012 - 2014, maximum sustainable yield (MSY), and total negative log-likelihood for sensitivity runs conducted. Note that likelihoods may not be comparable between models.

| Sensitivity run description | $\begin{gathered} \hline S_{0} \\ (\mathbf{1 0 0 0 s} \text { of } \\ \text { fish) } \end{gathered}$ | $\mathrm{S}_{2014}$ (1000s of fish $)$ | $\begin{gathered} \hline \text { 1-SPR } \\ 2012 \text { - } \\ 2014 \\ \hline \end{gathered}$ | $\begin{gathered} \hline \text { MSY } \\ \text { (mt) } \end{gathered}$ | Total likelihood |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Base case | 88.2 | 83.3 | 0.08 | 806.5 | 654.47 |
| Alternative removal scenarios (Section 6.1.1) |  |  |  |  |  |
| High catch | 99.9 | 94.9 | 0.08 | 907.3 | 654.73 |
| Low catch | 75.9 | 71.7 | 0.08 | 712.0 | 653.80 |
| Unfished initial conditions | 76.2 | 77.2 | 0.09 | 784.5 | 654.41 |

Alternative stock-recruitment
(Section 6.1.2)

| $\mathrm{Z}_{\text {frac }}$ |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $Z_{\text {frac }}$ at 0.3 | 203.4 | 202.1 | 0.04 | 1185.3 | 659.12 |
| $Z_{\text {frac }}$ at 0.4 | 134.3 | 129.8 | 0.05 | 911.1 | 657.54 |
| $Z_{\text {frac }}$ at 0.5 | 104.7 | 99.7 | 0.07 | 826.6 | 655.95 |
| $Z_{\text {frac }}$ at 0.7 | 77.8 | 74.2 | 0.09 | 813.7 | 653.19 |
| $Z_{\text {frac }}$ at 0.8 | 70.6 | 68.2 | 0.10 | 833.7 | 652.44 |
| $Z_{\text {frac }}$ at 0.9 | 65.7 | 64.1 | 0.10 | 863.8 | 652.06 |
| Beverton-Holt |  |  |  |  |  |
| $h$ at 0.495 (equivalent to base case) | 110.2 | 62.7 | 0.10 | 763.7 | 655.90 |
| $h$ at 0.4 | 147.8 | 90.5 | 0.07 | 745.3 | 658.85 |
| $h$ at 0.6 | 90.3 | 50.7 | 0.12 | 796.6 | 652.88 |
| $h$ estimated (0.890) | 63.3 | 43.8 | 0.14 | 843.5 | 648.87 |
| Sigma-R |  |  |  |  |  |
| Sigma-R at 0.3 | 74.1 | 68.6 | 0.09 | 668.2 | 655.93 |

Alternative life history
(Section 6.1.3)
Natural mortality
0.50 M

| 95.9 | 80.6 | 0.13 | 727.9 | 651.28 |
| ---: | ---: | ---: | ---: | ---: |
| 87.5 | 79.0 | 0.11 | 759.9 | 652.80 |
| 104.3 | 104.9 | 0.05 | 985.0 | 656.04 |
|  |  |  |  |  |
| 78.8 | 77.8 | 0.08 | 797.4 | 667.20 |
|  |  |  |  |  |
| 93.1 | 59.2 | 0.10 | 758.8 | 655.29 |
|  |  |  |  |  |
| 199.8 | 202.7 | 0.04 | 1206.7 | 659.28 |
| 134.8 | 97.7 | 0.08 | 773.8 | 657.83 | and biennial reproductive cycle ( $\mathrm{M}=0.0757$ )


| Sensitivity run description | $\begin{gathered} \mathrm{S}_{0} \\ (1000 \mathrm{~s} \text { of } \\ \text { fish) } \\ \hline \end{gathered}$ | $\begin{gathered} S_{2014} \\ (1000 \mathrm{~s} \text { of } \\ \text { fish) } \end{gathered}$ | $\begin{gathered} \hline \hline \text { 1-SPR } \\ 2012- \\ 2014 \end{gathered}$ | $\begin{gathered} \text { MSY } \\ \text { (mt) } \end{gathered}$ | Total likelihood |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Alternative data sources and weightings (Section 6.1.4) |  |  |  |  |  |
| Include S6 as juvenile index | 88.3 | 84.1 | 0.08 | 809.2 | 652.78 |
| Max weighting factors |  |  |  |  |  |
| Max weighting factor $>1$ | 88.2 | 90.3 | 0.08 | 791.8 | 1954.92 |
| Max weighting factor $>1$ except S6 and F3 | 89.6 | 82.6 | 0.08 | 802.2 | 1467.91 |
| Downweighting size composition data |  |  |  |  |  |
| Downweight F1 | 75.4 | 73.5 | 0.09 | 708.0 | 248.29 |
| Downweight F2 | 91.4 | 85.2 | 0.08 | 836.6 | 626.60 |
| Downweight F3 | 88.2 | 82.1 | 0.08 | NA | 597.10 |
| Downweight F8 | 88.1 | 83.2 | 0.08 | 812.3 | 654.16 |
| Downweight S6 | 88.5 | 82.0 | 0.08 | 803.9 | 606.14 |
| Upweight CAAL data |  |  |  |  |  |
| Upweight CAAL data | 87.9 | 82.5 | 0.08 | 797.9 | 851.46 |
| Alternative selectivity assumptions (Section 6.1.5) |  |  |  |  |  |
| Alternative time blocks | 85.8 | 78.1 | 0.09 | 815.4 | 705.98 |
| F3 size selectivity | 88.1 | 83.1 | 0.08 | 797.0 | 777.70 |
| F6 estimate selectivity | 88.1 | 83.9 | 0.08 | 803.0 | 656.47 |
| Alternative spline parametrization |  |  |  |  |  |
| Last knot at 215 cm | 87.7 | 82.7 | 0.08 | 801.5 | 654.55 |
| Last knot at 235 cm | 88.5 | 83.6 | 0.08 | 806.3 | 654.22 |

Table 7.1. Estimated reference points for the base case model.

|  | Estimate (95\% CI) | Units |
| :---: | :---: | :---: |
| Virgin Conditions |  |  |
| Number of mature female sharks (spawning abundance) ( $\mathrm{S}_{0}$ ) | 88.2 (69.5-107.0) | 1000s of sharks |
| Reproductive output | 352.9 (278.0-427.8) | 1000s of pups |
| Summary biomass at age-1+ ( $\mathrm{B}_{0}$ ) | 28,096 (21,768-34,424) | Metric tons |
| Recruitment at age-0 ( $\mathrm{R}_{0}$ ) MSY-based reference points | 77.1 (60.7-93.5) | 1000s of sharks |
| MSY | 806.5 (614.7-998.3) | Metric tons |
| Number of mature female sharks at MSY (spawning abundance) ( $\mathrm{S}_{\mathrm{MSY}}$ ) | 43.5 (34.6-52.4) | 1000s of sharks |
| Minimum stock size threshold (MSST) (1-M)* ${ }^{\text {MSY }}$ | 35.7 (28.4-43.0) | 1000s of sharks |
| Reproductive output at MSY | 174.0 (138.3-209.7) | 1000s of pups |
| Fishing intensity at MSY (1-SPR ${ }_{\text {MSY }}$ ) | 0.39 (0.37-0.40) | NA |

Table 8.1. Summary of reference points and management quantities for the base case and three alternative states of nature. $\mathrm{C}_{2014}$ is the estimated fishery removals in metric tons in 2014. 1$\mathrm{SPR}_{1214}$ is the average of the estimated fishing intensity (1-SPR) from 2012 through 2014. Key management quantities for the USA fishery management plan are in bold. Under the current USA fishery management plan, this stock is declared to be in an overfished state if $\mathrm{S}_{2014} / \mathrm{MSST}$ is $<1$. Overfishing is considered to be occurring if ( $1-\mathrm{SPR}_{1214)} /\left(1-\mathrm{SPR}_{\mathrm{MSY}}\right)$ is $>1$.

|  | Base case | Alternative reproductive biology (12years median age-of maturity; biennial; $\mathbf{M}=0.0757$ ) | Alternative stockrecruitment $\left(Z_{\text {frac }}=0.4\right)$ | Alternative stockrecruitment $\left(Z_{\text {frac }}=0.8\right)$ |
| :---: | :---: | :---: | :---: | :---: |
| MSY (t) | 806.5 | 773.8 | 911.1 | 833.7 |
| Number of mature female sharks at MSY (SMSY) (1000s of sharks) | 43.5 | 33.9 | 71.6 | 32.0 |
| Number of mature female sharks under virgin conditions ( $\mathrm{S}_{0}$ ) (1000s of sharks) | 88.2 | 67.4 | 134.3 | 70.6 |
| Minimum stock size threshold (MSST) | 35.7 | 27.9 | 58.8 | 26.3 |
| (1-M)* $\mathrm{S}_{\text {MSY }}$ |  |  |  |  |
| Fishing intensity at MSY (1SPR $_{\text {MSY }}$ ) | 0.39 | 0.39 | 0.34 | 0.45 |
| $\mathrm{C}_{2014} / \mathrm{MSY}$ | 0.20 | 0.21 | 0.17 | 0.19 |
| $\mathrm{S}_{2014} / \mathrm{S}_{\text {MSY }}$ | 1.91 | 1.44 | 1.81 | 2.13 |
| $\mathrm{S}_{2014} / \mathrm{S}_{0}$ | 0.94 | 0.72 | 0.97 | 0.97 |
| S $2014 / \mathrm{MSST}$ | 2.33 | 1.75 | 2.21 | 2.59 |
| (1-SPR1214)/(1-SPRmsy) | 0.21 | 0.20 | 0.16 | 0.21 |

Table 9.1. Decision table of 10 year projections for three alternative states of nature based on two major axes of uncertainty: 1) reproductive biology and 2) stock-recruitment relationship; and three future catch scenarios: 1) average catch for 2012 - 2014; 2) 2 * average catch for 2012 2014; and 3) total annual catch of USA swordfish/shark drift gillnet and recreational fishery (i.e., F1, F2, F4, and F5) at the 340 t PFMC harvest guideline and rest of fisheries at average catch of 2012 - 2014. Note that the total removals shown for scenario 1 and 2 are approximate ( $\pm 4 \mathrm{t}$ ) because catches by USA recreational fishery (F4 and F5) are in numbers of fish and conversion to catch in weight depends on the estimated growth for each model.

| Forecast <br> catch <br> scenario <br> (see <br> legend) | Year | Total removals <br> (t) | Base model |  | Alternative reproductive biology (12-years median age-of maturity; biennial; $\mathrm{M}=0.0757$ ) |  | Alternative stockrecruitment$\left(z_{\text {frac }}=0.4\right)$ |  | Alternative stockrecruitment$\left(\mathrm{z}_{\text {frac }}=0.8\right)$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Number of mature females (1000s of fish) | Depletion | Number of mature females (1000s of fish) | Depletion | Number of mature females (1000s of fish) | Depletion | Number of mature females (1000s of fish) | Depletion |
| Average | 2015 | 182.5 | 89.8 | 1.02 | 98.0 | 0.73 | 138.4 | 1.03 | 74.2 | 1.05 |
| catch | 2016 | 183.2 | 92.7 | 1.05 | 97.7 | 0.72 | 141.7 | 1.06 | 76.9 | 1.09 |
| 2012-14 | 2017 | 183.7 | 96.2 | 1.09 | 97.9 | 0.73 | 146.2 | 1.09 | 80.1 | 1.13 |
|  | 2018 | 184.1 | 94.6 | 1.07 | 105.1 | 0.78 | 143.4 | 1.07 | 78.9 | 1.12 |
|  | 2019 | 184.3 | 90.9 | 1.03 | 117.1 | 0.87 | 137.5 | 1.02 | 75.6 | 1.07 |
|  | 2020 | 184.2 | 89.3 | 1.01 | 124.0 | 0.92 | 135.1 | 1.01 | 73.6 | 1.04 |
|  | 2021 | 183.7 | 86.2 | 0.98 | 129.8 | 0.96 | 130.8 | 0.97 | 69.9 | 0.99 |
|  | 2022 | 183.2 | 82.9 | 0.94 | 137.7 | 1.02 | 126.1 | 0.94 | 66.2 | 0.94 |
|  | 2023 | 182.6 | 80.1 | 0.91 | 142.9 | 1.06 | 122.4 | 0.91 | 63.0 | 0.89 |
|  | 2024 | 182.0 | 78.7 | 0.89 | 148.5 | 1.10 | 120.9 | 0.90 | 61.0 | 0.86 |
| 2X | 2015 | 365.5 | 89.7 | 1.02 | 98.0 | 0.73 | 138.3 | 1.03 | 74.1 | 1.05 |
| average | 2016 | 367.1 | 92.0 | 1.04 | 97.6 | 0.72 | 141.0 | 1.05 | 76.2 | 1.08 |
| catch | 2017 | 368.1 | 94.9 | 1.08 | 97.8 | 0.73 | 145.0 | 1.08 | 78.8 | 1.12 |
| 2012-14 | 2018 | 368.9 | 92.7 | 1.05 | 104.9 | 0.78 | 141.5 | 1.05 | 76.9 | 1.09 |
|  | 2019 | 369.0 | 88.3 | 1.00 | 116.9 | 0.87 | 134.9 | 1.00 | 73.0 | 1.03 |
|  | 2020 | 368.4 | 85.9 | 0.97 | 123.5 | 0.92 | 131.7 | 0.98 | 70.1 | 0.99 |
|  | 2021 | 367.2 | 82.2 | 0.93 | 129.2 | 0.96 | 126.7 | 0.94 | 65.8 | 0.93 |
|  | 2022 | 365.8 | 78.5 | 0.89 | 136.7 | 1.01 | 121.8 | 0.91 | 61.7 | 0.87 |
|  | 2023 | 364.5 | 75.6 | 0.86 | 141.5 | 1.05 | 118.0 | 0.88 | 58.4 | 0.83 |
|  | 2024 | 363.4 | 74.3 | 0.84 | 146.7 | 1.09 | 116.6 | 0.87 | 56.6 | 0.80 |
| Harvest | 2015 | 440.7 | 89.8 | 1.02 | 98.0 | 0.73 | 138.4 | 1.03 | 74.1 | 1.05 |
| guideline | 2016 | 440.7 | 91.6 | 1.04 | 97.6 | 0.72 | 140.6 | 1.05 | 75.8 | 1.07 |
| 340 t | 2017 | 440.7 | 94.0 | 1.07 | 97.8 | 0.73 | 144.0 | 1.07 | 77.9 | 1.10 |
| for | 2018 | 440.7 | 91.3 | 1.04 | 104.8 | 0.78 | 140.1 | 1.04 | 75.6 | 1.07 |
| F1, F2, | 2019 | 440.7 | 86.8 | 0.98 | 116.6 | 0.87 | 133.3 | 0.99 | 71.5 | 1.01 |
| F4 \& F5 | 2020 | 440.7 | 84.5 | 0.96 | 123.2 | 0.91 | 130.2 | 0.97 | 68.8 | 0.97 |
|  | 2021 | 440.7 | 80.9 | 0.92 | 128.6 | 0.95 | 125.4 | 0.93 | 64.7 | 0.92 |
|  | 2022 | 440.7 | 77.6 | 0.88 | 135.9 | 1.01 | 120.8 | 0.90 | 60.9 | 0.86 |
|  | 2023 | 440.7 | 75.1 | 0.85 | 140.4 | 1.04 | 117.5 | 0.87 | 58.0 | 0.82 |
|  | 2024 | 440.7 | 74.2 | 0.84 | 145.2 | 1.08 | 116.6 | 0.87 | 56.6 | 0.80 |

## FIGURES

Data by type and year


Figure 2.1. Summary of data used in the assessment. Description of fleets (F1 - F8) and abundance indices (S1 - S6) are found in Table 2.1.


Figure 2.2. Estimated annual (upper) and seasonal (lower) common thresher shark removals by fleet. Description of fleets (F1 - F8) are found in Table 2.1. Note that removals in upper panel are stacked but not in lower panel.


Figure 2.3. Estimated relationship between alternate and fork length for common thresher sharks along the USA West Coast. Fork length $(\mathrm{cm})=2.3627 \times$ Alternate length $(\mathrm{cm})+16.82(\mathrm{~N}=$ 3043 fish; adj. $\mathrm{R}^{2}=0.9165$ ).


Figure 3.1. Fixed weight-at-length (upper), maturity-at-age (middle), and annual fecundity-atlength (lower) relationships used in the base case model. See Section 2.3 and 3.4.1.


Figure 4.1. Convergence analysis of the base case model. Total negative log-likelihood of the base case model (Model 1) and 50 models using different phasing and initial parameters (upper); and estimated log virgin recruitment $[\mathrm{LN}(\mathrm{R} 0)]$, with the base case model in red (lower).


Figure 4.2. Observed (open circles) and expected (blue line) relative abundance of common thresher sharks from sub-adult/adult (S1, S2, and S3) and recruitment (S4 and S5) abundance indices in the base case model. Error bars indicate 95\% confidence intervals.


Figure 4.3. Observed (grey) and model predicted (red: female; blue: male; green: sex-combined) overall size compositions in 2 cm bins for the base case model. Size compositions for the MXART (F8) fleet were aggregated into a single year and input as a super year.


Figure 4.4. Observed (grey) and model predicted (green: sex-combined) overall size
compositions in 7 cm bins for the base case model. Size compositions for the MXDGNLL (F6) fleet were not fit in the base case model but selectivity for F6 was assumed to be the same as the USDGN (F1) fleet.


Figure 4.5. Observed (grey) and model predicted (red: female; blue: male; green: sex-combined) overall size compositions in 2 (upper) and 7 (lower) cm bins for the base case model. Size bins that approximated age-0 sized fish were aggregated into a single bin for the USSN (F3) fleet.


Figure 4.6. Pearson residuals of model fit to size composition data in 2 cm bins for the base case model. Filled and open circles represent observations (i.e., proportions at size) that are larger and smaller than model predictions, respectively. Blue and red circles represent male and female samples respectively. Area of circles are proportional to absolute values of residuals. Residuals of F8 are not shown here because its size composition data were input as a super year (i.e., a single year of observation) and residuals are better seen in Fig. 4.3.


Figure 4.7. Pearson residuals of model fit to size composition data in 7 cm bins (left panels) and age-0 aggregated 2 cm (upper right; blue: male; red: female) and 7 cm bins (middle right) for the base case model. Filled and open circles represent observations that are larger and smaller than model predictions, respectively. Area of circles are proportional to absolute values of residuals.


Figure 4.8. Base case model fit to conditional-age-at-length data from the USDGN (F1) fleet.


Figure 4.9. Retrospective analysis of base case model. Estimated spawning abundance (1000s of mature female sharks) (upper) and fishing intensity (1-SPR) (lower) with successive elimination of $1-5$ years of terminal year data.


Figure 4.10. Likelihood profiles with respect to virgin recruitment $\left[\log \left(R_{0}\right)\right]$ of the main data components (upper left), abundance indices (lower left), main sex-specific size compositions using 2 cm bins (upper right), and size compositions using alternative binning structures (Section 2.1.4), of the base case model.


