## DUSKY SHARK ASSESSMENT SUMMARY

The Summary Report provides a broad but concise view of the salient aspects of the stock assessment. It recapitulates: (a) the information available to and prepared by the Data Workshop; (b) the application of those data, development and execution of one or more assessment models, and identification of the most reliable model configuration as the base run by the Assessment Process (AP); and (c) the findings and advice determined during the Review Workshop.

### Stock Status and Determination Criteria

Assessment results indicated that the dusky shark stock was overfished (SSB2009/SSBMSY of 0.41 to 0.50) and therefore subject to rebuilding. Current F values over all sensitivities also indicated that the stock was subject to overfishing (*F*2009/*F*MSY of 1.39 to 4.35).

**Table 1.** Summary of stock status determination criteria.

| Criteria | Recommended Values* from SEDAR 21 | |
|---|---|---|
| | Definition | Value* |
| M (Instantaneous natural mortality; per year) | Value used for MSST calculations | 0.0666 |
| $F_{2009}$ (per year) | Apical Fishing mortality in 2009 | 0.055 |
| $F_{MSY}$ (per year) | $F_{MSY}$ | 0.035 |
| $SSB_{2009}/SSB_0$ | Relative Spawning stock biomass | 0.15 |
| $SSB_{MSY}$ (relative to virgin) | Relative $SSB_{MSY}$ | 0.35 |
| $SSB_{MSST}$ (relative to virgin biomass) | (1-M)*$SSB_{MSY}$ | 0.33 |
| MFMT (per year) | $F_{MSY}$ | 0.035 |
| $F_{OY}$ (per year) | $F_{OY}$ = 75% $F_{MSY}$ | 0.026 |
| Biomass Status | $SSB_{2009}$/MSST | 0.47 |
| Exploitation Status | $F_{2009}/F_{MSY}$ | 1.59 |

* Values presented are from the base model configuration but it is important to note that that the Review Panel recommended all runs in the addendum be considered equally plausible

### Stock Identification and Management Unit

After considering the available data, the Data Workshop Life History working group concluded that dusky sharks in the U.S. waters of the western North Atlantic Ocean (including the Gulf of Mexico) should be considered a single stock. Genetic data indicate no significant differentiation between the Gulf of Mexico and western North Atlantic Ocean and tag-recapture data showed a high frequency of movements between basins.

**Species Distribution**:

The dusky shark, Carcharhinus obscurus, is a common coastal and pelagic shark that inhabits warm temperate and tropical coastal waters of the western North Atlantic, ranging from southern New England to the Caribbean and Gulf of Mexico to southern Brazil. It avoids areas of lower salinity and is rarely found in estuarine environments.

**Stock Life History**

- As there are currently no natural mortality estimates for dusky shark available based on direct empirical data, the Data Workshop Life History Working Group was concluded that the range of survivorship estimates by age to be used for priors would be based on Peterson and Wroblewski and Lorenzen estimates without using the Lorenzen-Hoenig hybrid because the models for Lorenzen and Hoenig produced similar results.
- The values of M recommended by the Life History WG resulted in a negative population growth rate when used in a life table (where fishing mortality was set to zero). The Assessment Panel agreed that rather than taking the *average* of the Hoenig, Peterson and Wroblewski, Chen and Watanabe, and Lorenzen methods, the *maximum* of the four methods mentioned was used instead.
- The most recent information on the age and growth of dusky shark is a 1995 publication in the journal Fishery Bulletin and was recommended for use in the assessment. However, maximum observed age for females in that study was 33 years. Current data from through a single tag recapture indicates a maximum age of approximately 39 years.
- Data on reproduction suggested a 3-year reproductive cycle consisting of a 2-year gestation period and a 1-year resting period. Litter sizes ranged from 3–12 embryos.