Figure 4.11. Model fits to sub-adult/adult abundance indices (S1: upper left; S2: middle left; S3: lower left), estimated female spawning abundance (upper right) (1000s of mature female sharks), and fishing intensity (middle right) ( $1-\mathrm{SPR}$ ) of the base case model (blue) and an age-structured production model (red) with similar model specifications to the base case model but fitting only to the catch and sub-adult/adult abundance indices.


Figure 5.1. Estimated growth curve of female (solid red line) and male (dashed blue line) common thresher sharks. Shaded areas represent the $95 \%$ confidence intervals. The coefficient of variation of length at age were fixed at birth (0.08) and Linf (0.05), and linearly interpolated between those two points.


Figure 5.2. Estimated length selectivities of USDGN (F1) and USDGNs2 (F2) fleets by time period (left panels) and time-varying contour plots (right panels) in the base case model. Male selectivity was assumed to be the same as female selectivity for all fleets. Selectivities of F4, F6, S1, S2, and S3 were mirrored to F1, while F5 and F7 were mirrored to F2.


Figure 5.3. Estimated length selectivities of the MXART (F8) fleet and USJUV0614 (S6) survey in the base case model. Male selectivity was assumed to be the same as female selectivity for all fleets.


Figure 5.4. Estimated age selectivities of the USSN (F3) fleet by time period (left panels) and time-varying contour plots (right panels) in the base case model. Male selectivity was assumed to be the same as female selectivity for all fleets. Selectivities of S4 and S5 were mirrored to F3.


Figure 5.5. Size composition data of the USDGNs2 (F2) fleet during 1981 - 1989. Note the large number of large fish >200 cm between 1985 and 1988.


Figure 5.6. Historical catch-at-age (1000s of fish) estimated by the base case model. The base case model was parameterized with 26 age classes (age-0 to 25) but ages-6+ ( $100 \%$ maturity) were summed for clarity.


Figure 5.7. Sex ratio (male/female) of numbers at age estimated in the base case model.


Figure 5.8. Estimated number of mature female sharks in Q2 (upper left); spawning depletion based on number of mature female sharks ( $\mathrm{S} / \mathrm{S}_{0}$ ) (lower left); biomass of mature female sharks (upper right); and seasonal total biomass (age-1+) (lower right). Dashed lines indicate 95\% confidence intervals; and closed circles and error bars indicate estimated quantities and 95\% confidence intervals under virgin conditions, respectively. Estimated virgin number of mature female sharks $\left(\mathrm{S}_{0}\right)$ is 88,220 fish. Spawning output in number of pups is $4 *$ number of mature females.


Figure 5.9. Estimated log-recruitment deviations (upper left), recruitment bias adjustment (lower left), spawner-recruit relationship (upper right), and recruitment time series (lower right) from the base case model.


Figure 5.10. Estimated fishing mortality at age (F-at-age) for female (upper) and male (lower) common thresher sharks from the base case model.


Figure 5.11. Estimated fishing intensity (1-SPR) from the base case model. Black line indicates the maximum likelihood estimate while dashed lines indicate 95\% confidence intervals.


Figure 6.1. Estimated catch in metric tons (mt) (upper left), number of mature female sharks (lower left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and sensitivity runs using high (blue) and low (red) catch scenarios.


Figure 6.2. Estimated number of mature females (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and a sensitivity run assuming that the model started under virgin conditions (red).


Figure 6.3. Estimated stock-recruitment relationship parameters of virgin recruitment ( $\operatorname{LN}(R 0)$ : solid line) and shape parameter, ( $\beta$ : dashed line) (upper left), and total negative log-likelihood (lower left) under a range of fixed $z_{\text {frac }}$ values. Expected pup survival (upper right) and recruitment (lower right) with respect to the number of mature females relative to virgin conditions, which is equivalent to spawning depletion, under a range of fixed $z_{\text {frac }}$ values. The base case model has a fixed $z_{\text {frac }}$ value of 0.6.


Figure 6.4. Estimated number of mature female sharks (upper left), number of mature female sharks under virgin conditions (lower left; solid line) and in the terminal year (2014) (lower left; dashed line), spawning depletion (upper right), and fishing intensity (1-SPR) (lower right) under a range of fixed $z_{\text {frac }}$ values. The base case model had a fixed $z_{\text {frac }}$ value of 0.6.


Figure 6.5. Estimated number of mature female sharks (upper left), recruitment (lower left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and several sensitivity runs assuming Beverton-Holt stock-recruitment relationships with steepness (h) equal to the base case model (h=0.495; red), slightly lower ( $\mathrm{h}=0.4$; yellow) and higher ( $\mathrm{h}=0.6$; green) than the base case model, and estimated steepness (h=0.89; blue).





Figure 6.6. Estimated recruitment (upper left), recruitment deviates (lower left), number of mature female sharks (upper right), spawning depletion (middle right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and a sensitivity run assuming a $\sigma_{R}$ of 0.3 (red).



Figure 6.7. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and sensitivity runs assuming various levels of natural mortality ( $50 \%, 75 \%$, and $125 \%$ of the natural mortality used in the base case model). A sensitivity run was also performed at 1.5 M but did not converge.



Figure 6.9. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and sensitivity runs assuming a median age of maturity of 12 years, a biennial reproductive cycle, and a combination of both.


Figure 6.10. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and a sensitivity run including the S6 index from the USA juvenile thresher survey.


Figure 6.11. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and sensitivity runs that allowed the weighting factors, calculated using the Francis (2011) method, for the size composition and conditional age-at-length data to be $>1$. Dashed lines indicate $95 \%$ confidence intervals. Confidence intervals could not be calculated when weighting factors for the USJUV0614 (S6) survey and the F3 fleet were >1 because of the non-positive definite Hessian matrix.


Figure 6.12. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and sensitivity runs that down-weighted the size composition data from various fleets (F1, F2, F3, F8 and S6).
Down-weighting the USSN (F3) fleet resulted in a non-positive definite Hessian matrix.


Figure 6.13. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and a sensitivity run that up-weighted the conditional age-at-length data with weighting factors equal to 1 .


Figure 6.14. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and a sensitivity run that used alternative selectivity time blocks (1985 - 2000 and 2001 - 2014).


Figure 6.15. Estimated selectivity (upper left), and model fits to non-sex specific size composition (middle left) and size specific size composition (lower left) of the USSN (F3) fleet for a sensitivity run that used size selectivity for F3 instead of age selectivity. Estimated number of mature female sharks (upper right), spawning depletion (middle right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and sensitivity run (red).



Figure 6.17. Estimated selectivity of the USDGNs2 (F2) fleet (1985-1988) for the base case model and two sensitivity runs with different positions on the last knot of the spline (upper left).. Estimated number of mature females (upper right), spawning depletion (mid right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and sensitivity runs.


Figure 8.1. Kobe time series plot of the ratio of spawning abundance (S; number of mature female sharks) relative to the minimum stock size threshold reference point (MSST; (1$\mathrm{M}) * \mathrm{~S}_{\mathrm{MSY}}$ ) and ratio of the fishing intensity (1-SPR) relative to the maximum fishing mortality threshold (MFMT; 1-SPR ${ }_{\text {MSY }}$ ) for the base case model. Values for the start (1969) and end (2014) years are indicated by blue triangle and white circle, respectively. White lines indicate the $95 \%$ confidence intervals. Grey numbers indicate selected years.


Figure 8.2. Kobe plot of the ratio of spawning abundance (S; number of mature female sharks) relative to the minimum stock size threshold reference point (MSST; (1-M)*S ${ }_{\mathrm{MSY}}$ ) and ratio of the fishing intensity (1-SPR) relative to the maximum fishing mortality threshold (MFMT; 1SPR $_{\mathrm{MSY}}$ ) for the end year (2014) of the base case model (white circle) and three alternative states of nature: 1) alternative reproductive biology with a biennial reproductive cycle, 12 years median age-at-maturity, and natural mortality of 0.0757 (white square); 2 ) alternative stock-recruitment with $Z_{\text {frac }}$ of 0.4 (blue triangle); and 3) alternative stock-recruitment with $Z_{\text {frac }}$ of 0.8 (blue diamond). White and blue lines indicate the respective $95 \%$ confidence intervals.

# APPENDIX A: Abundance indices for the USA swordfish/shark gillnet fishery 

## INTRODUCTION

The most important commercial fishery for common thresher sharks is the USA swordfish/shark drift gillnet (USDGN) fishery, which began in 1977-78 (Hanan et al. 1993). The USDGN fishery began with about 15 vessels in Southern California but the number of vessels grew rapidly (Hanan et al. 1993). Although the initial primary targets were common thresher and shortfin mako sharks, fishermen soon discovered that they could efficiently catch swordfish with the same gear, and switched to primarily targeting swordfish because of substantially higher exvessel prices (Hanan et al. 1993). Since those early days, the primary target of the USDGN fishery has been swordfish, with common thresher and shortfin mako sharks being secondary targets.

Fishing operations of the USDGN fishery have been heavily regulated to reduce adverse interactions with other fisheries, fishing mortality of common thresher sharks, and incidental bycatch of marine mammals and sea turtles (Hanan et al. 1993; PFMC 2003). Details of current and historical regulations have been documented by Hanan et al. (1993), PFMC (2003), and PFMC (2015) (Table 1.1 in the main document). There appeared to be three major periods for the USDGN fishery with respect to fishery operations and regulations: 1) 1977 -1991; 2) 1992 2000; and 3) 2001 - 2014. The first period (1977-1991) encompassed the initial expansion of the fishery and the switch from primarily targeting pelagic sharks to swordfish. There were also early attempts at regulating the USDGN fishery, which resulted in frequent changes in regulations that included gear restrictions, swordfish catch, swordfish to shark catch ratios, seasonal closures, and time-area closures. In particular, time-area closures in California were enacted or modified in 1982, 1985, and 1989, which likely affected the CPUE of sharks for the USDGN fishery (Urbisci et al. in review). Washington and Oregon also started and closed their drift gillnet fisheries in 1983 and 1989 respectively. The time-area closures for the USDGN fishery was relatively stable during the second period (1992 - 2000), after the closure period for California was changed to May 1 through August 14 in 1992. The second period was a period of decline in the USDGN fishery, with the number of vessels landing fish declining from 119 in 1992 to 72 in 2000 (PFMC 2015). This decline continued in the third period (2001-2014), which was marked by the enactment of a large time-area closure in 2001 to protect leatherback turtles. The number of vessels in the USDGN fishery landing fish declined from 61 in 2001 to 18 in 2014 (PFMC 2015).

Three indices representing different regulatory and operational periods were developed for the USDGN fishery: Index 1: 1982 - 1984; Index 2: 1992 - 2000; and Index 3: 2001 - 2013. Changes in the regulations and fishery operations of this fishery have likely affected the
catchability of this fishery (Urbisci et al. in review). The most important regulatory changes occurred in 1982, 1985, 1989, 1992, and 2001, when time-area closures were implemented or changed. For this assessment, we did not attempt to account for the effect of these time-area closures in our GLMs. Instead, we developed shorter time series within the periods when regulatory changes were likely less important. Logbook data for 2014 was also not available by the time that development of abundance indices was completed. An abundance index was not developed for the 1985 - 1991 period because of changing regulations and fishery operations. In addition, preliminary examination of the logbook data indicated that the CPUE of the fishery rapidly increased and decreased several fold during this period, which indicated that changing regulations and fishing operations likely resulted in the exploitation of some local areas of high thresher abundance.

Regulatory changes have affected the start of the fishing season over the years. Therefore, only data from seasons 3 and 4 (i.e., Aug - Oct and Nov - Jan) were used for the abundance indices because fishing consistently occurred during those seasons. Three bimonthly periods within the six month period were used as factors in the GLMs to account for changes in thresher CPUE due to time of year.

The annual decile rank of swordfish catch of a given drift gillnet set was included in the GLMs to account for shifts in the targeting by the fishery from pelagic sharks to swordfish. In the initial development of the fishery, the primary target of the fishery changed from pelagic sharks to swordfish because of higher market prices. However, the targeting switch was constrained by regulations restricting the total amount of monthly swordfish landings and requirements to land equal amounts of shark. Even after regulations restricting swordfish catch were removed, USDGN vessels likely switched between swordfish and pelagic sharks depending on availability and market prices. The annual decile rank of swordfish catch was determined by ranking the swordfish catch from all sets within a given year, and then splitting the ranks into deciles (e.g., 0$10 \%, 10-20 \%$ ).

## MATERIALS AND METHODS

## Data

The abundance indices were developed from set-by-set logbook data submitted by skippers of vessels in the USDGN fishery after a mandatory logbook program was established in 1980, with the initial data collected in the 1981 - 1982 fishing season (Hanan et al. 1993). Data collected by the logbooks include catch (numbers of fish) by species, date, mesh size, net length, hours soaked, set number, and geographical position. Geographical positions were entered as CDFG block numbers (predominantly 10 min by 10 min squares), which were subsequently converted to latitudes and longitudes based on the center of the blocks. Coverage rate of the logbooks (proportion of landed weight reported in the logbooks) was estimated by Hanan et al. (1993) to be poor in the 1981 - 1982 fishing season (1\% for thresher sharks) but was very good for all
subsequent years, exceeding $100 \%$ coverage for most years. The catch and effort in the logbook data therefore appeared to be representative of the fishery, except for the 1981 - 1982 season.

Preliminary examination of the data indicated that two stages of filtering were required before the data could be used for developing abundance indices. The number of sets in the data after each filtering stage is summarized in Table A. 1 and the spatial distribution of the sets and catch can be seen in Fig. A.1. The two filtering stages were:

1. Identifying swordfish/shark (large-mesh) drift gill net sets

The original data set included data from small-mesh drift gillnet and set net fisheries targeting coastal and demersal fish species but did not specifically identify sets from the swordfish/shark fishery using large-mesh drift gillnets. The logbook data were therefore filtered to select for data where gear type was identified as "drift gillnet", and target species identified as swordfish and/or shark, and mesh size was $\geq 14$ inches or unspecified.

## 2. Identifying abnormal fishing operations

The majority of fishing operations for the USDGN fishery used nets about 1,000 fathoms long and had soak times within 24 hours. However, abnormal fishing operations could result from nets being left in the water, and experimental trips using shorter nets and/or soak times. Sets with abnormal fishing operations or misreported information were identified and removed in the second filtering stage because it was considered inappropriate to use data from these abnormal fishing operations. Abnormal sets were identified based on fishery knowledge. As a result, sets that recorded missing or abnormal soak times ( $<3$ or $>17$ hours), net lengths ( $<250$ or $>2000 \mathrm{~m}$ ), mesh size ( $<14$ or $>23$ inches), locations (latitude: $<32$ or $>45^{\circ} \mathrm{N}$; distance from shore: $>200$ km ), and depth (>6201 m). In addition, only data from August through January were used for the abundance indices in order to maintain consistency with the fleet definitions used in the assessment model.

The logbook data were divided into strata based on available factors. Season was categorized as three bimonthly periods ([Aug, Sep], [Oct, Nov], [Dec, Jan]). Five areas were defined based on the latitude ([32, 34), [34, 36), [36, 38), [38, 40), and $\geq 40^{\circ} \mathrm{N}$ ). Other factors included water depth (11 levels: [0, 250), [250, 500), [500, 750), [750, 1000), [1000, 1250), [1250, 1500), [1500, 1750), [1750, 2000), [2000, 3000), [3000, 4000), and $\geq 4000 \mathrm{~m}$ ), distance from shore ( 7 levels: $[0,25),[25,50),[50,75),[75,100),[100,125),[125,150$ ), and $\geq 150 \mathrm{~km}$ ), mesh size ( 3 levels: unknown, [14, 19), and $\geq 19$ inches), and percentile rank of swordfish catch (swfrank) ( 10 levels: [0, 10), [10, 20), [20, 30), [30, 40), [40, 50), [50, 60), [60, 70), [70, 80), [80, 90), [90, 100]\%).

## Models

Delta-lognormal models (Lo et al. 1992) were used to standardize the catch per unit effort (CPUE) to obtain the abundance indices used in the stock assessment because the data set
contained a large proportion of sets with zero thresher catch (Fig. A.2). Catch was defined as the sum of all kept and discarded common thresher sharks in a single set, and effort was defined as the product of the length of the net (km) and soak time (hours). Delta-lognormal models assumes that the proportion of sets with positive catch have a binomial error structure and is modeled by a GLM with a logit link function, and the catch rate of sets with positive catch has a lognormal error distribution and is modeled by a lognormal GLM. The standardized index is the product of the back-transformed marginal year effects (Searle 1980) of these two components, with a correction for the bias in the lognormal back transformation. Estimates of variance were obtained by jackknifing the data set, using a modified version of delta_glm_1-7-2 function (E. J. Dick, pers. comm.) in R (function was modified to allow for different explanatory factors for the binomial and lognormal functions).

A forward-backward stepwise model selection process, with AIC as the selection criteria, was used to determine the set of factors that explained the catch of common thresher sharks in the logbook data. The binomial and lognormal models for each time period were selected independently.

## RESULTS AND DISCUSSION

Based on the stepwise model selection process, the final delta-lognormal models for each time period were:

1982-1984
Binom: $\operatorname{logit}(\pi) \sim$ year + lat + season + distance + swfrank + depth $+\operatorname{offset}[\log ($ eff $)]+\varepsilon$
Lognormal: $\log ($ catch $) \sim$ year + lat + season + distance + swfrank + depth $+\operatorname{offset[log(eff)]+\varepsilon }$

1992-2000
Binom: $\operatorname{logit}(\pi) \sim$ year + lat + season + distance + swfrank + depth + mesh $+\operatorname{offset}[\log ($ eff $)]+\varepsilon$
Lognormal: $\log ($ catch $) \sim$ year + lat + distance + swfrank + depth + mesh $+\operatorname{offset}[\log ($ eff $)]+\varepsilon$

2001-2013
Binom: $\operatorname{logit}(\pi) \sim$ year + lat + season + distance + swfrank + depth + mesh $+\operatorname{offset}[\log ($ eff $)]+\varepsilon$
Lognormal: $\log ($ catch $) \sim$ year + lat + season + distance + swfrank + depth + mesh + offset $[\log ($ eff $)]+\varepsilon$
where $\pi$ was the probability of a set having positive common thresher shark catch, and the random error structures of the binomial and lognormal models were assumed to be Binom(n, $\pi$ ) and $\mathrm{N}(0, \sigma)$ respectively. Deviance tables for the three time periods are found in Table A.2. No first-order interactions were included in the final model selection process because abundance indices with or without first-order interactions were highly similar.

Model diagnostics indicated adequate performance of the lognormal and binomial models for all three abundance indices (Fig. A. 3 - A.8). For all three time periods, the lognormal residuals were slightly skewed because the lognormal models had problems fitting sets with small numbers of fish. However, the mean predicted values of both the lognormal and binomial component models were highly representative of the observed values after aggregation into spatial and temporal bins.

In the first time period (1982-1984), the standardization resulted in an abundance index that was more consistently and more steeply declining than the nominal CPUE (Fig. A.9). The standardized abundance index for the second time period (1992-2000) indicated that the common thresher shark population was increasing rapidly during this period but there were moderate amounts of variability in the estimates (Fig. A.10). The lognormal model reduced the variability apparent in the CPUE of positive sets but the variability in the binomial component was not visibly reduced. The third period (2001 - 2013) was marked by high interannual variability in the relative abundance estimates and there were no obvious trends during this period (Fig. A.11). The jackknife procedure resulted in coefficients of variation (CVs) that were relatively high, especially for 1982 - 1984 (Table A. 3 and Fig. A.12).

Appendix Table A.1. Amount of data (number of sets) in the logbook data set before and after two stages of filtering for the swordfish/shark drift gillnet fishery.

| Period | Number of sets prior <br> to filtering | Number of sets after <br> stage 1 filtering | Number of sets after <br> stage 2 filtering |  |
| :--- | :--- | ---: | ---: | ---: |
| $1982-1984$ |  | 83116 | 31173 | 21950 |
| $1992-2000$ | 79428 | 28245 | 25305 |  |
| $2001-2013$ |  | 47844 | 11511 | 9699 |

Appendix Table A.2. Deviance analysis of explanatory variables in delta-lognormal models for common thresher shark catch rates of USA swordfish/shark drift gillnet fishery for three time periods: 1) 1982 - 1984; 2) 1992 - 2000; and 3) 2001 - 2013.

```
1982-1984
```

| Model factors | Df |  | Deviance | Residual Df | Residual Deviance | Pr(>Chi) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Binomial: |  |  |  |  |  |  |
| AIC $=21735$ |  |  |  |  |  |  |
| Null |  |  |  | 21949 | 23219 |  |
| Year |  | 2 | 38.18 | 21947 | 23180 | 5.13E-09 |
| Latitude |  | 4 | 735.70 | 21943 | 22445 | <2.2E-16 |
| Season |  | 2 | 184.29 | 21941 | 22260 | <2.2E-16 |
| Distance from shore |  | 6 | 374.49 | 21935 | 21886 | <2.2E-16 |
| Decile rank of swordfish catch |  | 8 | 99.22 | 21927 | 21787 | <2.2E-16 |
| Depth |  | 10 | 118.16 | 21917 | 21669 | <2.2E-16 |
| Lognormal: |  |  |  |  |  |  |
| Null |  |  |  | 4628 | 4555.1 |  |
| Year |  | 2 | 37.71 | 4626 | 4517.4 | 1.1E-12 |
| Latitude |  | 3 | 848.51 | 4623 | 3668.9 | <2.2E-16 |
| Season |  | 2 | 67.36 | 4621 | 3601.6 | <2.2E-16 |
| Distance from shore |  | 6 | 232.39 | 4615 | 3369.2 | $<2.2 \mathrm{E}-16$ |
| Decile rank of swordfish catch |  | 8 | 123.23 | 4607 | 3245.9 | <2.2E-16 |
| Depth |  | 10 | 98.80 | 4597 | 3147.2 | $<2.2 \mathrm{E}-16$ |

## Appendix Table A.2. Continued.

$$
1992-2000
$$

| Model <br> factors | Df | Deviance | Residual Df | Residual <br> Deviance | Pr(>Chi) |
| :--- | ---: | ---: | ---: | ---: | ---: |
| Binomial: |  |  |  |  |  |
| AIC = 18802 |  |  |  |  |  |
| Null | 8 | 660.11 | 25304 | 21690 |  |
| Year | 4 | 230.86 | 25296 | 21030 | $<2.2 \mathrm{E}-16$ |
| Latitude | 2 | 129.00 | 25290 | 20799 | $<2.2 \mathrm{E}-16$ |
| Season | 6 | 1075.00 | 25284 | 20670 | $<2.2 \mathrm{E}-16$ |
| Distance from <br> shore |  |  | 19595 | $<2.2 \mathrm{E}-16$ |  |
| Decile rank of | 8 | 508.04 | 25276 | 19087 | $<2.2 \mathrm{E}-16$ |
| swordfish |  |  |  |  |  |
| catch | 10 | 358.66 | 25266 | 18728 | $<2.2 \mathrm{E}-16$ |
| Depth | 2 | 8.47 | 25264 | 18720 | 0.0145 |

## Lognormal:

AIC = 10043

| Null |  |  | 3704 | 4767.4 | $8.0 \mathrm{E}-09$ |
| :--- | ---: | ---: | ---: | ---: | ---: |
| Year | 8 | 46.75 | 3696 | 4720.7 | $<2.2 \mathrm{E}-16$ |
| Latitude | 4 | 752.55 | 3692 | 3968.1 | $<2.2 \mathrm{E}-16$ |
| Distance from <br> shore | 6 | 400.48 | 3686 | 3567.7 | $<2.2 \mathrm{E}-16$ |
| Decile rank of <br> swordfish | 8 | 264.60 | 3678 | 3303.1 | $<2.2 \mathrm{E}-16$ |
| catch |  |  |  |  |  |
| Depth <br> Mesh | 10 | 105.79 | 3668 | 3197.3 | $<2.2 \mathrm{E}-16$ |

## Appendix Table A.2. Continued.

2001-2013

| Model <br> factors | Df | Deviance | Residual Df | Residual <br> Deviance | $\boldsymbol{P r}(>$ Chi) |
| :--- | ---: | ---: | ---: | ---: | ---: |
| Binomial: |  |  |  |  |  |
| AIC = 10697 |  |  | 9698 | 11891 |  |
| Null | 12 | 314.86 | 9686 | 11576 | $<2.2 \mathrm{E}-16$ |
| Year | 4 | 13.00 | 9682 | 11563 | 0.0112 |
| Latitude | 2 | 258.04 | 9680 | 11305 | $<2.2 \mathrm{E}-16$ |
| Season | 6 | 315.45 | 9674 | 10990 | $<2.2 \mathrm{E}-16$ |
| Distance from <br> shore |  |  |  |  |  |
| Decile rank of <br> swordfish | 9 | 235.57 | 9665 | 10754 | $<2.2 \mathrm{E}-16$ |
| catch |  |  |  |  |  |
| Depth | 10 | 105.03 | 9655 | 10649 | $<2.2 \mathrm{E}-16$ |
| Mesh | 2 | 43.98 | 9653 | 10605 | $2.8 \mathrm{E}-10$ |

## Lognormal:

AIC = 7342.6

| Null |  |  | 2745 | 3149.8 |  |
| :--- | ---: | ---: | ---: | ---: | ---: |
| Year | 12 | 80.12 | 2733 | 3069.7 | $3.3 \mathrm{E}-15$ |
| Latitude | 4 | 44.09 | 2729 | 3025.6 | $9.2 \mathrm{E}-11$ |
| Season | 2 | 12.61 | 2727 | 3013.0 | $5.3 \mathrm{E}-04$ |
| Distance from <br> shore | 6 | 461.32 | 2721 | 2551.7 | $<2.2 \mathrm{E}-16$ |
| Decile rank of <br> swordfish | 9 | 163.89 | 2712 | 2387.8 | $<2.2 \mathrm{E}-16$ |
| catch |  |  |  |  |  |
| Depth <br> Mesh | 10 | 110.77 | 2702 | 2277.0 | $<2.2 \mathrm{E}-16$ |

Table A.3. Estimated relative abundance index values, standard errors (SEs), and coefficients of variation (CVs) for three time periods: 1982 - 1984; 1992 - 2000; and 2001-2013 for the USA swordfish/shark drift gillnet fishery. The SEs and CVs were estimated with a jackknife procedure.

| Year | Index | SE | CV |
| :---: | :---: | :---: | :---: |
| 1982-1984 |  |  |  |
| 1982 | 0.01229 | 0.00345 | 0.28035 |
| 1983 | 0.00921 | 0.00256 | 0.27814 |
| 1984 | 0.00763 | 0.00212 | 0.27842 |
| 1992-2000 |  |  |  |
| 1992 | 0.00047 | 5.45E-05 | 0.11681 |
| 1993 | 0.00066 | $7.40 \mathrm{E}-05$ | 0.11289 |
| 1994 | 0.00107 | $1.21 \mathrm{E}-04$ | 0.11289 |
| 1995 | 0.00076 | $9.68 \mathrm{E}-05$ | 0.12739 |
| 1996 | 0.00099 | $1.24 \mathrm{E}-04$ | 0.12568 |
| 1997 | 0.00112 | $1.34 \mathrm{E}-04$ | 0.11994 |
| 1998 | 0.00214 | $2.58 \mathrm{E}-04$ | 0.12047 |
| 1999 | 0.00126 | $1.64 \mathrm{E}-04$ | 0.12996 |
| 2000 | 0.00191 | $2.84 \mathrm{E}-04$ | 0.14880 |
| 2001-2013 |  |  |  |
| 2001 | 0.01269 | 0.00250 | 0.19702 |
| 2002 | 0.00631 | 0.00128 | 0.20242 |
| 2003 | 0.00575 | 0.00122 | 0.21192 |
| 2004 | 0.00518 | 0.00112 | 0.21691 |
| 2005 | 0.01830 | 0.00372 | 0.20352 |
| 2006 | 0.00687 | 0.00137 | 0.19910 |
| 2007 | 0.02289 | 0.00451 | 0.19697 |
| 2008 | 0.00685 | 0.00151 | 0.22096 |
| 2009 | 0.00391 | $8.79 \mathrm{E}-04$ | 0.22504 |
| 2010 | 0.01745 | 0.00403 | 0.23111 |
| 2011 | 0.01148 | 0.00264 | 0.23021 |
| 2012 | 0.00711 | 0.00162 | 0.22832 |
| 2013 | 0.01244 | 0.00247 | 0.19884 |



Appendix Figure A.1. Spatial distribution of sets (left) and common thresher shark catch (right) for the USA swordfish/shark drift gillnet fishery over three periods used for abundance indices.


Appendix Figure A.2. Proportion of sets with zero thresher shark catch (upper), nominal catch-per-unit-effort (CPUE) of sets with positive thresher catch (middle), and overall nominal CPUE (lower) for common thresher sharks caught by the USA swordfish/shark drift gillnet fishery.


Appendix Figure A.3. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 1982 - 1984 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.


Appendix Figure A.4. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 1982-1984 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.


Appendix Figure A.5. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 1992 - 2000 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.


Appendix Figure A.6. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 1992-2000 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.


Appendix Figure A.7. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 2001-2013 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.


Appendix Figure A.8. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 2001-2013 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.


Appendix Figure A.9. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USA swordfish/shark drift gillnet fishery during 1982 - 1984. Indices are plotted relative to the value of the initial year.


Appendix Figure A.10. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USA swordfish/shark drift gillnet fishery during 1992 - 2000. Indices are plotted relative to the value of the initial year.


Appendix Figure A.11. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USA swordfish/shark drift gillnet fishery during 2001-2013. Indices are plotted relative to the value of the initial year.


Appendix Figure A.12. Standardized abundance indices of the USA swordfish/shark drift gillnet fishery during three periods: 1982 - 1984 (upper), 1992 - 2000 (middle), and 2001 - 2013 (lower). Dashed lines indicate 95\% confidence intervals derived from jackknifing the data set.

# APPENDIX B: Abundance indices for the USA nearshore set gillnet and small-mesh drift gillnet fishery 

## INTRODUCTION

A secondary USA commercial fishery that catches common thresher sharks is the nearshore set gillnet and small-mesh drift gillnet (USSN) fishery that target nearshore species like barracuda, white seabass, and halibut. The key differences between this fishery and the USA swordfish/shark drift gillnet (USDGN) fishery are that the USSN fishery uses nets with smaller mesh size (typically <10 inches) and operates in shallow, nearshore waters. Most of the catch and effort of the USSN fishery centers around the Southern California Bight but some parts of the fishery operates in nearshore areas as far north as around Mendocino, California (Fig. B.1).

The USSN does not target common thresher sharks but occasionally capture common thresher sharks as bycatch. The continental shelf of the Southern California Bight is a known nursery area for common thresher sharks along the USA West Coast and the USSN fishery therefore catches predominantly age-0 common thresher sharks (Cartamil et al. 2010). These abundance indices were therefore considered to be recruitment indices.

In 1994, the California Marine Resources Protection Act of 1990 began prohibiting all gillnets and trammel nets within 3 nm of the California mainland and within 1 nm (or waters $<70$ fathoms deep) of the Channel Islands. This resulted in the USSN fishery fishing in slightly deeper waters from 1994. In addition, data from 1981-1985 were not used because the USSN data were mixed with the USDGN data and could not be easily separated until after 1985, when the USDGN fishery moved out of the 75 nm zone due to regulations. Based on these changes, two indices representing different regulatory and operational periods were developed for the USSN fishery: Index 1: 1985 - 1993; and Index 2: 1994 - 2014.

Unlike the USDGN fishery, data from all four seasons were used in the indices from the USSN fishery. In addition, it was also not necessary to correct for the USSN fishery targeting swordfish instead of pelagic sharks because neither swordfish nor pelagic sharks were targets of the fishery.

## MATERIALS AND METHODS

## Data

The abundance indices were developed from set-by-set logbook data submitted by skippers of vessels in the USSN fishery after a mandatory logbook program was established in 1980, with the initial data collected in the 1981-1982 fishing season (Hanan et al. 1993). This was the same logbook program for the USDGN fishery. Data collected by the logbooks included catch (numbers of fish) by species, date, mesh size, net length, hours soaked, set number, and geographical position. Geographical positions were entered as CDFG block numbers
(predominantly 10 min by 10 min squares), which were subsequently converted to latitudes and longitudes based on the center of the blocks.

Preliminary examination of the data indicated that two stages of filtering were required before the data could be used for developing abundance indices. The number of sets in the data after each filtering stage is summarized in Table B. 1 and the spatial distribution of the sets and catch can be seen in Fig. A.1. The two filtering stages were:

## 1. Identifying USSN sets

The original data set included data from both the USSN and USDGN fisheries. The logbook data were therefore filtered to select for data where gear type was identified as "set net", and target species were not identified as swordfish or shark, and mesh size was $\leq 10$ inches or unspecified.
2. Identifying abnormal fishing operations

The majority of fishing operations for the USSN fishery used nets ranging from 250 to 1,000 fathoms long and had soak times of one or two days. However, abnormal fishing operations could result from nets being left in the water, and experimental trips using shorter nets and/or soak times. Sets with abnormal fishing operations or misreported information were identified and removed in the second filtering stage because it is inappropriate to use data from these abnormal fishing operations. Abnormal sets were identified based on fishery knowledge. As a result, sets that recorded missing or abnormal soak times ( $<6$ or $>48$ hours), net lengths ( $<100$ or $>2000 \mathrm{~m}$ ), mesh size ( $<2$ or $>10$ inches), locations (latitude: $<32$ or $>40^{\circ} \mathrm{N}$; distance from shore: $>20 \mathrm{~km}$ ), and depth ( $>100 \mathrm{~m}$ ).

The logbook data were divided into strata based on available factors. Season was categorized as four trimonthly periods ([Feb, Apr], [May, Jul], [Aug, Oct], [Nov, Dec]). Six areas were defined based on the latitude ([32, 33), [33, 34), [34, 35), [35, 36), $\left[36,37\right.$ ), and $[37,40]{ }^{\circ} \mathrm{N}$ ). Other factors included water depth (4 levels: [0, 20), [20, 40), [40, 80), and [80, 100] m), distance from shore (4 levels: $[0,5$ ), $[5,10$ ), $[10,15$ ), and $[15,20] \mathrm{km}$ ), and mesh size ( 5 levels: unknown, $[1,3$ ), $[3$, $6),[6,8)$, and $[8,10]$ inches).

## Models

Delta-lognormal models (Lo et al. 1992) were used to standardize the catch per unit effort (CPUE) to obtain the abundance indices used in the stock assessment because the data set contained a large proportion of sets with zero thresher catch (Fig. A.2). Catch was defined as the sum of all kept and discarded common thresher sharks in a single set, and effort was defined as the product of the length of the net (km) and soak time (days). Delta-lognormal models assumes that the proportion of sets with positive catch have a binomial error structure and is modeled by a GLM with a logit link function, and the catch rate of sets with positive catch has a lognormal error distribution and is modeled by a lognormal GLM. The standardized index was the product
of the back-transformed marginal year effects (Searle 1980) of these two components, with a correction for the bias in the lognormal back transformation. Estimates of variance were obtained by jackknifing the data set, using a modified version of delta_glm_1-7-2 function (E. J. Dick, pers. comm.) in R (function was modified to allow for different factors for the binomial and lognormal functions).

A forward-backward stepwise model selection process, with AIC as the selection criteria, was used to determine the set of factors that explained the catch of common thresher sharks in the logbook data. The binomial and lognormal models for each time period were selected independently.

## RESULTS AND DISCUSSION

Based on the stepwise model selection process, the final delta-lognormal models for each time period were:

1985-1993
Binom: $\operatorname{logit}(\pi) \sim$ year + lat + season + distance $+\operatorname{mesh}+\operatorname{offset}[\log ($ eff $)]+\varepsilon$
Lognormal: $\log ($ catch $) \sim$ year + lat + distance + depth + mesh $+\operatorname{offset}[\log ($ eff $)]+\varepsilon$

1992-2000
Binom: $\operatorname{logit}(\pi) \sim$ year + lat + season + depth + mesh $+\operatorname{offset}[\log ($ eff $)]+\varepsilon$
Lognormal: $\log ($ catch $) \sim$ year + lat + depth + mesh $+\operatorname{offset}[\log ($ eff $)]+\varepsilon$
where $\pi$ was the probability of a set having positive common thresher shark catch, and the random error structures of the binomial and lognormal models were assumed to be Binom(n, $\pi$ ) and $\mathrm{N}(0, \sigma)$ respectively. Deviance tables for both time periods are found in Table B.2. No firstorder interactions were included in the final model selection process because abundance indices with or without first-order interactions were highly similar.

Model diagnostics indicated adequate performance of the lognormal and binomial models for all three abundance indices (Fig. B. 3 - B.6). For both time periods, the lognormal residuals were slightly skewed because the lognormal models had problems fitting sets with small numbers of fish. However, the mean predicted values of both the lognormal and binomial component models were highly representative of the observed values after aggregation into spatial and temporal bins.

In the first time period (1985 - 1993), a large spike in the nominal index was substantially reduced by the standardization, resulting in an index that gradually decreased to a minimum in 1989 before gradually increasing (Fig. B.7). The standardized abundance index for the second time period (1994-2014) indicated that the common thresher shark recruitment increased
substantially during this period, albeit with substantial variability (Fig. B.8). The lognormal model reduced the variability apparent in the CPUE of positive sets but the variability in the binomial component was not visibly reduced. The jackknife procedure resulted in coefficients of variation (CVs) that were relatively high (Table B. 3 and Fig. B.9).