**Assessment Methods**

- Without accurate knowledge of the magnitude of total catches and discards, it is not possible to estimate absolute abundance levels for the population. An alternative modeling methodology appropriate to these situations is to re-scale the model population dynamics as proportional to virgin (unexploited) conditions. This approach is known as an Age-structured Catch Free Model (ASCFM).
- The model started in 1960 and ended in 2009, with the historic period covering 1960-1974, the first modern period spanning 1975-1999, and the second modern period spanning 2000-2009.
- Estimated model parameters were pup (age-0) survival, catchability coefficients associated with indices, a parameter representing the slope of the relationship between PLL effort and fishing mortality for the period 1960-1979, additional variance parameters for each index, relative depletion in 1975, and fishing mortality in the modern periods.

- Fishing mortality starting in 1980 was modeled using a correlated random walk and so are not 'full' parameters. Pup survival was given an informative lognormal prior with median=0.81 (mean=0.85, mode=0.77), a CV of 0.3, and was bounded between 0.50 and 0.99.
- The minimum spawning stock threshold (MSST) is typically calculated as (1-M)*$SSB_{MSY}$ when absolute biomass is estimable. Although only relative estimates are possible here (i.e., $SSB_{2009}/SSB_{MSY}$), it is still possible to calculate $SSB_{2009}/SSB_{MSST}$ as $SSB_{2009}$/((1-M)*$SSB_{MSY}$).

**Assessment Data**

- Length-frequency information from animals caught in scientific observer programs, recreational fishery surveys, and various fishery-independent surveys were used to generate age-frequency distributions through age-length keys and generate selectivity curves for different gear types.
- Five indices were used in the base model run: two fishery-independent series (VIMS LL, NELL) and three fishery-dependent series (the commercial BLLOP and PLLOP observer indices and the recreational LPS). Two additional fishery- independent indices were recommended for use in sensitivity runs: UNC LL and NMFS Historical LL.
- Life history inputs used in the assessment include age and growth, several parameters associated with reproduction, including sex ratio, reproductive frequency, fecundity at age, maturity at age, month of pupping, and natural mortality. The ASCFM uses most life history characteristics as constants (inputs) and others are estimated parameters, which are given priors and initial values.
- Relative effort series for the three fleets (bottom longline, pelagic longline, and recreational) are used to determine a single, annual weighted selectivity vector for modeling fishing mortality

**Catch Trends**

Commercial and recreational dusky shark catch information was compiled by the Data Workshop (see Data Workshop Report) but was deemed highly uncertain, primarily due to misreporting and misidentification, and not used in the assessment.

**Fishing Mortality Trends**

Fishing mortality was low from 1960 through the early 1980s, and then is estimated to have ramped up to unsustainably high levels in the l990s, and to have declined following prohibition of dusky landing in 2000. The moratorium on dusky catch appears to have been an effective management tool in this regard, although terminal estimates of fishing mortality still indicate the stock is undergoing overfishing.

**Stock Abundance and Biomass Trends**

- Recruitment is predicted to have remained at roughly virgin levels until 1990, after which it declined slightly.
- Declines in spawning stock biomass are estimated to be partially compensated for by increases in pup survival (i.e., density dependent recruitment).
- All abundance trajectories show relatively little depletion until the late 1980s; by 2009 depletion in spawning stock biomass is estimated to be around 85%. The ASCFM predicted an increasing abundance (in numbers) from 2004-present, but a continued decrease in biomass. This apparent contradiction is attributable to decreasing number of older (and heavier) sharks even while the numbers of younger fish are increasing.

**Projections**

Projections were started in 2009 and run until the year 2108. All projections used 10,000 Monte Carlo bootstrap simulations with initial values pulled from a multivariate normal distribution. Moments of the bootstrap runs were summarized using quantiles, with median used for the central tendency, and 30$^{th}$ percentile used as the criterion for whether a projection had a 70% chance of rebuilding by 2108. Each projection was summarized with respect to landings (dressed weight and numbers), recruitment, and mature spawning stock biomass.