Appendix Table B.1. Amount of data (number of sets) in the logbook data set before and after two stages of filtering for the USA nearshore set net fishery.

| Period | Number of sets prior <br> to filtering | Number of sets after <br> stage 1 filtering | Number of sets after <br> stage 2 filtering |  |
| :--- | :--- | ---: | ---: | ---: |
| $1985-1993$ |  | 192166 | 124542 | 68045 |
| $1994-2014$ | 99174 | 62474 | 33680 |  |

Appendix Table B.2. Deviance analysis of explanatory variables in delta-lognormal models for common thresher shark catch rates of USA nearshore set net fishery for two time periods: 1) 1985 - 1993; and 2) 1994 - 2014.

1985-1993

| Model factors | Df |  | Deviance | Residual Df | Residual Deviance | Pr(>Chi) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{aligned} & \text { Binomial: } \\ & \text { AIC = } 20812 \end{aligned}$ |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| Null |  |  |  | 68044 | 23752 |  |
| Year |  | 8 | 58.98 | 68036 | 23694 | 7.38E-10 |
| Latitude |  | 5 | 1574.51 | 68031 | 22119 | <2.2E-16 |
| Season |  | 3 | 1027.70 | 68028 | 21091 | <2.2E-16 |
| Distance from shore |  | 3 | 44.72 | 68025 | 21047 | $1.06 \mathrm{E}-09$ |
| Mesh |  | 4 | 282.50 | 68021 | 20764 | <2.2E-16 |
| Lognormal: AIC $=8113$ |  |  |  |  |  |  |
| Null |  |  |  | 2851 | 3316.0 |  |
| Year |  | 8 | 113.22 | 2843 | 3202.8 | <2.2E-16 |
| Latitude |  | 5 | 156.94 | 2838 | 3045.9 | <2.2E-16 |
| Distance from shore |  | 3 | 71.74 | 2835 | 2974.1 | $1.67 \mathrm{E}-15$ |
| Depth |  | 3 | 13.36 | 2832 | 2960.8 | 3.86E-03 |
| Mesh |  | 4 | 139.13 | 2828 | 2821.6 | $<2.2 \mathrm{E}-16$ |

Appendix Table B.2. Continued.
1994-2014

| Model <br> factors | Df | Deviance | Residual Df | Residual <br> Deviance | $\operatorname{Pr}(>$ Chi) |
| :--- | ---: | ---: | ---: | ---: | ---: |
| Binomial: |  |  |  |  |  |
| AIC = 18684 |  |  | 33679 | 21582 |  |
| Null | 20 | 741.31 | 33659 | 20841 | $<2.2 \mathrm{E}-16$ |
| Year | 5 | 464.32 | 33654 | 20377 | $<2.2 \mathrm{E}-16$ |
| Latitude | 3 | 917.66 | 33651 | 19459 | $<2.2 \mathrm{E}-16$ |
| Season | 3 | 251.24 | 33648 | 19208 | $<2.2 \mathrm{E}-16$ |
| Depth | 4 | 595.40 | 33644 | 18612 | $<2.2 \mathrm{E}-16$ |

## Lognormal:

AIC = 8807

| Null |  |  | 3077 | 3850.9 |  |
| :--- | ---: | ---: | ---: | ---: | ---: |
| Year | 20 | 138.38 | 3057 | 3712.6 | $<2.2 \mathrm{E}-16$ |
| Latitude | 5 | 124.80 | 3052 | 3587.8 | $<2.2 \mathrm{E}-16$ |
| Depth | 3 | 165.85 | 3049 | 3421.9 | $<2.2 \mathrm{E}-16$ |
| Mesh | 3 | 338.23 | 3046 | 3083.7 | $<2.2 \mathrm{E}-16$ |

Table B.3. Estimated relative abundance index values, standard errors (SEs), and coefficients of variation (CVs) for two time periods: 1985 - 1993; and 1994 - 2014 for the USA nearshore set net fishery. The SEs and CVs were estimated with a jackknife procedure.

| Year | Index | SE | $\mathbf{C V}$ |
| :---: | :---: | :---: | :---: |
|  | $\mathbf{1 9 8 5}-\mathbf{1 9 9 3}$ |  | 0.22246 |
| 1985 | 0.07149 | 0.01590 | 0.22000 |
| 1986 | 0.05076 | 0.01117 | 0.23149 |
| 1987 | 0.07998 | 0.01852 | 0.23024 |
| 1988 | 0.06265 | 0.01442 | 0.23056 |
| 1989 | 0.04039 | 0.00931 | 0.23840 |
| 1990 | 0.07087 | 0.01689 | 0.23477 |
| 1991 | 0.05103 | 0.01198 | 0.24198 |
| 1992 | 0.06788 | 0.01643 | 0.23061 |
| 1993 | 0.08320 | 0.01919 |  |
| 1994 | $\mathbf{1 9 9 4}-\mathbf{2 0 1 4}$ |  | 0.25464 |
| 1995 | 0.20827 | 0.05303 | 0.23268 |
| 1996 | 0.20266 | 0.04715 | 0.21991 |
| 1997 | 0.29486 | 0.06484 | 0.29964 |
| 1998 | 0.45911 | 0.09166 | 0.19030 |
| 1999 | 0.49911 | 0.10357 | 0.20322 |
| 2000 | 0.55780 | 0.10615 | 0.21287 |
| 2001 | 0.33207 | 0.06748 | 0.22537 |
| 2002 | 0.69024 | 0.14693 | 0.20489 |
| 2003 | 0.38927 | 0.08773 | 0.20710 |
| 2004 | 0.22220 | 0.04553 | 0.22886 |
| 2005 | 0.29735 | 0.06158 | 0.19227 |
| 2006 | 0.24872 | 0.05692 | 0.20402 |
| 2007 | 1.00752 | 0.19371 | 0.21220 |
| 2008 | 0.69005 | 0.14078 | 0.19518 |
| 2009 | 0.38999 | 0.08275 | 0.210675 |
| 2010 | 0.69659 | 0.13596 | 0.19746 |
| 2011 | 0.76876 | 0.15233 | 0.24029 |
| 2012 | 0.51435 | 0.10836 | 0.41220 |
| 2013 | 0.72856 | 0.14386 |  |
| 2014 | 0.21324 | 0.05124 | 0.33390 |
|  | 0.81005 |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |



Appendix Figure B.1. Spatial distribution of sets (left) and common thresher shark catch (right) for the USSN fishery over three periods used for abundance indices.


Appendix Figure B.2. Proportion of sets with zero thresher shark catch (upper), nominal catch-per-unit-effort (CPUE) of sets with positive thresher catch (middle), and overall nominal CPUE (lower) for common thresher sharks caught by the USSN fishery.


Appendix Figure B.3. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 1985-1993 common thresher shark abundance index for the USSN fishery.


Appendix Figure B.4. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 1985-1993 common thresher shark abundance index for the USSN fishery.


Appendix Figure B.5. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 1994-2014 common thresher shark abundance index for the USSN fishery.


Appendix Figure B.6. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 1994-2014 common thresher shark abundance index for the USSN fishery.


Appendix Figure B.7. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USSN fishery during 1985 - 1993. Indices are plotted relative to the value of the initial year.


Appendix Figure B.8. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USSN fishery during 1994-2014. Indices are plotted relative to the value of the initial year.


Appendix Figure B.9. Standardized abundance indices of the USSN fishery during two periods: 1985 - 1993 (upper), and 1994 - 2014 (lower). Dashed lines indicate 95\% confidence intervals derived from jackknifing the data set.

# APPENDIX C: Abundance index for the USA juvenile thresher shark survey 

## INTRODUCTION

The Southwest Fisheries Science Center (SWFSC) has conducted an annual juvenile thresher survey in September from 2006 through 2014. This fishery-independent survey was developed after an initial study on the nursery ground of the common thresher shark (Smith 2005). The study indicated that longline gear in nearshore waters would be successful in catching young-ofyear and juvenile common thresher sharks.

The basic survey design consisted of 12 area blocks and a minimum of three longline sets were required for each block (Fig. C.1). Each longline set consisted of a one mile long pelagic monofilament longline with 100 hooks. The longline was deployed from a small commercial longline vessel and anchored at each end. The hooks were expected to fish approximately 6-8 m below the surface and were baited with primarily sardines but mackerels were sometimes used when sardines were not available. The longline sets were deployed in areas where bottom depth is $<25$ fathoms ( $\sim 45 \mathrm{~m}$ ). Sharks were tagged and released alive, if possible.

Several operational factors of this survey impacted how the data from this survey was utilized in this assessment. Most importantly, the location and timing of each set was determined by the captain of the vessel, within the constraints set by NOAA scientists. The sets were in effect targeted at thresher sharks and were somewhat similar to commercial longline sets, albeit with standardized fishing gear. In addition, after the initial three sets within a block were completed and there was time available, the captain was free to set again in the same area. Therefore, the first three sets in an area block could have been used as learning sets, and may have provided information on where it was more likely to encounter common thresher sharks during subsequent sets in the same block. Preliminary analysis of the catch-per-unit-effort (CPUE) indicated that sets after the initial three sets in an area had a significant positive effect on encountering nonzero thresher catch.

Another important factor was that soak times of each set were inconsistent and varied substantially (Table C.1). When relatively large numbers of sharks were caught, soak times were sometimes cut to reduce shark mortality and possible hook saturation. Occasionally on some sets in the past, if a shark was observed to be hooked, the shark would be brought aboard and released, and the hook was then rebaited and put back into the water. This practice was considered inappropriate and has since been discontinued.

Other secondary factors likely impacting the CPUE of the survey were Marine Protected Areas (MPAs) and consumption of baits by sea lions. In 2012, several areas within survey blocks became unavailable to the survey due to MPAs being implemented. Preliminary analysis
indicated that sets within those areas before they became MPAs had higher CPUEs. Sea lions would also occasionally consume the baits on the longline making the longline less effective in catching fish. If the survey data indicated that baits were consumed by sea lions, the data from the set were discarded before further analysis.

## MATERIALS AND METHODS

## Data

The abundance index was developed using set-by-set data from 2006 through 2014. A series of criteria was used to identify sets with abnormal fishing operations: 1) sets with important missing data; 2) sets conducted outside of established area blocks; 2) sets with depth $>25$ fathoms; 3) sets where sea lions were observed to consume baits; 4) sets outside of September; 5) experimental sets with non-standard gear configurations (e.g., one set used only 50 hooks); and 6) sets with soak time of $>4$ hours. A total of 35 sets with abnormal fishing operations were identified out of 440 sets in the initial dataset. The remaining 405 sets were used to derive the abundance index, with some variability in the number of sets for each year (Table C.1).

The data were divided into strata based on available factors. Twelve areas were defined based on the experimental blocks. Other factors included water depth (5 levels: [0,10), [10,20), [20,30), $[30,40)$, and $[40,50] \mathrm{m}$ ), bait - percentage of sardine (4 levels: $[0,25$ ), $[25,50),[50,75)$, and [75,100] \%), first 3 sets ( 2 levels: 0,1 ), and MPA sets ( 2 levels: 0,1 ). We used soak time in hours as the fishing effort of each set because soak times varied substantially from set to set (Table C.1) but the number of hooks used were relatively constant ( 401 sets used 100 hooks but 4 sets used 104 hooks) for each set.

## Models

Delta-lognormal models (Lo et al. 1992) were used to standardize the catch per unit effort (CPUE) to obtain the abundance indices used in the stock assessment because the data set contained a large proportion of sets with zero thresher catch (Fig. C.2). Catch was defined as the sum of all common thresher sharks caught in a single set, and effort was defined as the soak time (hours). A delta-lognormal model assumes that the proportion of sets with positive catch has a binomial error structure and is modeled by a GLM with a logit link function, and the catch rate of sets with positive catch has a lognormal error distribution and is modeled by a lognormal GLM. The standardized index is the product of the back-transformed marginal year effects (Searle 1980) of these two components, with a correction for the bias in the lognormal back transformation. Estimates of variance were obtained by jackknifing the data set, using a modified version of delta_glm_1-7-2 function (E. J. Dick, pers. comm.) in R (function was modified to allow for different factors for the binomial and lognormal functions).

A forward-backward stepwise model selection process, with AIC as the selection criteria, was used to determine the set of factors that explained the catch of common thresher sharks in the
survey data. The binomial and lognormal models for each time period were selected independently.

## RESULTS AND DISCUSSION

Based on the stepwise model selection process, the final delta-lognormal models were:
2006-2014
Binom: $\operatorname{logit}(\pi) \sim$ year + area + first3sets + offset $[\log (e f f)]+\varepsilon$
Lognormal: $\log ($ catch $) \sim$ year + area + mpasets $+\operatorname{offset[\operatorname {log}(eff)]+\varepsilon ~}$
where $\pi$ was the probability of a set having positive common thresher shark catch, and the random error structures of the binomial and lognormal models were assumed to be Binom( $\mathrm{n}, \pi$ ) and $\mathrm{N}(0, \sigma)$ respectively. Deviance tables for both time periods are found in Table C.2. No firstorder interactions were included in the final model selection process because abundance indices with or without first-order interactions were highly similar.

Model diagnostics indicated adequate performance of the lognormal and binomial models for all three abundance indices (Fig. C. 3 - C.4). The lognormal residuals were relatively well represented by a normal distribution. In addition, the mean predicted values of both the lognormal and binomial component models were highly representative of the observed values after aggregation into spatial and temporal bins.

The standardized index from the USA juvenile thresher survey showed a generally increasing trend in recruitment from 2006 through 2011 but a decreasing trend in the last three years (2012 - 2014) (Fig. C.5). However, the apparent trends in the index are highly uncertain because the jackknife procedure resulted in large coefficients of variation (CVs), ranging from 0.43 to 0.55 (Table C. 3 and Fig. C.6).

Appendix Table C.1. Catch and effort from the longline juvenile thresher shark survey conducted in nearshore waters of Southern California by NOAA Fisheries' Southwest Fisheries Science Center. Each longline set consists 100 hooks except for 4 sets with 104 hooks.

| Year | Number of sets <br> prior to filtering | Number of sets <br> after filtering | Number of <br> common thresher <br> sharks | Soak time (h) <br> Mean $\pm$ SD |
| :--- | :--- | :--- | :---: | :---: |
| 2006 | 50 | 45 | 253 | $2.3 \pm 0.5$ |
| 2007 | 49 | 44 | 113 | $2.3 \pm 0.4$ |
| 2008 | 48 | 41 | 282 | $2.2 \pm 0.5$ |
| 2009 | 50 | 47 | 213 | $2.3 \pm 0.4$ |
| 2010 | 48 | 43 | 263 | $2.1 \pm 0.5$ |
| 2011 | 47 | 46 | 412 | $2.1 \pm 0.6$ |
| 2012 | 50 | 45 | 268 | $2.3 \pm 0.4$ |
| 2013 | 49 | 47 | 285 | $2.4 \pm 0.4$ |
| 2014 | 49 | 47 | 147 | $2.2 \pm 0.3$ |

Appendix Table C.2. Deviance analysis of explanatory variables in delta-lognormal models for common thresher shark catch rates of USA juvenile thresher survey for 2006-2014.

| Model <br> factors | Df | Deviance | Residual Df | Residual <br> Deviance | Pr(>Chi) |
| :--- | ---: | ---: | ---: | ---: | ---: |
| Binomial: |  |  |  |  |  |
| AIC = 464.0 |  |  | 404 | 521.95 |  |
| Null | 11 | 43.41 | 396 | 478.54 | $7.35 \mathrm{E}-07$ |
| Year | 1 | 6.11 | 385 | 428.43 | $5.98 \mathrm{E}-07$ |
| Area |  |  | 384 | 421.99 | 0.0111 |
| First 3 sets in |  |  |  |  |  |
| an area block |  |  |  |  |  |
|  |  |  |  |  |  |
| Lognormal: |  |  |  | 275 | 336.08 |
| AIC = 841.7 | 11 | 25.74 | 267 | 322.93 | 0.1737 |
| Null | 6.37 | 256 | 297.17 | 0.0202 |  |
| Year |  |  | 255 | 290.80 | 0.0181 |
| Area |  |  |  |  |  |
| Set in MPA |  |  |  |  |  |

Table C.3. Estimated relative abundance index values, standard errors (SEs), and coefficients of variation (CVs) for the USA juvenile thresher survey. The SEs and CVs were estimated with a jackknife procedure.

| Year | Index | $\mathbf{S E}$ | $\mathbf{C V}$ |
| :---: | :---: | :---: | :---: |
| 2006 | 3.20419 | 1.75810 | 0.54869 |
| 2007 | 1.70947 | 0.87744 | 0.51328 |
| 2008 | 3.64873 | 3.57938 | 0.46797 |
| 2009 | 5.43268 | 1.43589 | 0.47143 |
| 2010 | 8.82981 | 2.33678 | 0.43013 |
| 2011 | 4.87355 | 4.38673 | 0.49681 |
| 2012 | 5.18471 | 2.22676 | 0.45691 |
| 2013 | 1.73476 | 2.36088 | 0.45535 |
| 2014 |  | 0.90736 | 0.52305 |



Appendix Figure C.1. Locations of 440 sets and 12 sampling areas of the U.S. juvenile thresher shark survey from 2006 through 2014. Areas where fishing was prohibited after 2012 (i.e., MPAs) are shown in red.


Appendix Figure C.2. Proportion of sets with zero thresher shark catch (upper), nominal catch-per-unit-effort (CPUE) of sets with positive thresher catch (middle), and overall nominal CPUE (lower) for common thresher sharks caught by the USA juvenile thresher survey.


Appendix Figure C.3. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 2006 - 2014 common thresher shark abundance index for the USA juvenile thresher survey.


Appendix Figure C.4. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 2006-2014 common thresher shark abundance index for the USA juvenile thresher survey.


Appendix Figure C.5. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USA juvenile thresher survey. Indices are plotted relative to the value of the initial year.


Appendix Figure C.6. Standardized abundance indices of the USA juvenile thresher survey. Dashed lines indicate $95 \%$ confidence intervals derived from jackknifing the data set.

# APPENDIX D: Common thresher shark assessment model files 

## Starter file

\#V3.24U<br>\#C 2015 thresher shark assessment<br>2015_THR_dat.txt<br>2015_THR_ctl.txt<br>0 \# $0=$ use init values in control file; $1=$ use ss3.par<br>1 \# run display detail $(0,1,2)$<br>1 \# detailed age-structured reports in REPORT.SSO $(0,1)$<br>0 \# write detailed info from first call to echoinput.sso $(0,1)$<br>0 \# write parm values to ParmTrace.sso ( $0=$ no,1=good,active; 2=good,all; 3=every_iter,all_parms; 4=every,active)<br>1 \# write to cumreport.sso ( $0=$ no,1=like\&timeseries; 2=add survey fits)<br>0 \# Include prior_like for non-estimated parameters $(0,1)$<br>1 \# Use Soft Boundaries to aid convergence $(0,1)$ (recommended)<br>1 \# Number of datafiles to produce: 1st is input, 2nd is estimates, 3rd and higher are bootstrap<br>10 \# Turn off estimation for parameters entering after this phase<br>10 \# MCeval burn interval<br>2 \# MCeval thin interval<br>0 \# jitter initial parm value by this fraction<br>1967 \# min yr for sdreport outputs (-1 for styr)<br>2014 \# max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs<br>0 \# N individual STD years<br>\#vector of year values<br>0.0001 \# final convergence criteria (e.g. $1.0 \mathrm{e}-04$ )<br>0 \# retrospective year relative to end year (e.g. -4)<br>1 \# min age for calc of summary biomass<br>1 \# Depletion basis: denom is: $0=$ skip; $1=$ rel X*B0; $2=$ rel X*Bmsy; $3=$ rel X*B_styr<br>1 \# Fraction (X) for Depletion denominator (e.g. 0.4)<br>4 \# SPR_report_basis: $0=$ skip; $1=(1-S P R) /\left(1-S P R \_t g t\right) ; 2=(1-S P R) /\left(1-S P R \_M S Y\right) ; 3=(1-S P R) /\left(1-S P R \_B t a r g e t\right) ; 4=r a w S P R$<br>1 \# F_report_units: $0=$ skip; $1=$ exploitation(Bio); 2=exploitation(Num); 3=sum(Frates); 4=true F for range of ages<br>\#COND 10 15 \#_min and max age over which average F will be calculated with F_reporting=4<br>2 \# F_report_basis: 0=raw; 1=F/Fspr; 2=F/Fmsy ; 3=F/Fbtgt<br>999 \# check value for end of file

## Forecast file

\#V3.24U
\#C 2015 thresher shark assessment
\# for all year entries except rebuilder; enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
1 \# Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2 \# MSY: $1=$ set to $\mathrm{F}(\mathrm{SPR}) ; 2=$ calc $\mathrm{F}(\mathrm{MSY}) ; 3=$ set to $\mathrm{F}(\mathrm{Btgt}) ; 4=$ set to F (endyr)
0.5 \# SPR target (e.g. 0.40)
0.5 \# Biomass target (e.g. 0.40)
\#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF (enter actual year, or values of 0 or -integer to be rel. endyr)
-40-40-40
\# 201020142010201420102014 \# after processing
1 \#Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast below
\#
0 \# Forecast: $0=$ none; $1=\mathrm{F}(\mathrm{SPR}) ; 2=\mathrm{F}(\mathrm{MSY}) 3=\mathrm{F}$ (Btgt); $4=$ Ave F (uses first-last relF yrs); $5=$ input annual F scalar
0 \# N forecast years
0 \# F scalar (only used for Do_Forecast==5)
\#_Fcast_years: beg_selex, end_selex, beg_relF, end_relF (enter actual year, or values of 0 or -integer to be rel. endyr)
2010201420102014
\# 1180631114166759281576317131936290657 \# after processing
0 \# Control rule method ( $1=$ catch=f(SSB) west coast; 2=F=f(SSB) )
0 \# Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40); (Must be > the no F level below)
0 \# Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
0.75 \# Control rule target as fraction of Flimit (e.g. 0.75)

3 \#_N forecast loops (1=OFL only; 2=ABC; 3=get F from forecast ABC catch with allocations applied)
3 \#_First forecast loop with stochastic recruitment
0 \#_Forecast loop control \#3 (reserved for future bells\&whistles)
0 \#_Forecast loop control \#4 (reserved for future bells\&whistles)
0 \#_Forecast loop control \#5 (reserved for future bells\&whistles)
0 \#FirstYear for caps and allocations (should be after years with fixed inputs)
0 \# stddev of $\log$ (realized catch/target catch) in forecast (set value $>0.0$ to cause active impl_error)
0 \# Do West Coast gfish rebuilder output (0/1)
0 \# Rebuilder: first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
0 \# Rebuilder: year for current age structure (Yinit) ( -1 to set to endyear +1 )
1 \# fleet relative F : $1=$ use first-last alloc year; $2=$ read seas(row) x fleet(col) below
\# Note that fleet allocation is used directly as average F if Do_Forecast=4
0 \# basis for fcast catch tuning and for fcast catch caps and allocation (2=deadbio; 3=retainbio; 5=deadnum; 6=retainnum)
\# Conditional input if relative F choice $=2$
\# Fleet relative F: rows are seasons, columns are fleets
\#_Fleet: F1_US_DGN_9114 F2_US_DGN_8690 F3_US_DGN_6985 F4_US_SN_9114 F5_US_SN_6990 F6_US_OTH F7_US_REC
F8_MX_DGN F9_MX_LL F10_MX_ART
\# 0000000000
\# 0000000000
\# 0000000000
\# 0000000000
\# max totalcatch by fleet (-1 to have no max) must enter value for each fleet
\# max totalcatch by area (-1 to have no max); must enter value for each fleet
\# fleet assignment to allocation group (enter group ID\# for each fleet, 0 for not included in an alloc group)
\#_Conditional on >1 allocation group
\# allocation fraction for each of: 0 allocation groups
\# no allocation groups
0 \# Number of forecast catch levels to input (else calc catch from forecast F)
2 \# code means to read fleet/time specific basis (2=dead catch; $3=$ retained catch; 99=F) as below (units are from fleetunits; note new codes in
SSV3.20)
\# Input fixed catch values
\#Year Seas Fleet Catch(or_F) Basis
\#
999 \# verify end of input

## Data file

\#V3.24U
\#_SS-V3.24U-fast;_08/29/2014;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_11.2_Linux64_compiled_on_RHEL6.6
\#_Start_time: Mon Aug 31 11:55:19 2015
\#_Number_of_datafiles: 1
\#C 2015 thresher shark assessment

| \#C FleetID | FleetID2 | Description | Shortname | Comments |
| :--- | :--- | :--- | :--- | :--- |
| \#C 1 | F1 | US_DGN_fishery | USDGN | Incl_US_Misc_catch |
| \#C 2 | F2 | US_DGN_fishery_Seas2 | USDGNs2 | Incl_US_Misc_catch |
| \#C 3 | F3 | US_SN_fishery | USSN |  |
| \#C 4 | F4 | US_Rec_Fishery | USREC |  |
| \#C 5 | F5 | US_Rec_Fishery_Seas2 | USRECs2 |  |
| \#C 6 | F6 | MX_DGN_LL_Fishery | MXDGNLL |  |
| \#C 7 | F7 | MX_DGN_LL_Fishery_Seas2 | MXDGNLLs2 |  |
| \#C 8 | F8 | MX_Artisanal_Fishery | MXART |  |
| \#C 9 | S1 | US_DGN_Index_1_(1982-1984) | USDGN8284 |  |
| \#C 10 | S2 | US_DGN_Index_2_(1992-2000) | USDGN9200 |  |
| \#C 11 | S3 | US_DGN_Index_3_(2001-2013) | USDGN0113 |  |
| \#C 12 | S4 | US_SN_Index_1_(1985-1993) | USSN8593 |  |
| \#C 13 | S5 | US_SN_Index_2_(1994-2014) | USSN9414 |  |
| \#C 14 | S6 | US_Juvy_Thr_Survey_(2006-2014) | USJUV0614 |  |

\#_observed data:
1969 \#_styr
2014 \#_endyr
4 \#_nseas
333 \#_months/season
2 \#_spawn_seas
8 \#_Nfleet
6 \#_Nsurveys
1 \#_N_areas
F1\%F2\%F3\%F4\%F5\%F6\%F7\%F8\%S1\%S2\%S3\%S4\%S5\%S6
$0.50 .50 .50 .50 .50 .50 .50 .50 .50 .50 .50 .50 .50 .5 \#$ _surveytiming_in_season
11111111111111 \#_area_assignments_for_each_fishery_and_survey
11122111 \#_units of catch: 1=bio; 2=num
0.10 .10 .10 .10 .10 .10 .10 .1 \#_se of log(catch) only used for init_eq_catch and for Fmethod 2 and 3; use -1 for discard only fleets

2 \#_Ngenders
25 \#_Nages
94.08001 .1600023 .26 \#_init_equil_catch_for_each_fishery

184 \#_N_lines_of_catch_to_read
\#_catch_biomass(mtons):_columns_are_fisheries,year,season
13.57500 .1450 .1470004 .02619691
017.4350 .69800 .564004 .74519692
34.85300 .6380 .140006 .58619693
35.95300 .3410 .3150005 .55419694
11.46300 .2770 .1510004 .02619701
032.2731 .29600 .56004 .74519702
43.6200 .7020 .1350006 .58619703
31.90500 .5580 .3150005 .55419704
0000.1470004 .02619711
039.7731 .72300 .56004 .74519712
21.39600 .6810 .1340006 .58619713
0000.3150005 .55419714
21.69800 .2220 .1470004 .02619721
020.4231 .56300 .565004 .74519722
49.54700 .6740 .1340006 .58619723
28.075000 .3150005 .55419724
0000.1480004 .02619731
070.7780 .84400 .561004 .74519732
42.04100 .3420 .1360006 .58619733
0000.3160005 .55419734
35.52700 .4250 .1490004 .02619741
023.3710 .88500 .567004 .74519742
63.53700 .5010 .1430006 .58619743
21.80300 .6660 .3190005 .55419744
36.93600 .4160 .1470004 .02619751
097.1932 .72500 .565004 .74519752
76.64700 .8910 .1360006 .58619753
30.33301 .110 .3160005 .55419754
60.62900 .5870 .1480005 .76619761
0133.5123 .81400 .576006 .79519762
84.18301 .0250 .140009 .43319763
119.0702 .2670 .3160007 .42319764 75.88800 .8970 .1480003 .21719771 0166.9955 .77700 .56003 .79219772 90.79200 .8490 .1380005 .26319773
79.38501 .4090 .3160004 .57219774 30.78400 .9170 .1490003 .09419781 0254.09920 .18900 .564003 .64719782 221.23107 .8290 .140005 .06319783 70.82502 .9850 .3150004 .66719784 80.76703 .1670 .1470003 .79319791 0380.27428 .82800 .56004 .46919792 412.994013 .9880 .1340006 .20419793 251.45809 .5420 .3150006 .63119794 210.58902 .1020 .4090007 .40919801 0486.39612 .05700 .004008 .73219802 1057.19014 .4660 .00600012 .1219803 371.02207 .4850 .00100011 .47219804 247.71606 .8420 .0020009 .98819811 0747.88335 .04100 .0010011 .77219812 495.486021 .5250 .00200016 .34119813 98.94010 .6840 .11200016 .38919814 381.602017 .9040 .11100016 .26119821 0846.65793 .79600 .210019 .16419822 449.797023 .5160 .19500026 .60419823 131.608 .1841 .61500022 .70319824 1.3700 .7950 .20100014 .42819831 0835.47144 .00903 .0020017 .00419832 307.478015 .8790 .08600023 .60519833 129.29506 .5740 .19900019 .04419834 23.27502 .4050 .1740009 .47319841 0754.33294 .89700 .0030011 .16419842 267.82203 .8680 .43700015 .49719843 156.15501 .089000 .182011 .43819844 4.12100 .1610 .00103 .04202 .99719851 0890.69364 .83700 .19402 .733 .53319852 205.96300 .8270 .20802 .36604 .90419853 31.76300 .1160 .00201 .20205 .20719854 3.08700 .441 .361013 .14505 .75519861 0325.9197 .12600 .007011 .7976 .78319862 516.46500 .9160 .004010 .22409 .41519863 141.39900 .297004 .47308 .77219864 3.46400 .3260 .002044 .71307 .34119871 0285.02114 .36604 .055040 .1278 .65119872 183.8800 .5310 .788034 .777012 .00919873 115.67900 .1870 .00109 .251010 .9419874 7.55100 .3390052 .41608 .60519881 0134.5272 .52100 .877047 .0410 .14119882 252.10500 .7560 .009040 .768014 .07819883 172.91800 .111009 .318010 .7919884 4.76500 .540 .001035 .9303 .93219891 0114.3971 .85700 .015032 .2454 .63519892 93.7600 .2240 .801027 .94606 .43219893 236.77400 .4280 .005010 .21806 .47619894 4.16800 .3660 .007088 .67206 .46919901 0104.6461 .72500 .014079 .5777 .62519902 150.22101 .6960 .023068 .967010 .58519903 183.28500 .1430016 .48408 .26519904 2.08300 .3490072 .83303 .41619911 0147.6522 .14300065 .3644 .02619912 224.52100 .2260056 .64805 .58919913 83.36300 .0370018 .0105 .85319914 1.65700 .25600134 .55606 .31119921 0154.8581 .74000120 .7567 .43919922 98.02300 .41500104 .655010 .32419923 39.22900 .0320026 .93108 .25119924 5.60100 .83400142 .56903 .90119931 038.0350 .81100 .8690127 .9464 .59719932 126.07100 .2271 .3710110 .88706 .38219933
105.89801 .1230 .486027 .01705 .43919934 21.08304 .5550 .2250125 .69803 .4419941 063.5172 .18101 .720112 .8064 .05319942 121.69201 .5791 .655097 .76505 .62619943 137.77201 .0030022 .38804 .5819944 3.86501 .1621 .744086 .89702 .37719951 056.1752 .75800 .455077 .9842 .80219952 91.98201 .6060 .455067 .58703 .88919953 114.49204 .8190019 .38303 .75519954 1.44401 .72100125 .35903 .4319961 084.5224 .700 .6270112 .5024 .04219962 158.2302 .4970 .076097 .50205 .61119963 118.69601 .7340025 .55105 .05419964 10.40601 .14200140 .5403 .84519971 055.0416 .10400 .1260126 .1264 .53219972 124.86606 .2440 .1260109 .3106 .29119973 65.54101 .3350 .209029 .46805 .94619974 1.26601 .02800166 .75805 .1619981 084.7855 .93300 .4640148 .7856 .08119982 148.72903 .1240 .1280129 .03708 .44119983 121.26303 .120 .509029 .44406 .77919984 1.05200 .5010 .366092 .49903 .29319991 0110.79612 .9300 .258081 .9043 .88219992 109.95303 .5440 .414071 .09905 .38819993 83.16202 .5830021 .70405 .56119994 1.64301 .5070 .7020114 .58605 .83820001 0106.11821 .74900 .819098 .9026 .88120002 71.52303 .3690 .819086 .12409 .5520003 101.47304 .1030027 .04308 .65520004 2.63203 .21400103 .20606 .70220011 099.6614 .3700 .629086 .9787 .920012 125.40503 .321 .574075 .967010 .96620013 111.21606 .9020026 .68509 .52520014 12.88701 .6410099 .35406 .45320021 088.23718 .11400 .979083 .7337 .60520022 115.80701 .3360 .665073 .134010 .55720023 137.65201 .4440025 .44409 .10220024 11.41808 .6660 .167092 .48306 .00620031 072.9655 .35701 .722077 .9417 .07920032 49.83500 .790 .318068 .07609 .82720033 73.67501 .0270028 .21909 .73720034 1.29301 .66100145 .00609 .41820041 023.92412 .38200 .2850122 .20611 .120042 22.86701 .4340 .0330106 .736015 .40720043 39.68701 .1774 .202033 .746012 .33820044 2.27302 .770 .027090 .90405 .90420051 029.244 .5600 .124076 .6096 .95820052 36.92601 .4930 .142066 .91209 .65920053 116.7400 .3460 .014024 .03208 .53720054 3.87201 .010 .032094 .36606 .12820061 031.37212 .78600 .776079 .537 .22420062 55.86401 .5110 .135069 .462010 .02620063 50.21703 .0560025 .41808 .99320064 2.90902 .3960 .0090104 .07806 .7620071 024.9985 .01500 .627087 .7147 .96720072 63.90701 .6320 .862076 .611011 .05920073 98.20200 .6180 .036027 .83010 .08420074 5.99201 .1350 .0320105 .68807 .95720081 019.6655 .24300 .542087 .4799 .37820082 65.94702 .6690 .512076 .583013 .01820083 45.95103 .8180 .125026 .307011 .84620084 6.77502 .5250 .022025 .14609 .28920091 027.9115 .34500 .41010 .05510 .94820092 17.24202 .5040 .714010 .016015 .19720093 34.37402 .4520 .786019 .269013 .02420094 7.69405 .8130 .046022 .75608 .40620101 022.7697 .4700 .77609 .0999 .90820102 14.64501 .550 .29509 .063013 .75320103 32.59901 .640 .076017 .016011 .54720104 1.22901 .1921 .301018 .64106 .88720111

```
04.9395.006 0 0.74707.454 8.117 20112
7.02401.9380.34207.425011.266 20113
74.06801.3770.01015.288010.223 20114
3.33300.7130.0460 21.52607.952 20121
011.2212.27500.068 0 8.607 9.372 2012 2
10.19102.8070.24308.574013.01 20123
35.44401.5840.008017.207011.553 20124
1.21900.21600 22.779 0 8.415 2013 1
08.5291.65700.63409.108 9.91820132
4.18200.7590.1470 9.073013.767 2013 3
37.38200.550.023013.01209.282 20134
0.39300.8070.0020 20.98207.751 20141
019.2183.6170 0.29708.399.136 20142
3.09400.5290.19508.357012.6812014 3
9.41100.4120015.169010.35320144
#
64 #_N_cpue_and_surveyabundance_observations
#_Units: 0=numbers; 1=biomass; 2=F
#_Errtype:-1=normal; 0=lognormal; >0=T
#_Fleet Units Errtype
100 # F1
200 # F2
300 # F3
40 # F4
500 # F5
60 # F6
70 # F7
80 # F8
900 # S1
1000 # S2
1100 # S3
1200 # S4
1300 # S5
1400 # S6
#_year seas index obs err
    1982390.0122918 0.280355 # S1
1983 390.00920862 0.278143 # S1
1984 3 9 0.00763147 0.27842 # S1
1992 3 100.000466618 0.11681 # S2
19933100.000655651 0.112893 # S2
19943100.00107238 0.112887 # S2
1995 3 100.000760164 0.127392 # S2
1996 3100.000985173 0.12568 # S2
19973100.00111957 0.119943 # S2
19983 10 0.00213771 0.120471 # S2
19993 100.00126356 0.129961 # S2
2000 3 100.00190646 0.148804 # S2
20014110.0126904 0.197016 # S3
20024110.0063087 0.202422 # S3
2003411 0.00574843 0.211916 # S3
20044110.00517914 0.21691 # S3
2005411 0.0182973 0.20352 # S3
20064110.00686545 0.1991 # S3
20074110.0228914 0.196973 # S3
2008411 0.00684689 0.220957 # S3
2009411 0.00390685 0.225036 # S3
20104110.0174454 0.231113 # S3
20114110.0114837 0.230211 # S3
20124110.00711149 0.22832 # S3
20134110.0124422 0.19884 # S3
1985 2 120.071494 0.22246 # S4
1986 }2120.0507598 0.21999 # S
19872 120.0799821 0.23149 # S4
19882120.0626452 0.23024 # S4
19892120.0403903 0.23055 # S4
19902 120.070865 0.23839 # S4
19912 120.0510342 0.23477 # S4
19922120.0678798 0.24198 # S4
19932120.0831977 0.23061 # S4
```