- The $F_{current}$ projection scenario used a modal apical F of 0.055, and indicated a low probability of stock recovery by 2108.
- The $F_0$ scenario resulted in recovery from overfished status near the year 2050.
- The $F_{msy}$ scenario utilized a modal F of 0.035, and indicated that the probability of the stock rebuilding to MSY levels was less than 50% .
- The $F_{target}$ scenario, which reduced F to 0.028 in an effort to ensure that the probability of overfishing in any given year (p*) was less than 30%, still did not provide a large enough reduction in F to recover the stock by 2108.
- Reducing F to 0.027 (as in the $F_{rebuild50}$ scenario) was enough result in a 50% chance of rebuilding the stock; however, F had to be reduced to 0.023 (as in the $F_{rebuild70}$ scenario) to achieve a 70% probability of rebuilding the stock by 2108. In practice, the $F_{max}$ scenario yielded identical results to the Frebuild70 scenario.
- While the Fixed Removals scenario suggested reducing annual removals to a preset level of 21,200 lbs. (gutted weight) per year would be sufficient to rebuild the stock with 70% probability by 2108, several of the runs resulted stock collapse (e.g., when terminal biomass and productivity were sampled from the lower tails of their distributions).

**Scientific Uncertainty**

- Likelihood profiling was used to quantify uncertainty in terminal stock status, terminal fishing mortality, and productivity parameters for the base run and for several sensitivity runs. This procedure could also be used to estimate the probability that the stock was overfished or that overfishing was occurring given a specific model configuration.

- Uncertainty in data inputs and model configuration was examined through the use of sensitivity scenarios and retrospective runs. Eleven alternative runs were conducted in addition to the baseline run. Retrospective analyses, in which the model was refit while sequentially dropping the last three years of data to look for systematic bias in key model output quantities over time, were also conducted.
- A total of seven additional sensitivity analyses were run during the Review Workshop to provide verification that the results of the assessment were robust to assumptions about underlying stock productivity, choice of selectivity curves, choice of indices, and index weighting. Time series plots were produced for runs considered by reviewers to have encapsulated uncertainty in assessment results (High M, U-shaped M, High productivity, and Low Productivity).
- The greatest source of uncertainty about dusky sharks is clearly the amount of human induced removals (e.g., discards) that are occurring. Improving the reliability of removal data would help assessment modeling immensely.
- Estimates of stock status seemed to be quite robust to changes in life history parameters such as productivity and natural mortality.
- Estimates of stock status seemed most sensitive to including different groups of indices or to different ways of weighting indices.

**Significant Assessment Modifications**

The Review Panel requested seven additional sensitivity runs but no significant changes to the base model configuration were required.

**Sources of Information**

All information was copied directly or generated from the information available in the final Stock Assessment Report for SEDAR 21: HMS Dusky shark.

**Table 2:** Life history inputs used in the assessment. All these quantities are treated as constants in the model. (*Table 2.4 of the Assessment Workshop Report*)

| Age | Proportion mature | M |
|---|---|---|
| 1 | 0.00 | 0.104 |
| 2 | 0.00 | 0.104 |
| 3 | 0.00 | 0.104 |
| 4 | 0.00 | 0.104 |
| 5 | 0.00 | 0.104 |
| 6 | 0.00 | 0.098 |
| 7 | 0.00 | 0.092 |
| 8 | 0.00 | 0.088 |
| 9 | 0.00 | 0.084 |
| 10 | 0.00 | 0.080 |
| 11 | 0.00 | 0.077 |
| 12 | 0.00 | 0.074 |
| 13 | 0.00 | 0.072 |
| 14 | 0.00 | 0.070 |
| 15 | 0.01 | 0.068 |
| 16 | 0.02 | 0.066 |
| 17 | 0.05 | 0.064 |
| 18 | 0.13 | 0.063 |
| 19 | 0.28 | 0.061 |
| 20 | 0.51 | 0.060 |
| 21 | 0.74 | 0.059 |
| 22 | 0.88 | 0.058 |
| 23 | 0.95 | 0.057 |
| 24 | 0.98 | 0.056 |
| 25 | 0.99 | 0.055 |
| 26 | 1.00 | 0.054 |
| 27 | 1.00 | 0.053 |
| 28 | 1.00 | 0.052 |
| 29 | 1.00 | 0.052 |
| 30 | 1.00 | 0.051 |
| 31 | 1.00 | 0.048 |
| 32 | 1.00 | 0.048 |
| 33 | 1.00 | 0.048 |
| 34 | 1.00 | 0.048 |
| 35 | 1.00 | 0.048 |
| 36 | 1.00 | 0.048 |
| 37 | 1.00 | 0.048 |
| 38 | 1.00 | 0.048 |
| 39 | 1.00 | 0.048 |
| 40 | 1.00 | 0.048 |

| | |
|---|---|
| Sex ratio at birth: | 1:1 |
| Reproductive frequency: | 3 yr |
| Pupping month: | June |
| Gestation period: | 12 months |
| Fecundity: | 7.13 pups |
| $L_{inf}$ | 350.3 cm FL |
| k | 0.039 |
| $t_0$ | -7.04 |
| Weight vs length relation: | $W=0.000032415L2^{.7862}$ |
| maturity ogive: | a=-19.76, b=0.99 |

**Table 3:** Apical instantaneous fishing mortality rates by year. (*Table 3.5 from the Assessment Workshop Report*)

| Year | Total F |
|---|---|
| 1960 | 0.003 |
| 1961 | 0.003 |
| 1962 | 0.006 |
| 1963 | 0.007 |
| 1964 | 0.010 |
| 1965 | 0.010 |
| 1966 | 0.007 |
| 1967 | 0.006 |
| 1968 | 0.007 |
| 1969 | 0.009 |
| 1970 | 0.010 |
| 1971 | 0.014 |
| 1972 | 0.014 |
| 1973 | 0.014 |
| 1974 | 0.014 |
| 1975 | 0.020 |
| 1976 | 0.019 |
| 1977 | 0.019 |
| 1978 | 0.016 |
| 1979 | 0.012 |
| 1980 | 0.014 |
| 1981 | 0.017 |
| 1982 | 0.022 |
| 1983 | 0.029 |
| 1984 | 0.038 |
| 1985 | 0.051 |
| 1986 | 0.068 |
| 1987 | 0.092 |
| 1988 | 0.121 |
| 1989 | 0.156 |
| 1990 | 0.188 |
| 1991 | 0.212 |
| 1992 | 0.225 |
| 1993 | 0.229 |
| 1994 | 0.232 |
| 1995 | 0.237 |
| 1996 | 0.254 |
| 1997 | 0.287 |
| 1998 | 0.335 |
| 1999 | 0.385 |
| 2000 | 0.385 |
| 2001 | 0.333 |
| 2002 | 0.249 |
| 2003 | 0.171 |
| 2004 | 0.116 |
| 2005 | 0.083 |
| 2006 | 0.064 |
| 2007 | 0.054 |
| 2008 | 0.049 |
| 2009 | 0.056 |

**Table 4:** Predicted relative recruitment (numbers), abundance (numbers), total biomass (kg), and spawning stock biomass (kg). All estimates are presented relative to virgin levels. (*Table 3.4 in Assessment Workshop Report*)