19942130.2082710 .25464 \# S5
19952130.2026570 .232678 \# S5
19962130.294860 .219906 \# S5
19972130.4591130 .199639 \# S5
19982130.4991130 .207498 \# S5 19992130.5578040 .190297 \# S5 20002130.3320730 .203221 \# S5 20012130.6902430 .21287 \# S5 20022130.3892680 .225373 \# S5 20032130.2221970 .204888 \# S5 20042130.297345 0.2071 \# S5 20052130.2487220 .228862 \# S5 20062131.007520 .192267 \# S5 20072130.6900490 .204015 \# S5 20082130.3899850 .212196 \# S5 20092130.696590 .195183 \# S5 20102130.768759 0.198151 \# S5 20112130.514355 0.210665 \# S5 20122130.7285560 .197459 \# S5 20132130.2132410 .240291 \# S5 20142130.810052 0.4122 \# S5 20063143.20419 0.548688 \# S6 20073141.709470 .513279 \# S6 20083147.64873 0.46797 \# S6 20093143.04584 0.471428 \# S6 20103145.43268 0.430134 \# S6 20113148.829810 .496809 \# S6 20123144.873550 .456906 \# S6 20133145.18471 0.455354 \# S6 20143141.73476 0.523049 \# S6

0 \#_N_fleets_with_discard
\#_discard_units (1=same_as_catchunits(bio/num); 2=fraction; 3=numbers)
\#_discard_errtype: >0 for DF of T-dist(read CV below); 0 for normal with CV; -1 for normal with se; -2 for lognormal
\#Fleet Disc_units err_type
0 \#N discard obs
\#_year seas index obs err
\#
0 \#_N_meanbodywt_obs
30 \#_DF_for_meanbodywt_T-distribution_like
2 \# length bin method: 1=use databins; 2=generate from binwidth,min,max below; 3=read vector
1 \# binwidth for population size comp
40 \# minimum size in the population (lower edge of first bin and size at age 0.00)
310 \# maximum size in the population (lower edge of last bin)
-1 \#_comp_tail_compression
0.001 \#_add_to_comp

0 \#_combine males into females at or below this bin number
130 \#_N_LengthBins
404244464850525456586062646668707274767880828486889092949698100102104106108110112114116118120122 124126128130132134136138140142144146148150152154156158160162164166168170172174176178180182184186188 190192194196198200202204206208210212214216218220222224226228230232234236238240242244246248250252254 256258260262264266268270272274276278280282284286288290292294296298
58 \#_N_Length_obs
\#Yr Seas Flt/Svy Gender Part Nsamp datavector(female-male)
1990313070000000000000000000000000100000000000000000000000000030000000110001010 000000000000000000000000000000000000000000000000000000000000000000000000000000 000000000000000010100000000120000012110000000000000000000000000000000000000000 0000000000000000000000000000000000
1990413060000000000000000000000000000000000000000010000010001110012001231216242 021000000000000000000000000000000000000000000000000000000000000000000000000000 020000000000000000000000000000210117613221736131100101000000000000000000000000 0000000000000000000000000000000000
1991313060000000000000001000000100100001020010400104035952352300403416264002600 120320100000000000000000000000000000000000000000000000000000000000000000000002 000120100000221200213220296615232004000023242211123012021000000000000000000000 0000000000000000000000000000000000
1991413012000000000000000000000000000000000000000000000000110000020000220501002 000210000000000000000000000000000000000000000000000000000000000000000000000000

00000000000000000000000000000000000314001012002000001000100000000100000000 00000000000000000000000000000000
1992313011000000000000000000000000000000000000000000000000000000000000100000200 11001124000010002000000000100100000000000000000000000000000000000000000000 000000000000000000000000002100000000000002200040302002220202042406600020402244 2000202200000000000000000000000000
1992413010000000000000000000000000000000000000020000000000001000000000000000 0200020020010001200000000000000100000000000000000000000000000000000000000000 000000000000000000000000000000000001000000040000000300000000000000000000000 000000000000000000000000000000000
1993 313060000000000000000001000000000000000000000000000000000000000000000000 000000000050000000000000200000000000000000000000000000000000000000000000000 00000000000000000000000000000000000010000100000130000300000100000000000000 000000000000000000000000000000000
1993413016000000000000000000000000000000002030007020422624216109459555836133023 215030400002000010000000000000000000020000000000010000000000000000000000000 0000000000020020030000200602107331138103442104320230710104310200021000000000000 00000000000000000000000000000000000000
1994313020000000000000000000000000000000000010000002130421111140132231521211003 011000100110000000000000100000000000000000000000000000000000000000000000000000 000000000000000000000000201012223244214502321130401031110100000200000000000000 00000000000000000000000000000000000
19944130310000000000000000002020111121021113713366210416051658710746264161065986 400582323204010000010000010000000000000000000000000000000000000000000000000000 000101000021000034253653434454392424356833696656847846433434241062202000201000 00100000000000000000000000000000000000
1995313010000000000000000000000000000000000000000004120000140243002314322220411 132050000020000000000000002000000000000000000000000000000000000000000000000000 000000000000000000000000002221000533701233123222103400000110002000000100002000 00000000000000000000000000000000000
1995413011000000000000000000000000000000000000001010000000201012120010032002000 002000000000000000000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000001001100110400012000122000000000001000000030000000 00000000000000000000000000000000000
1996313014000000000000000000000000000000000012100111301032109530413255400442022 200000201020010000000000000000000000000000000000000000000000000000000000000000 000000000000000001000011011117323232111012543401210001000011001100000000000000 000000000000000000000000000000000000
1996413016000000000000000000000000000000000000000001002100002300424210881481686 26141414866140166012642020000000000000000000000000002000000000000000000000000000 0000000000000000000000000000000205110000023120382101820220201861010261610138420822 206404020202400221000000000002000000000000000000000
19973130360000000000000000000011000010000005123120403133223565386111212108387135 1567791214552660300000000000200000000000000000000000000000000000000000000000000 0000000001000000001010200010000130057285101392823113113573543200101000000000000 0000000000000000000000000000000000000000000
1997413021000000000000000000000000101100000100211001010020000032200201003601002 002341201022200003000001000000000000000000000000000000000000000000000000000000 000000000010000121120111020110101223112023202433100102250020200000000000000000 00020020000000000000000000000000000
1998313021000000000000000000050300060000300055360576332570577210123514510171317420 6971613820521241202000000000000000000000000000000000000000000000000000000000000 00000000033032000000603030630320303434062525331071317309218571123138002110060000 0000000003000000000000000000000000000000000000
19984130300000000000000000000000000000000000000002000220212204003114032102101120 204301131200100002020000000000000000000000000000000000000000000000000000000000 0000000000000000000000002000002424011070852412310381360012202000222000000000000 0040020000000000000000000000000000000
1999313080000000000000000000000000000000000000000000000000000000000000001000200 004000003000000000000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000003000000083000000000000200402000010000000200000000 0000000000000000000000000000000000
19994130320000000000000000000000000023000000000002202230083157614158818221105923 001080100001000000000000000000000000000000000000000000000000000000000000000000 00000000000000000000000000010205522531171083165141061000300320000001000000000000 00000000000000000000000000000000000000000
2000313080000000000000000000000000000000000000000000000000000000000101010300000 000003000000000010000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000000001000213021100000000000000000000000300 0000000000000000000000000000000000

2000413032000000000000000000000000200000000010000000496111118512111314161016181710 1918164216463125072030400000000000000000000000000000000000000000000000000000000 0000000000000000004000000000000030021207156172212142012252722184122165744401683034 3000000000000010100100000000000000000000000000000000000
2001313017000000000000000000000000000000000000000000010005200802100451027720015 300007032000000000002000000000000000000001000000000000000000000000000000000000 000000000000000000000000000003030030100400151030100000000000000000000000000000 00000000000000000000000000000000000
200141302300000000000000000000000020244440024221041046109448712491255741465836018 080516233100007000000020000000000000000000000000000000000000000000000000000000 00000000000020452200006825121012268642119571391031167778774222200323000200022000 000000000000000000000000000000000000000000000
2002313013000000000000000000000000000000000000000000000000103100024050060000100 030001000001000000000000020000000000000000000000000000000000000000000000000000 000000000000000000000000000000001010000100201000000030003033003304003000006000 00000000000000000000000000000000000
2002413019000000000000000000000000000030001003001608242546364393621200075162012 240102200000000100000000000000000000000000000000000000000000000000000000000000 000000000001000000002130044604823481602100116041031010120000000000000000001000 000000000000000000000000000000000000
2003313050000000000000000000000000000000000000000000010000000000000001011005000 001000000400000000100000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000000000100010000101010000000000000000000000 0000000000000000000000000000000000
200341302600000000000000000000000020020002000402207240064163296212071371225122960 787220655420000021000000000020000000000000000000000000000000000000000000000000 00000000002002000670200280200226601346191313024815027722125007000143000000000000 000000000000000000000000000000000000000000
2004313060000000000000000000000000003000000300003300030000000000000000000200003 030001000000000000000000000000000000000000000000000000000000000000000000000000 003000000000000000030000400001000000000000000000000200000000000000000000000000 0000000000000000000000000000000000
2004413023000000000000000000000000000000000000201000000002000055150033031341100 402361210010000000000000000000010000000000000000000000000000000000000000000000 000000000011000000040000000000021030000165221550613044120101002000000000000000 00000000000000000000000000000000000
200531308000000000000000000000000000010000000000030100323003960221053106138379104 098122240000000020200000000000000000000000000000000000000000000000000000000000 00000000000000000000000000000000032058110317314271410610520244220200000000000000 0000000000000000000000000000000000000000000
200541302900000000000000000020000000000000002000201111100150224952232261025107610 15261015131106661104350100010000000000300000000000000000000000000000000000000000 000000000000000000000000000000100223510120313267107371631251520468515120500404855 14000004010000034000000000000000000000000000000000000
2006313080000000000000000000000000000000000000000100001012221033046210848344451 710232110100000000000500000000000000000000000000000000000000000000000000000000 000000000000000001000000000100012010253543903530223200002000000000000000000000 0000000000000000000000000000000000
2006413018000000000000000000000000000000000000000000000010000000000113341101251 120200000005000000000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000010010131320100102210500000201000000005000000 00000000000000000000000000000000000
2007313050000000000000000000000000000000000000000000000000000000000980530050020 000300000000000000000000000000000000000000000000000000000000000000000000000000 000000000000000300000000000000000000030000030007020020000000000000000000000000 0000000000000000000000000000000000
2007413015000000000000000000000000000000000000000000000010012611451702200236614 331101111000200100000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000002000221210201421323223010302420000000000100000000 00000000000000000000000000000000000
2008313070000000000000000000221012001121200221031011025204352110224021201100302 231060002000020000000010010000000000000000000000000000000000000000000000000000 020013111001010020011221007111111113113020212020000001200002010000000000000000 0000000000000000000000000000000000
2008413080000000000000000000000000000000000000000000000000000000203000000000011 000000000000000000000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000000302000002300000100000000000000000000000 0000000000000000000000000000000000
2009413050000000000000000000000000000000000000000000000000000030000207000020000 000070000000000000000000000000000000000000000000000000000000000000000000000000

0000000000000000000000000000000000020100000000000000000000000000000000 0000000000000000000000000000000
201041306000000000000000000000000000000000000000190019020001911221957241012038238 422192120210001938190000000000020000000000000000000000000000000000000000000 000000000000000000001900000000000038000190191933191195719191901923802003819138019190 019000001900000000000000000000000000000000000000000000000
20114130140000000000000000000000000000000020000020200246031010595961569102506374 3013601402002100000000908030000033100005000300000000000500000000000000000000 000000000010000000000000000100370833314798517291240434378136000000000006000000 000000000005000005000000000000000000000
201241305000000000000000000000000000000000000000000000000200004112442200000410 000000034000000000000000000000000000000000000000000000000000000000000000000 00000000000000000000000000000000010041300022000050820024000000000000000000 00000000000000000000000000000000000
20134130180000000000020000000000000000000000000000000000000003000120210003527 39120501005000000000000000000300000000000000000000000000000000000000000000 0000020000000000000000000000000103000242217260052605200002830440000050420300 03000000000000000000000000000000000
1991223080000000000000000000000000001000103001000100102020001000010101102301000 000000000000100000000000000001000000000100000000000000000000000000000000000000 000100100001100020111013230000110001100202002000011000000000000000010000000 000000000000000000000000000000000
1992223070000000000000010000001011000000002210011113115233103422201101100110121 100021010000000000001000000200000000000000000000000000000000000000000000000 10001030001001302012000102140442001252201000110000101100000100000000000000010 00000000000000000000000000000000
2011-1800300000000001002110371417241815332413221981316912564565362150134211301010002 0000000000010000000000000000000000000000000000000000000000000000000000000000 00000000000000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000
20112-800300000000001002110371417241815332413221981316912564565362150134211301010002 0000000000010000000000000000000000000000000000000000000000000000000000000000 00000000000000000000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000000000
20113-800300000000001002110371417241815332413221981316912564565362150134211301010002 0000000000010000000000000000000000000000000000000000000000000000000000000000 00000000000000000000000000000000000000000000000000000000000000000000000000 00000000000000000000000000000000000000000
2011-4-80030000000000100211037141724181533241322198131691256456536215013421130101000 20000000000010000000000000000000000000000000000000000000000000000000000000 00000000000000000000000000000000000000000000000000000000000000000000000000000 00000000000000000000000000000000000000000
20063143029000000000100001137111068625010252303146742422011200000000000000000100 0000000000000000000000000000000000000000000000000000000000000000000000013 354813107823140112304353533322021201110000010000000000000000000000000000000000 00000000000000000000000000000000000
2007314302200000000000000200235243424324323311032001100101000010000000000000000 000000000000000000000000000000000000000000000000000000000000000000010000231 152284212121243111015312100011010000000000000000000000000000000000000000000 00000000000000000000000000000000000
2008314303900000000000010101243239626342264757342345234032110102000001000000000 0000000000000000000000000000000000000000000000000000000000000000000010010000 32735896420266446471068544552125501220010000000100000000000000000000000000000 00000000000000000000000000000000000
2009314303200000000000013213432203352322644421343230141301111201101100000000000 00000000000000000000000000000000000000000000000000000000000000000000000000001 2364643432305423566425213111102402001100000000010000000000000000000000000000 00000000000000000000000000000000000
20103143033000000000010000332437228012121327255433356512486714430220000100100000 00000000000000000000000000000000000000000000000000000000000000000000000000001 2063667110321375546424413374146322300202010000000000000000000000000000000000 000000000000000000000000000000000
201131430380000000000100010137912651031525128817121343310242654680206114201201100 0000000000000000000000000000000000000000000000000000000000000000000000000 002941381710625204663108863136445461545321001002200100000000000000000000000000 000000000000000000000000000000000000000
2012314303800000000000010316812894711223003263343436414104101012203100001000000 001000000000000000000000000000000000000000000000000000000000000000000001002 5771416102643131342222644234122102010210000100000000000000000000000000000000000 0000000000000000000000000000000000000

2013314303600000000000000013344485463110424528222112244271536361320010110000000 000000000000000000000000000000000000000000000000000000000000000010000000010000 211537743312234432301314634634435132413111200000000000000000000000000000000000 000000000000000000000000000000000000
2014314302300000000000000010013106101020000127115303222232222204040122011002000 000101000000000000000000000000000000000000000000000000000000000000000000000001 002120211011021001012223523325213121200001000000000000000000000000000000000000 000000000000000000000000000000000000

26 \#_N_age_bins
012345678910111213141516171819202122232425
2 \#_N_ageerror_definitions
-1 -1 -1 -1 -1 -1 -1 -1-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
0.0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .0010 .001 0.0010 .0010 .001
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
0.1756840 .1756840 .3513670 .5270510 .7027350 .8784181 .05411 .229791 .405471 .581151 .756841 .932522 .10822 .283892 .459572 .63525 2.810942 .986623 .162313 .337993 .513673 .689353 .865044 .040724 .21644 .39209

152 \#_N_Agecomp_obs
3 \#_Lbin_method: 1=poplenbins; 2=datalenbins; 3=lengths
1 \#_combine males into females at or below this bin number
\#Yr Seas Flt/Svy Gender Part Ageerr Lbin_lo Lbin_hi Nsamp datavector(female-male)
19902110210410510100000000000000000000000000000000000000000000000000 19902110212712810001000000000000000000000000000000000000000000000000 19902110214014110010000000000000000000000000000000000000000000000000 19922110223423510000000000001000000000000000000000000000000000000000 19924110219519610000000010000000000000000000000000000000000000000000 19934110225225310000000000000000000010000000000000000000000000000000 19943110219019110000001000000000000000000000000000000000000000000000 19943110219719810000000010000000000000000000000000000000000000000000 1995 3110219920010000001000000000000000000000000000000000000000000000 19953110223123210000000000000100000000000000000000000000000000000000 19964110215315410000100000000000000000000000000000000000000000000000 19964110215415510000100000000000000000000000000000000000000000000000 19964110215916010000001000000000000000000000000000000000000000000000 19964110216216310001000000000000000000000000000000000000000000000000 19964110216316410001000000000000000000000000000000000000000000000000 19964110216616710001000000000000000000000000000000000000000000000000 19964110216716810000001000000000000000000000000000000000000000000000 19964110217317410000001000000000000000000000000000000000000000000000 19964110218418510000001000000000000000000000000000000000000000000000 19964110218618720000002000000000000000000000000000000000000000000000 19964110219019110000000010000000000000000000000000000000000000000000 19964110219119210000010000000000000000000000000000000000000000000000 19964110219319410000000001000000000000000000000000000000000000000000 19964110219619720000000100100000000000000000000000000000000000000000 19964110219719810000001000000000000000000000000000000000000000000000 19964110219819910000000100000000000000000000000000000000000000000000 19963110214014110000100000000000000000000000000000000000000000000000 1996 3110214314410001000000000000000000000000000000000000000000000000 19963110214414510010000000000000000000000000000000000000000000000000 19963110214915010001000000000000000000000000000000000000000000000000 19963110215215310000100000000000000000000000000000000000000000000000 19963110215815910000001000000000000000000000000000000000000000000000 19963110215916010000100000000000000000000000000000000000000000000000 19963110216016110001000000000000000000000000000000000000000000000000 19963110216716810000100000000000000000000000000000000000000000000000 19963110216917010000100000000000000000000000000000000000000000000000 19963110217017110000100000000000000000000000000000000000000000000000 19963110217717810000100000000000000000000000000000000000000000000000 19963110217918010000001000000000000000000000000000000000000000000000 19963110219819910000001000000000000000000000000000000000000000000000 19974110214414510010000000000000000000000000000000000000000000000000 19974110216416510000100000000000000000000000000000000000000000000000 19974110217717810000001000000000000000000000000000000000000000000000 19974110219819910000000010000000000000000000000000000000000000000000 19974110222522610000000000000000010000000000000000000000000000000000 19973110212812910001000000000000000000000000000000000000000000000000 19973110213013110010000000000000000000000000000000000000000000000000 19973110213613710000100000000000000000000000000000000000000000000000

19973110213813910001000000000000000000000000000000000000000000000000 19973110213914010001000000000000000000000000000000000000000000000000 19973110214014130001200000000000000000000000000000000000000000000000 19973110214114210001000000000000000000000000000000000000000000000000 19973110214314430002100000000000000000000000000000000000000000000000 19973110214614730000300000000000000000000000000000000000000000000000 19973110214814910000010000000000000000000000000000000000000000000000 19973110214915010000010000000000000000000000000000000000000000000000 19973110215015110001000000000000000000000000000000000000000000000000 19973110215115210000100000000000000000000000000000000000000000000000 19973110215315430000003000000000000000000000000000000000000000000000 19973110215415510000010000000000000000000000000000000000000000000000 19973110215515610000100000000000000000000000000000000000000000000000 19973110215715830000101100000000000000000000000000000000000000000000 19973110215815920000200000000000000000000000000000000000000000000000 19973110215916020000020000000000000000000000000000000000000000000000 19973110216216310001000000000000000000000000000000000000000000000000 19973110216516620000002000000000000000000000000000000000000000000000 19973110216616750000014000000000000000000000000000000000000000000000 19973110217017130000001200000000000000000000000000000000000000000000 19973110217117220000002000000000000000000000000000000000000000000000 19973110217517630000011100000000000000000000000000000000000000000000 19973110217617710000000100000000000000000000000000000000000000000000 19973110217717810000001000000000000000000000000000000000000000000000 19973110217817930000011100000000000000000000000000000000000000000000 19973110217918010000000100000000000000000000000000000000000000000000 19973110218118210000000100000000000000000000000000000000000000000000 19973110218418510000001000000000000000000000000000000000000000000000 19973110218618710000000100000000000000000000000000000000000000000000 19973110219219310000000010000000000000000000000000000000000000000000 19973110219519610000000001000000000000000000000000000000000000000000 19973110219920010000000010000000000000000000000000000000000000000000 19973110222222310000000001000000000000000000000000000000000000000000 19984110220020110000000000100000000000000000000000000000000000000000 19983110216516610000010000000000000000000000000000000000000000000000 19983110217617710000001000000000000000000000000000000000000000000000 19983110217717810000010000000000000000000000000000000000000000000000 19983110218418510000000010000000000000000000000000000000000000000000 19983110218818910000001000000000000000000000000000000000000000000000 19983110218919010000000100000000000000000000000000000000000000000000 19983110219219310000000100000000000000000000000000000000000000000000 19922310213713810010000000000000000000000000000000000000000000000000 1990212029910010000000000000000000000000001000000000000000000000000 19902120212512610000000000000000000000000000100000000000000000000000 19902120213213310000000000000000000000000000100000000000000000000000 19902120213813910000000000000000000000000000100000000000000000000000 19943120220020110000000000000000000000000000000000000100000000000000 19953120222322410000000000000000000000000000000000000001000000000000 19964120215715810000000000000000000000000000000100000000000000000000 19964120215815910000000000000000000000000000001000000000000000000000 19964120215916010000000000000000000000000000000100000000000000000000 19964120216016110000000000000000000000000000010000000000000000000000 19964120216416510000000000000000000000000000001000000000000000000000 19964120216716810000000000000000000000000000000100000000000000000000 19964120216917010000000000000000000000000000000010000000000000000000 19964120217417510000000000000000000000000000000100000000000000000000 19964120217517610000000000000000000000000000000010000000000000000000 19964120217717810000000000000000000000000000000100000000000000000000 19964120217817910000000000000000000000000000000001000000000000000000 19964120217918010000000000000000000000000000000010000000000000000000 19964120218218310000000000000000000000000000000100000000000000000000 19964120218318410000000000000000000000000000000010000000000000000000 19964120218718810000000000000000000000000000000000100000000000000000 19964120219219310000000000000000000000000000000000000010000000000000 19964120220320410000000000000000000000000000000000010000000000000000 19964120220420510000000000000000000000000000000000010000000000000000 19964120222022110000000000000000000000000000000000000100000000000000 19964120222222310000000000000000000000000000000000000000100000000000 19964120225625710000000000000000000000000000001000000000000000000000 19963120213313410000000000000000000000000000100000000000000000000000

19963120213713810000000000000000000000000000001000000000000000000000 19963120214014110000000000000000000000000000001000000000000000000000 19963120215015110000000000000000000000000000001000000000000000000000 19963120215715810000000000000000000000000000010000000000000000000000 19963120216216310000000000000000000000000000001000000000000000000000 19963120216616710000000000000000000000000000000100000000000000000000 19974120215715810000000000000000000000000000001000000000000000000000 19974120218218310000000000000000000000000000000010000000000000000000 19974120219419510000000000000000000000000000000001000000000000000000 19973120213513620000000000000000000000000000110000000000000000000000 19973120213713810000000000000000000000000000010000000000000000000000 19973120214014120000000000000000000000000000011000000000000000000000 19973120214314410000000000000000000000000000010000000000000000000000 19973120214414520000000000000000000000000000110000000000000000000000 19973120214614710000000000000000000000000000001000000000000000000000 19973120214814910000000000000000000000000000010000000000000000000000 19973120214915010000000000000000000000000000001000000000000000000000 19973120215115210000000000000000000000000000000100000000000000000000 19973120215215320000000000000000000000000000010100000000000000000000 19973120215315410000000000000000000000000000001000000000000000000000 19973120216116210000000000000000000000000000001000000000000000000000 19973120216316420000000000000000000000000000001100000000000000000000 19973120216416510000000000000000000000000000000100000000000000000000 19973120216716810000000000000000000000000000000100000000000000000000 19973120216917020000000000000000000000000000000200000000000000000000 19973120217317410000000000000000000000000000001000000000000000000000 19973120218518610000000000000000000000000000000001000000000000000000 19984120215615710000000000000000000000000000001000000000000000000000 19984120223123210000000000000000000000000000000000000000001000000000 19983120216116210000000000000000000000000000000010000000000000000000 19983120217817910000000000000000000000000000000001000000000000000000 19983120218018110000000000000000000000000000000010000000000000000000 1998 3120218218310000000000000000000000000000000010000000000000000000 19983120222622710000000000000000000000000000000000000000010000000000

0 \#_N_MeanSize-at-Age_obs
\#Yr Seas Flt/Svy Gender Part Ageerr Ignore datavector(female-male) \# samplesize(female-male)

0 \#_N_environ_variables
0 \#_N_environ_obs
3 \# N sizefreq methods to read
3810431 \#Sizefreq N bins per method
222 \#Sizetfreq units(bio/num) per method
333 \#Sizefreq scale(kg/lbs/cm/inches) per method
0.0010 .0010 .001 \#Sizefreq mincomp per method

33137 \#Sizefreq N obs per method
\#_Sizefreq bins
404754616875828996103110117124131138145152159166173180187194201208215222229236243250257264271278285 292299
40949698100102104106108110112114116118120122124126128130132134136138140142144146148150152154156158 160162164166168170172174176178180182184186188190192194196198200202204206208210212214216218220222224 226228230232234236238240242244246248250252254256258260262264266268270272274276278280282284286288290 292294296298
4096103110117124131138145152159166173180187194201208215222229236243250257264271278285292299
\#_Year season Fleet Gender Partition SampleSize <data>
119811100600000000001135192426412319189563020111000000000000000000000000000000000 000000000000
11981310022000043310114333156681163142121100000000000000000000000000000000000000 000000000
1198141009000000000010222211000011210100000000000000000000000000000000000000000 0000000
1198211001300000001242761720252528291615112100000000000000000000000000000000000000 00000000000000
1198231001240000118698143645485344456353454745382421231264100000000000000000000000000 00000000000000000000
11982410017000001001013788169109464110100000000000000000000000000000000000000000 000000000
11983310048011201268121226294547384428161371424420000000000000000000000000000000000 000000000000000

11983410065001415232012554311218242322151444220010101000000000000000000000000000000 000000000000000
119843100490000000000181019192425211155554120000000001000000000000000000000000000 0000000000000
119844100450000001205588131416201210313012110000000000000000000000000000000000000 000000000000
11985310036000000264531013613546311011120000000000000000000000000000000000000000 0000000000
1198541001500001310112164411000200100000000000000000000000000000000000000000000 00000000
11986310053001177323187115106783372010121100000000000000000000000000000000000000 000000000
11986410037000031211192220323439393535261183302000100000000000000000000000000000000 00000000000000000
11987310040000001012243121091488834523511100000000000000000000000000000000000000 0000000000
119874100180000246813283131188452123011010000000000000000000000000000000000000000 00000000000
1198831008500129398128122829342719251876411001001000000000000000000000000000000000 00000000000000
11988410060000020542120152529302734513330131322101010000000000000000000000000000000 00000000000000000
11989310049002313304776162296136565201110110100000000000000000000000000000000000 00000000000
119894100550003174155486069727075323734231414113401000000000000000000000000000000000 0000000000000000000
11990310013000178365871214697110000100000000000000000000000000000000000000000000 000000000
119812200270015348824293840574546616873895141241091177560500000000000000000000000000 0000000000000000000
1198222002100001273382615121812817151710814597108420000000000000000000000000000000 000000000000000
119832200650104535141116314156787610210297694031312416251018611570200000000000000000000 00000000000000000000000
119842200520019172019153250796173858177735954322914222716169156153000000000000000000000 00000000000000000000000
119852200750031715425555052445056676866533529211814242320151059452110000000000000000000 00000000000000000000000
119862200520026166122526192817191510846777817131392157211101000000000000000000000000 00000000000000000
119872200390000008183829294429181785621491726272019116632000000000000000000000000000 00000000000000000
119882200230001102526217101313765446246977933410001000000000000000000000000000000 000000000000
1198922009000000210151828263020151712513102201000000010000000000000000000000000000 0000000000000
12007160030000001034212404550505552494245192722855401000000000000000000000000000000 0000000000000000
120073600200000000000001210202528292717146121000000000000000000000000000000000000 0000000000000
12008160030001346101791837741009368604920121840143000010000000000000000000000000000 00000000000000000
2199033308511020000000001000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000003100113000010000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000
2199123301813000001000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000019001000000000000000000000010000000000000 0000000000000000000000000000000000000000000000000000000000000000
2199133309800000100000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000005100000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000
2199223301520000010000000002200000100100000000000000000000000000000000000000000 000000000000000000000000000000000000012000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
2199233301423000100001000002000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000013000001001100000000100100000000000000000 0000000000000000000000000000000000000000000000000000000000000000
2199313301741122100000000001000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000402001010011012000000000000000000000000000 00000000000000000000000000000000000000000000000000000000000000

2199323302014010000110000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000012000010000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
2199333301690000211211010000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000601001101010000000000000010000000000000000 00000000000000000000000000000000000000000000000000000000000000
2199923305200000000000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000005000000000000000000000000000000000004000000 0000000000000000000000000000000000000000000000000000000000000
2199933306300000000000000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000008000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000
2201023301080001100000000000000000000010000000100000000100000000000000000000000 000000000000000000000000000000000000700000000000000000000000100000000000000000 00000000000000000000000000000000000000000000000000000000000000
2201133305100000000100000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000000100000000000010000000000000000000000000000 00000000000000000000000000000000000000000000000000000000000000
2201223307800000000011000000000000000000000000000000000000000000000000000000000 000000000000000000000000000000000008000000000000000000000000000000000100000000 0000000000000000000000000000000000000000000000000000000000000
3198433006100100000000000000000000000000000000000000000000000000000000000
31986230013214100000000000000000000000000000000000000000000000000000000000
319863300581110100000000000000000000000000000000000000000000000000000000
3198723009253301000010000000000000000000000000000000000000000000000000000
3198733005110000000000000000000000000000000000000000000000000000000000000
3198823006202132010002001000200000000000000000000000000000000000000000000
319892300155117886511000000000100000000000000000000000000000000000000000000
0 \# do tags (0/1)
0 \# no morphcomp data
999
ENDDATA

## Control file

\#V3.24U
\#C 2015 thresher shark assessment
\#_data_and_control_files: 2015_THR_dat.txt // 2015_THR_ctl.txt
\#_SS-V3.24U-fast;_08/29/2014;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_11.2_Linux64_compiled_on_RHEL6.6
1 \#_N_Growth_Patterns
1 \#_N_Morphs_Within_GrowthPattern
\#_Cond 1 \#_Morph_between/within_stdev_ratio (no read if N_morphs=1)
\#_Cond 1 \#vector_Morphdist_(-1_in_first_val_gives_normal_approx)
\#
1 \# number of recruitment assignments (overrides GP*area*seas parameter values)
0 \# recruitment interaction requested
\#GP seas area for each recruitment assignment
121
\#
\#_Cond 0 \# N_movement_definitions goes here if N_areas > 1
\#_Cond 1.0 \# first age that moves (real age at begin of season, not integer) also cond on do_migration>0
\#_Cond 1112410 \# example move definition for seas=1, morph=1, source=1 dest=2, age1=4, age2=10
\#
3 \#_Nblock_Patterns
531 \#_blocks_per_pattern
\# begin and end years of blocks
1982198419851988198919911992200020012014
198219841985198819892014
19942014
\#
0.5 \#_fracfemale

0 \#_natM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
\#_no additional input for selected M option; read 1P per morph
1 \# GrowthModel: 1=vonBert with L1\&L2; 2=Richards with L1\&L2; 3=age_speciific_K; 4=not implemented
0.125 \#_Growth_Age_for_L1

999 \#_Growth_Age_for_L2 (999 to use as Linf)
0 \#_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 \#_CV_Growth_Pattern: $0 \mathrm{CV}=\mathrm{f}(\mathrm{LAA}) ; 1 \mathrm{CV}=\mathrm{F}(\mathrm{A}) ; 2 \mathrm{SD}=\mathrm{F}(\mathrm{LAA}) ; 3 \mathrm{SD}=\mathrm{F}(\mathrm{A}) ; 4 \log \mathrm{SD}=\mathrm{F}(\mathrm{A})$
3 \#_maturity_option: 1=length logistic; 2=age logistic; 3=read age-maturity by GP; 4=read age-fecundity by GP; 5=read fec and wt from
wtatage.ss; 6=read length-maturity by GP
\#_Age_Maturity by growth pattern for females
000000.5111111111111111111111