| Year | Rec | N | B | SSB |
|---|---|---|---|---|
| 1960 | 1 | 1 | 1 | 1 |
| 1961 | 0.999951 | 0.998682 | 0.99921 | 0.999533 |
| 1962 | 0.99984 | 0.99731 | 0.998315 | 0.998757 |
| 1963 | 0.999654 | 0.994484 | 0.996476 | 0.997603 |
| 1964 | 0.999377 | 0.991575 | 0.994436 | 0.996036 |
| 1965 | 0.999 | 0.987221 | 0.991381 | 0.994032 |
| 1966 | 0.998517 | 0.983065 | 0.988229 | 0.992083 |
| 1967 | 0.998045 | 0.980735 | 0.985988 | 0.990335 |
| 1968 | 0.997621 | 0.97913 | 0.984104 | 0.988484 |
| 1969 | 0.997171 | 0.977176 | 0.981979 | 0.986243 |
| 1970 | 0.996625 | 0.974156 | 0.979173 | 0.983564 |
| 1971 | 0.995969 | 0.970786 | 0.976056 | 0.980355 |
| 1972 | 0.995179 | 0.965986 | 0.971978 | 0.976593 |
| 1973 | 0.994249 | 0.961134 | 0.967683 | 0.972518 |
| 1974 | 0.993235 | 0.956628 | 0.963417 | 0.968183 |
| 1975 | 0.992149 | 0.952375 | 0.959156 | 0.96317 |
| 1976 | 0.990884 | 0.945623 | 0.953303 | 0.957519 |
| 1977 | 0.989446 | 0.939929 | 0.947826 | 0.951703 |
| 1978 | 0.987953 | 0.934718 | 0.942461 | 0.945862 |
| 1979 | 0.98644 | 0.931074 | 0.937885 | 0.940277 |
| 1980 | 0.98498 | 0.929087 | 0.934242 | 0.934502 |
| 1981 | 0.983456 | 0.926132 | 0.929824 | 0.927964 |
| 1982 | 0.981714 | 0.921662 | 0.924322 | 0.920448 |
| 1983 | 0.979689 | 0.915072 | 0.917222 | 0.911471 |
| 1984 | 0.977237 | 0.9056 | 0.90777 | 0.900485 |
| 1985 | 0.974188 | 0.892397 | 0.895292 | 0.886936 |
| 1986 | 0.97035 | 0.87438 | 0.878923 | 0.869936 |
| 1987 | 0.96541 | 0.85013 | 0.857326 | 0.847257 |
| 1988 | 0.958596 | 0.817544 | 0.827446 | 0.817789 |
| 1989 | 0.949334 | 0.776492 | 0.789928 | 0.781932 |
| 1990 | 0.937392 | 0.727994 | 0.74518 | 0.739792 |
| 1991 | 0.922319 | 0.675232 | 0.694753 | 0.693271 |
| 1992 | 0.904215 | 0.623427 | 0.643046 | 0.645458 |
| 1993 | 0.883781 | 0.576536 | 0.593565 | 0.598539 |
| 1994 | 0.861648 | 0.535644 | 0.547865 | 0.553494 |
| 1995 | 0.838149 | 0.499891 | 0.505969 | 0.51039 |
| 1996 | 0.813259 | 0.467576 | 0.467093 | 0.468497 |
| 1997 | 0.786442 | 0.435832 | 0.429433 | 0.426537 |
| 1998 | 0.756545 | 0.401737 | 0.390986 | 0.383609 |
| 1999 | 0.722238 | 0.364273 | 0.350945 | 0.340164 |
| 2000 | 0.682937 | 0.325586 | 0.310673 | 0.299319 |
| 2001 | 0.640916 | 0.293626 | 0.275734 | 0.264761 |
| 2002 | 0.600735 | 0.272261 | 0.249197 | 0.237908 |
| 2003 | 0.566043 | 0.261757 | 0.231432 | 0.2179 |
| 2004 | 0.537919 | 0.259197 | 0.220403 | 0.202705 |
| 2005 | 0.515107 | 0.261073 | 0.213653 | 0.190506 |
| 2006 | 0.495799 | 0.264839 | 0.209418 | 0.180153 |
| 2007 | 0.478666 | 0.269008 | 0.206642 | 0.171011 |
| 2008 | 0.462931 | 0.272728 | 0.204682 | 0.162742 |
| 2009 | 0.448179 | 0.275546 | 0.20314 | 0.155 |