5 \#_First_Mature_Age
2 \#_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b; (4)eggs=a+b*L; (5)eggs=a+b*W
0 \#_hermaphroditism option: $0=$ none; $1=$ age-specific fxn
2 \#_parameter_offset_approach ( $1=$ none, $2=\mathrm{M}, \mathrm{G}, \mathrm{CV}$ _G as offset from female-GP1, $3=$ like SS2 V1.x)
1 \#_env/block/dev_adjust_method (1=standard; 2=logistic transform keeps in base parm bounds; $3=$ standard w/ no bound check)
\#
\#_growth_parms
\#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
$0.050 .80 .1790 .179-199-10000000$ \# NatM_p_1_Fem_GP_1
3010071.2608 85.2-19950000000 \# L_at_Amin_Fem_GP_1
200300251.924 246.6-1 9950000000 \# L_at_Amax_Fem_GP_1
$00.20 .1286050 .124-19950000000$ \# VonBert_K_Fem_GP_1
0.001 0.30.08 0.1-199-50000000 \# CV_young_Fem_GP_1
$0.0010 .30 .050 .05-199-60000000$ \# CV_old_Fem_GP_1
0000.179-199-10000000 \# NatM_p_1_Mal_GP_1
-2 $20.0044329474-19950000000$ \# L_at_Amin_Mal_GP_1
-2 2-0.0118114 221.6-19950000000 \# L_at_Amax_Mal_GP_1
-2 2 -0.02332 0.189-19950000000 \# VonBert_K_Mal_GP_1
0000.1 -199-50000000 \# CV_young_Mal_GP_1
0000.05-199-60000000 \# CV_old_Mal_GP_1
$020.0001880 .000188-199-30000000$ \# Wtlen_1_Fem
142.5188 2.5188-199-30000000 \# Wtlen_2_Fem

```
1105 5-1 99-30000000 # Mat50%_Fem
-5 0-3 -3 -1 99-30000000 # Mat_slope_Fem
0543-199-30000000 # Eggs_scalar_Fem
-1300-199-30000000 # Eggs_exp_len_Fem
020.0001880.000188-199-30000000 # Wtlen_1_Mal
142.5188 2.5188-1 99-30000000 # Wtlen_2_Mal
-4400-199-30000000 # RecrDist_GP_1
-4 400-1 99-30000000 # RecrDist_Area_1
-4 4-4 -4 -1 99-30000000 # RecrDist_Seas_1
-4400-199-30000000 # RecrDist_Seas_2
-4 4 -4 -4 -1 99 -30000000 # RecrDist_Seas_3
-4 4-4 -4-1 99-30000000 # RecrDist_Seas_4
-4411 -1 99-30000000 # CohortGrowDev
#
#_Cond 0 #custom_MG-env_setup (0/1)
#_Cond -2 2 0 0-1 99-2 #_placeholder when no MG-environ parameters
#
#_Cond 0 #custom_MG-block_setup (0/1)
#_Cond -2 2 0 0-1 99-2 #_placeholder when no MG-block parameters
#_Cond No MG parm trends
#
#_seasonal_effects_on_biology_parms
0000000000 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_Cond -2 200-1 99-2 #_placeholder when no seasonal MG parameters
#
#_Cond -4 #_MGparm_Dev_Phase
#
#_Spawner-Recruitment
7 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=survival_3Parm; 8=Shepard_3Parm
#_LO HI INIT PRIOR PR_type SD PHASE
1154.34499 7-1 99 1 # SR_LN(R0)
01 0.6 0.5-1 99-7 # SR_surv_Sfrac
0.473.0592 5-1 99 1 # SR_surv_Beta
0 20.5 0.5-1 99-1 # SR_sigmaR
-5 5 0 0-1 99-1 # SR_envlink
-4 400 -999 99-1 # SR_R1_offset
0000-1 99-1 # SR_autocorr
0 #_SR_env_link
0 #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
1 #do_recdev: 0=none; 1=devvector; 2=simple deviations
1969 # first year of main recr_devs; early devs can preceed this era
2014 # last year of main recr_devs; forecast devs start in following year
1 #_recdev phase
1 # (0/1) to read 13 advanced options
0 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
-4 #_recdev_early_phase
0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
1 #_lambda for Fcast_recr_like occurring before endyr+1
1972.58 #_last_early_yr_nobias_adj_in_MPD
1980.7 #_first_yr_fullbias_adj_in_MPD
2012.08 #_last_yr_fullbias_adj_in_MPD
2018.25 #_first_recent_yr_nobias_adj_in_MPD
0.8192 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated recdevs)
0 #_period of cycles in recruitment (N parms read below)
-5 #min rec_dev
5 #max rec_dev
0 #_read_recdevs
#_end of advanced SR options
#
#_placeholder for full parameter lines for recruitment cycles
# read specified recr devs
```

```
#_Yr Input_value
#
# all recruitment deviations
#DisplayOnly 0.228566 # Main_RecrDev_1969
#DisplayOnly 0.273254 # Main_RecrDev_1970
#DisplayOnly 0.247473 # Main_RecrDev_1971
#DisplayOnly 0.123546 # Main_RecrDev_1972
#DisplayOnly -0.0136806 # Main_RecrDev_1973
#DisplayOnly -0.0771674 # Main_RecrDev_1974
#DisplayOnly -0.10308 # Main_RecrDev_1975
#DisplayOnly -0.200984 # Main_RecrDev_1976
#DisplayOnly -0.393457 # Main_RecrDev_1977
#DisplayOnly -0.476102 # Main_RecrDev_1978
#DisplayOnly -0.190753 # Main_RecrDev_1979
#DisplayOnly -0.255826 # Main_RecrDev_1980
#DisplayOnly -0.356712 # Main_RecrDev_1981
#DisplayOnly -0.380224 # Main_RecrDev_1982
#DisplayOnly 0.0529326 # Main_RecrDev_1983
#DisplayOnly -0.183046 # Main_RecrDev_1984
#DisplayOnly -0.0141641 # Main_RecrDev_1985
#DisplayOnly 0.00661811 # Main_RecrDev_1986
#DisplayOnly 0.0561474 # Main_RecrDev_1987
#DisplayOnly -0.15337 # Main_RecrDev_1988
#DisplayOnly -0.383337 # Main_RecrDev_1989
#DisplayOnly -0.184369 # Main_RecrDev_1990
#DisplayOnly -0.098193 # Main_RecrDev_1991
#DisplayOnly 0.226842 # Main_RecrDev_1992
#DisplayOnly 0.116272 # Main_RecrDev_1993
#DisplayOnly -0.215973 # Main_RecrDev_1994
#DisplayOnly -0.119692 # Main_RecrDev_1995
#DisplayOnly 0.235584 # Main_RecrDev_1996
#DisplayOnly 0.317426 # Main_RecrDev_1997
#DisplayOnly 0.256081 # Main_RecrDev_1998
#DisplayOnly 0.465279 # Main_RecrDev_1999
#DisplayOnly 0.0998961 # Main_RecrDev_2000
#DisplayOnly 0.730913 # Main_RecrDev_2001
#DisplayOnly 0.121975 # Main_RecrDev_2002
#DisplayOnly -0.505468 # Main_RecrDev_2003
#DisplayOnly -0.227223 # Main_RecrDev_2004
#DisplayOnly -0.47988 # Main_RecrDev_2005
#DisplayOnly 0.567074 # Main_RecrDev_2006
#DisplayOnly 0.355006 # Main_RecrDev_2007
#DisplayOnly 0.0090772 # Main_RecrDev_2008
#DisplayOnly 0.27824 # Main_RecrDev_2009
#DisplayOnly 0.336999 # Main_RecrDev_2010
#DisplayOnly -0.027596 # Main_RecrDev_2011
#DisplayOnly 0.38719 # Main_RecrDev_2012
#DisplayOnly -0.570802 # Main_RecrDev_2013
#DisplayOnly 0.118709 # Main_RecrDev_2014
#
#Fishing Mortality info
0.1 # F ballpark for annual F (=Z-M) for specified year
-2008 # F ballpark year (neg value to disable)
3 F F_Method: 1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
4 # max F or harvest rate, depends on F_Method
# no additional F input needed for Fmethod 1
# if Fmethod=2; read overall start F value; overall phase; N detailed inputs to read
# if Fmethod=3; read N iterations for tuning for Fmethod 3
5 # N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#_initial_F_parms
```

```
#_LO HI INIT PRIOR PR_type SD PHASE
0 30.0238448 0-1 99 1 # InitF_1F1
0100-1 99-1 # InitF_2F2
0100-1 99-1 # InitF_3F3
0 30.0222067 0-1 99 1 # InitF_4F4
0100-1 99-1 # InitF_5F5
0100-1 99-1 # InitF_6F6
0100-1 99-1 # InitF_7F7
0 30.0444701 0-1 99 1 # InitF_8F8
#
#_Q_setup
# Q_type options: <0=mirror, 0=float_nobiasadj, 1=float_biasadj, 2=parm_nobiasadj, 3=parm_w_random_dev, 4=parm_w_randwalk,
5=mean_unbiased_float_assign_to_parm
#_for_env-var:_enter_index_of_the_env-var_to_be_linked
#_Den-dep env-var extra_se Q_type
0000 # 1 F1
0000 # 2 F2
0000# 3 F3
0000 # 4 F4
0000 # 5 F5
0000# 6 F6
0000 # 7 F7
0000 # 8 F8
0000 # 9 S1
0000# 10 S2
0000# 11 S3
0000# 12 S4
0000# 13 S5
0000# 14 S6
#
#_Cond 0 #_If q has random component, then 0=read one parm for each fleet with random q; 1=read a parm for each year of index
#_Q_parms(if_any);Qunits_are_ln(q)
#
#_size_selex_types
#discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_discarded_dead
#_Pattern Discard Male Special
24000 # 1 F1
27004 # 2 F2
0000 # 3 F3
15001 # 4 F4
15002 # 5 F5
15001 # 6 F6
15002 # 7 F7
24000# 8 F8
15001# 9 S1
15001# 10 S2
15001# 11 S3
0000# 12 S4
0000 # 13 S5
24000# 14 S6
#
#_age_selex_types
#_Pattern ___ Male Special
11000# 1 F1
11000# 2 F2
14000# 3 F3
11000#4 F4
11000#5 F5
11000 # 6 F6
11000# 7 F7
11000 # 8 F8
```

```
11000 # 9 S1
11000 # 10 S2
11000 # 11 S3
1500 3 # 12 S4
15003 # 13 S5
11000 # 14 S6
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
45 250156.911 150-199 20000012 # SizeSel_1P_1_F1
-4 9 -4 1-1 99-40000000 # SizeSel_1P_2_F1
-4126.49387 3-199 30000012 # SizeSel_1P_3_F1
-49 8.07035 3-199 30000012 # SizeSel_1P_4_F1
-9 9-2.24779 0-19940000012 # SizeSel_1P_5_F1
-1000 -1000-1000 0-1 99-40000000 # SizeSel_1P_6_F1
020150-1 99-990000000 # SizeSpline_Code_F2_2
-110.0670299 1-19930000000 # SizeSpline_GradLo_F2_2
-1 1-0.0659269 3-199 30000000 # SizeSpline_GradHi_F2_2
45 25075 3-1 99 -990000000 # SizeSpline_Knot_1_F2_2
45 250125 3-1 99-990000000 # SizeSpline_Knot_2_F2_2
45 250175 3-1 99-990000000 # SizeSpline_Knot_3_F2_2
45 250225 3-1 99 -990000000 # SizeSpline_Knot_4_F2_2
-9 9 -3.13397 3-199 300000 22 # SizeSpline_Val_1_F2_2
-9 9-0.579033 3-199 300000 2 2 # SizeSpline_Val_2_F2_2
-9 90 3-199-30000000 # SizeSpline_Val_3_F2_2
-9 9-3.1004 3-199 3000002 2 # SizeSpline_Val_4_F2_2
45 25079.5632 80-199 20000000 # SizeSel_8P_1_F8
-4 9-4 0-1 99 -400 00000 # SizeSel_8P_2_F8
-494.13469 3-199 30000000 # SizeSel_8P_3_F8
-496.73305 3-19930000000 # SizeSel_8P_4_F8
-1000 -1000-1000 -1000-1 99-2 0000000 # SizeSel_8P_5_F8
-1000 -1000 -1000 -1000 -1 99-2 0 0 0 0 0 0 0 # SizeSel_8P_6_F8
4525084.7435 80-199 20000000 # SizeSel_14P_1_S6
-4 9-4 0-1 99-40000000 # SizeSel_14P_2_S6
-495.09989 3-199 30000000 # SizeSel_14P_3_S6
-497.77898 3-199 30000000 # SizeSel_14P_4_S6
-1000 -1000 -1000 -1000 -1 99-2 000000 0 # SizeSel_14P_5_S6
-1000 -1000 -1000 -1000-1 99-2 0000000 # SizeSel_14P_6_S6
0100.1 0.1-1 99-20000000 # AgeSel_1P_1_F1
103025 25-1 99-20000000 # AgeSel_1P_2_F1
0100.1 0.1-1 99-20000000 # AgeSel_2P_1_F2
103025 25-1 99-20000000 # AgeSel_2P_2_F2
-995.824640-19920000032 # AgeSel_3P_1_F3
-9 9 -3.62717 0-199 200000 32 # AgeSel_3P_2_F3
-9 9 -4.35722 0-199 200000 32 # AgeSel_3P_3_F3
-99 9 -990 -1 99-20000000 # AgeSel_3P_4_F3
-99 9 -99 0-1 99 -2 00000000 # AgeSel_3P_5_F3
-99 9-9900-1 99-20000000 # AgeSel_3P_6_F3
-99 9 -990 -1 99-20000000 # AgeSel_3P_7_F3
-99 9-9900-1 99-20000000 # AgeSel_3P_8_F3
-99 9 -99 0-1 99 -2 0000000 # AgeSel_3P_9_F3
-99 9 -990 -1 99-20000000 # AgeSel_3P_10_F3
-99 9-990 -1 99-20000000 # AgeSel_3P_11_F3
-99 9 -99 0-1 99-20 0000000 # AgeSel_3P_12_F3
-99 9 -990 -1 99-2 0000000 # AgeSel_3P_13_F3
-99 9-99 0-1 99-20000000 # AgeSel_3P_14_F3
-99 9 -99 0-1 99-20000000 # AgeSel_3P_15_F3
-99 9 -99 0-1 99 -2 00000000 # AgeSel_3P_16_F3
-99 9-9900-1 99-20000000 # AgeSel_3P_17_F3
-99 9-99 0-1 99-20000000 # AgeSel_3P_18_F3
-99 9-990 -1 99-20000000 # AgeSel_3P_19_F3
-99 9-99 0-1 99-20000000 # AgeSel_3P_20_F3
-99 9-990-1 99-20000000 # AgeSel_3P_21_F3
```

-99 9-990-199-2 0000000 \# AgeSel_3P_22_F3
-99 9-990-199-20000000 \# AgeSel_3P_23_F3
-99 9-990-1 99-2 0000000 \# AgeSel_3P_24_F3
-99 9-990-199-20000000\# AgeSel_3P_25_F3
-99 9-990-199-20000000\# AgeSel_3P_26_F3
0100.10 .1 -199-2 0000000 \# AgeSel_4P_1_F4
$10302525-199-20000000$ \# AgeSel_4P_2_F4 0100.10 .1 -1 99-2 0000000 \# AgeSel_5P_1_F5 $10302525-199-20000000$ \# AgeSel_5P_2_F5 0100.1 0.1-199-20000000 \# AgeSel_6P_1_F6 $10302525-199-20000000$ \# AgeSel_6P_2_F6 0100.10 .1 -1 99-2 0000000 \# AgeSel_7P_1_F7 103025 25-199-2 0000000 \# AgeSel_7P_2_F7 0100.10 .1 -1 99-2 0000000 \# AgeSel_8P_1_F8 $10302525-199-20000000$ \# AgeSel_8P_2_F8 0100.10 .1 -1 99-2 0000000 \# AgeSel_9P_1_S1 103025 25-199-20000000 \# AgeSel_9P_2_S1 0100.10 .1 -1 99-2 0000000 \# AgeSel_10P_1_S2 $10302525-199-20000000$ \# AgeSel_10P_2_S2 $0100.10 .1-199-20000000$ \# AgeSel_11P_1_S3 $10302525-199-20000000$ \# AgeSel_11P_2_S3 0100.10 .1 -1 99-2 0000000 \# AgeSel_14P_1_S6 10302525 -1 99-2 0000000 \# AgeSel_14P_2_S6 \#_Cond 0 \#_custom_sel-env_setup (0/1)
\#_Cond -2 2 0-1 99 -2 \#_placeholder when no enviro fxns 1 \#_custom_sel-blk_setup (0/1)
45250154.333 150-1 995 \# SizeSel_1P_1_F1_BLK1repl_1982
45250137.941 150-1 995 \# SizeSel_1P_1_F1_BLK1repl_1985 45250130.305 150-1 995 \# SizeSel_1P_1_F1_BLK1repl_1989 45250160.807 150-1 995 \# SizeSel_1P_1_F1_BLK1repl_1992 45250163.568 150-1 995 \# SizeSel_1P_1_F1_BLK1repl_2001 -4 126.36891 3-1 995 \# SizeSel_1P_3_F1_BLK1repl_1982 -4 12 6.61094 3-1 99 5 \# SizeSel_1P_3_F1_BLK1repl_1985 -4 126.57527 3-1 995 \# SizeSel_1P_3_F1_BLK1repl_1989 -4 12 6.58495 3-1 99 5 \# SizeSel_1P_3_F1_BLK1repl_1992 -4 126.7557 3-1 99 5 \# SizeSel_1P_3_F1_BLK1repl_2001 -9 97.437620 -1 996 \# SizeSel_1P_4_F1_BLK1repl_1982 -9 9 7.9974 0-1996 \# SizeSel_1P_4_F1_BLK1repl_1985 -9 97.88338 0-1 99 6 \# SizeSel_1P_4_F1_BLK1repl_1989 -9 97.52408 0-1 99 6 \# SizeSel_1P_4_F1_BLK1repl_1992 -9 97.27887 0-1 99 6 \# SizeSel_1P_4_F1_BLK1repl_2001 -9 9-2.42415 0-1 99 6 \# SizeSel_1P_5_F1_BLK1repl_1982 -9 9-1.47418 0-1 99 6 \# SizeSel_1P_5_F1_BLK1repl_1985 -9 9 0.235937 0-1 996 \# SizeSel_1P_5_F1_BLK1repl_1989 -9 9-4.05288 0-1 99 6 \# SizeSel_1P_5_F1_BLK1repl_1992 -9 9-3.86467 0-1 996 \# SizeSel_1P_5_F1_BLK1repl_2001 -9 9-3.26024 3-1 996 \# SizeSpline_Val_1_F2_2_BLK2repl_1982 -9 9-1.09079 3-1 99 6 \# SizeSpline_Val_1_F2_2_BLK2repl_1985 -9 9-1.71958 3-1 996 \# SizeSpline_Val_1_F2_2_BLK2repl_1989 -9 9-0.738698 3-1 99 6 \# SizeSpline_Val_2_F2_2_BLK2repl_1982 -9 90.101155 3-199 6 \# SizeSpline_Val_2_F2_2_BLK2repl_1985 -9 9 0.980473 3-1 996 \# SizeSpline_Val_2_F2_2_BLK2repl_1989 -9 9-1.93409 3-199 6 \# SizeSpline_Val_4_F2_2_BLK2repl_1982 -9 90.078129 3-1 99 6 \# SizeSpline_Val_4_F2_2_BLK2repl_1985 -9 9-1.28522 3-1 99 6 \# SizeSpline_Val_4_F2_2_BLK2repl_1989
-9 96.98104 0-1 99 6 \# AgeSel_3P_1_F3_BLK3repl_1994
-9 9-5.6965 0-1 996 \# AgeSel_3P_2_F3_BLK3repl_1994
-9 9-5.27026 0-1 996 \# AgeSel_3P_3_F3_BLK3repl_1994
\#_Cond No selex parm trends
\#_Cond -4 \# placeholder for selparm_Dev_Phase
1 \#_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep in base parm bounds; $3=$ standard w/ no bound check)

```
#
# Tag loss and Tag reporting parameters go next
0 # TG_custom: 0=no read; 1=read if tags exist
#_Cond -661120.01-40000000 #_placeholder if no parameters
#
1 #_Variance_adjustments_to_input_values
#_fleet: 1234567891011121314
    0000000000.266360.332445000 #_add_to_survey_CV
    00000000000000 #_add_to_discard_stddev
    00000000000000#_add_to_bodywt_CV
    11111111111111#_mult_by_lencomp_N
    11111111111111##_mult_by_agecomp_N
    11111111111111#_mult_by_size-at-age_N
#
10 #_maxlambdaphase
1 #_sd_offset
#
25 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes: 1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch; 9=init_equ_catch;
# 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp; 16=Tag-negbin; 17=F_ballpark
#like_comp fleet/survey phase value sizefreq_method
19110
110110
111110
12110
113110
114100
41110
42110
48110
414110
5110.20
5310.20
61111
62111
63112
63113
66101
91110
92100
93100
94110
95100
96100
97100
98110
#
# lambdas (for info only; columns are phases)
# 0000000000#_CPUE/survey:_1
# 0000000000#_CPUE/survey:_2
# 0000000000#_CPUE/survey:_3
# 0000000000 #_CPUE/survey:_4
# 0000000000#_CPUE/survey:_5
# 0000000000 #_CPUE/survey:_6
# 0000000000#_CPUE/survey:_7
# 0000000000#_CPUE/survey:_8
# 1111111111#_CPUE/survey:_9
# 1111111111 #_CPUE/survey:_10
# 1111111111#_CPUE/survey:_11
# 1111111111#__CPUE/survey:_12
# 1111111111#_CPUE/survey:_13
```

```
# 0000000000#_CPUE/survey:_14
# 1111111111##_lencomp:_1
# 1111111111##_lencomp:_2
# 0000000000##lencomp:_3
# 0000000000 #_lencomp:_4
# 0000000000##lencomp:_5
# 0000000000##_lencomp:_6
# 0000000000 #_lencomp:_7
# 1111111111 #_lencomp:_8
# 0000000000 #_lencomp:_9
# 0000000000#_lencomp:_10
# 0000000000 #_lencomp:_11
# 0000000000#_lencomp:_12
# 0000000000#_lencomp:_13
# 11111111111#_lencomp:_14
# 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 #_agecomp:_1
# 0000000000 #_agecomp:_2
# 0.20.20.20.20.2 0.2 0.2 0.2 0.2 0.2 #_agecomp:_3
# 0000000000 #_agecomp:_4
# 0000000000##_agecomp:_5
# 0000000000#_agecomp:_6
# 0000000000#_agecomp:_7
# 0000000000 #_agecomp:_8
# 0000000000 #_agecomp:_9
# 0000000000#_agecomp:_10
# 0000000000 #_agecomp:_11
# 0000000000 #_agecomp:_12
# 0000000000 #_agecomp:_13
# 0000000000 #_agecomp:_14
# 1111111111#_sizefreq:_1
# 11111111111#_sizefreq:_2
# 11111111111#_sizefreq:_3
# 11111111111#_sizefreq:_4
# 0000000000 #_sizefreq:_5
# 1111111111#_init_equ_catch
# 1111111111##recruitments
# 1111111111##_parameter-priors
# 1111111111 #_parameter-dev-vectors
# 1111111111 #_crashPenLambda
# 000000000000 # F_ballpark_lambda
0 # (0/1) read specs for more stddev reporting
# 0 1-15 15 1-15 # placeholder for selex type, len/age, year, N selex bins,Growth pattern, N growth ages, NatAge_area(-1 for all),
NatAge_yr, N Natages
# placeholder for vector of selex bins to be reported
# placeholder for vector of growth ages to be reported
# placeholder for vector of NatAges ages to be reported
999
```