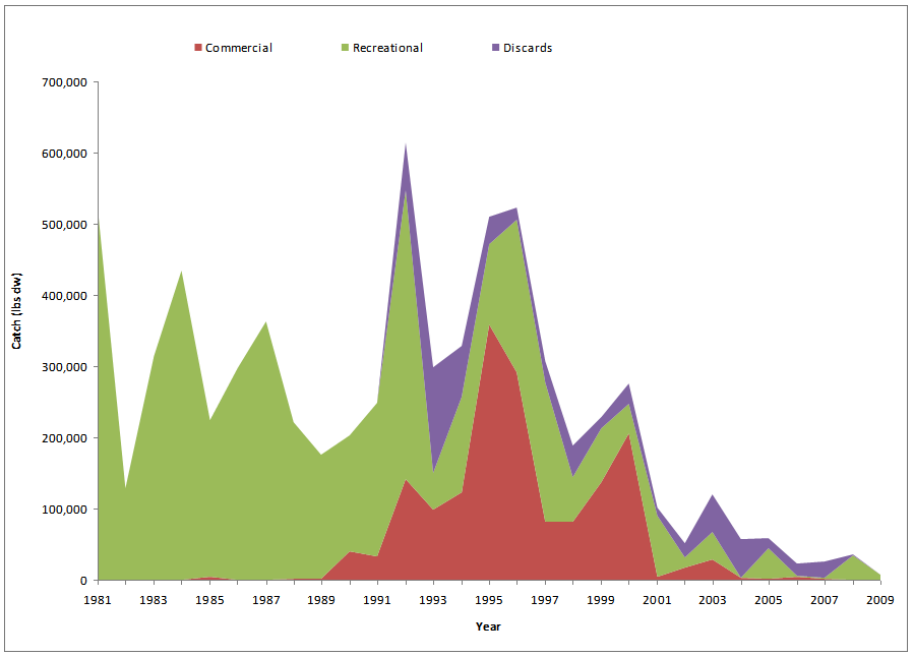


**Figure 1:** Total catches of dusky shark (in pounds dressed weight), 1981-2009. (*Figure 1 of the Data Workshop Report*)

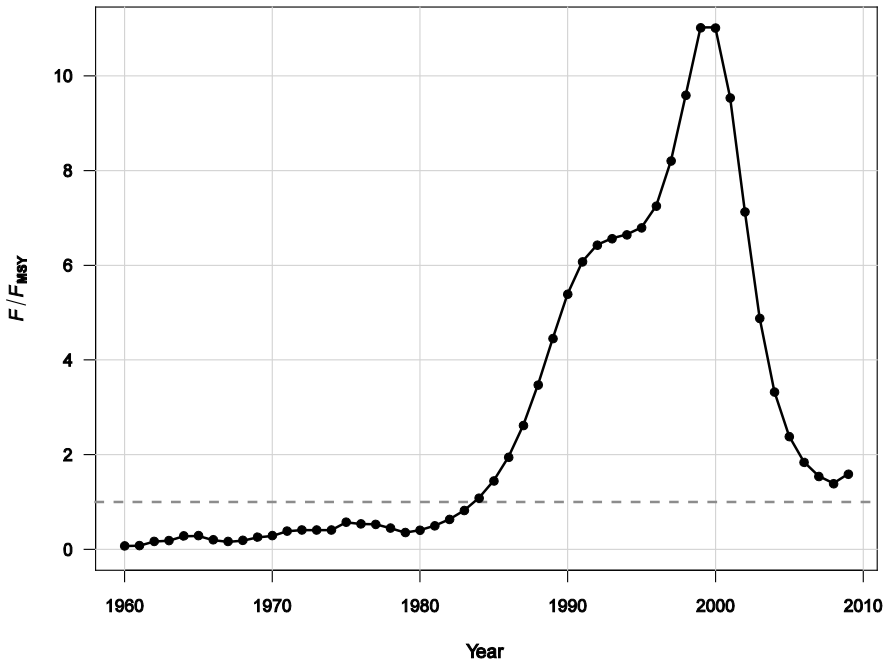


**Figure 2:** Apical fishing mortality relative to MSY levels for dusky sharks, 1960-2009. The base ASCFM indicated that overfishing has been occurring since 1984 (although there is considerable uncertainty about whether overfishing occurred during the last several years of the time series). (*Figure 3.14 in the Assessment Workshop Report*)

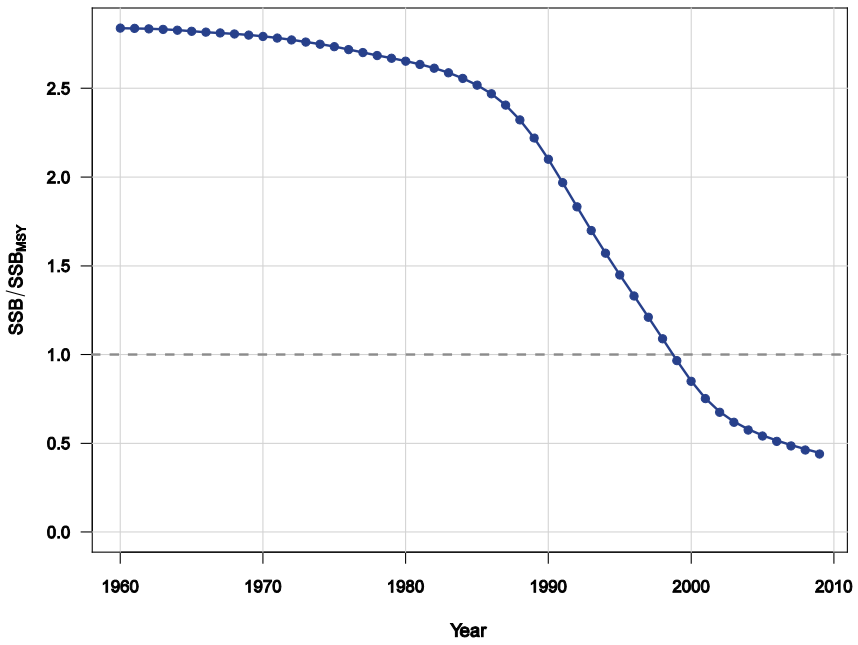


**Figure 3:** Spawning biomass relative to MSY levels over time from the base ASCFM model for dusky sharks. (*Figure 3.13 from the Assessment Workshop Report*)

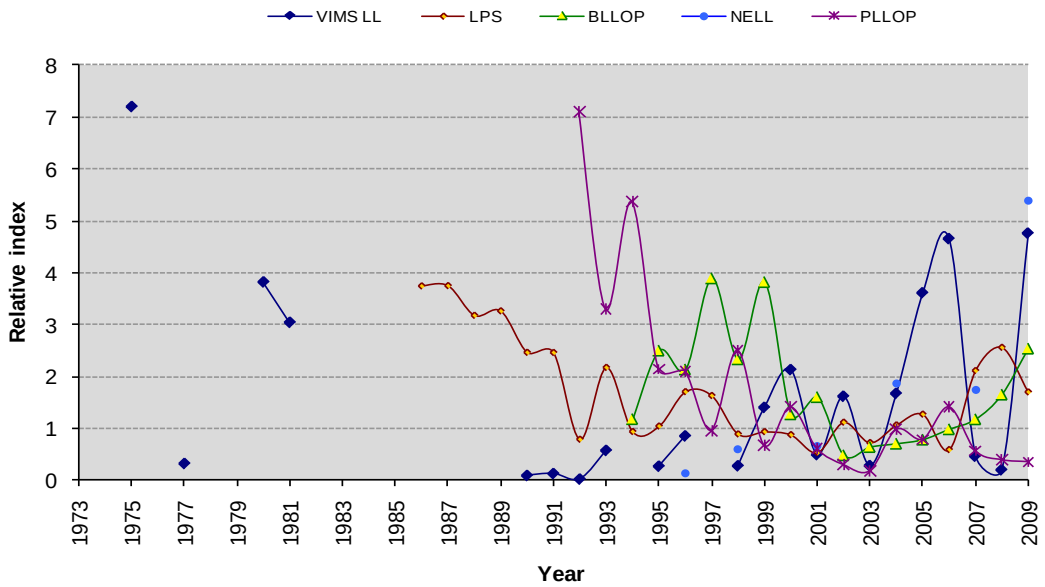


**Figure 4:** Baseline indices of relative abundance used for dusky shark. All indices are statistically standardized and scaled (divided by their respective mean and a global mean for overlapping years; except NMFS Historic LL). (*Figure 2.3 from the Assessment Workshop Report*)

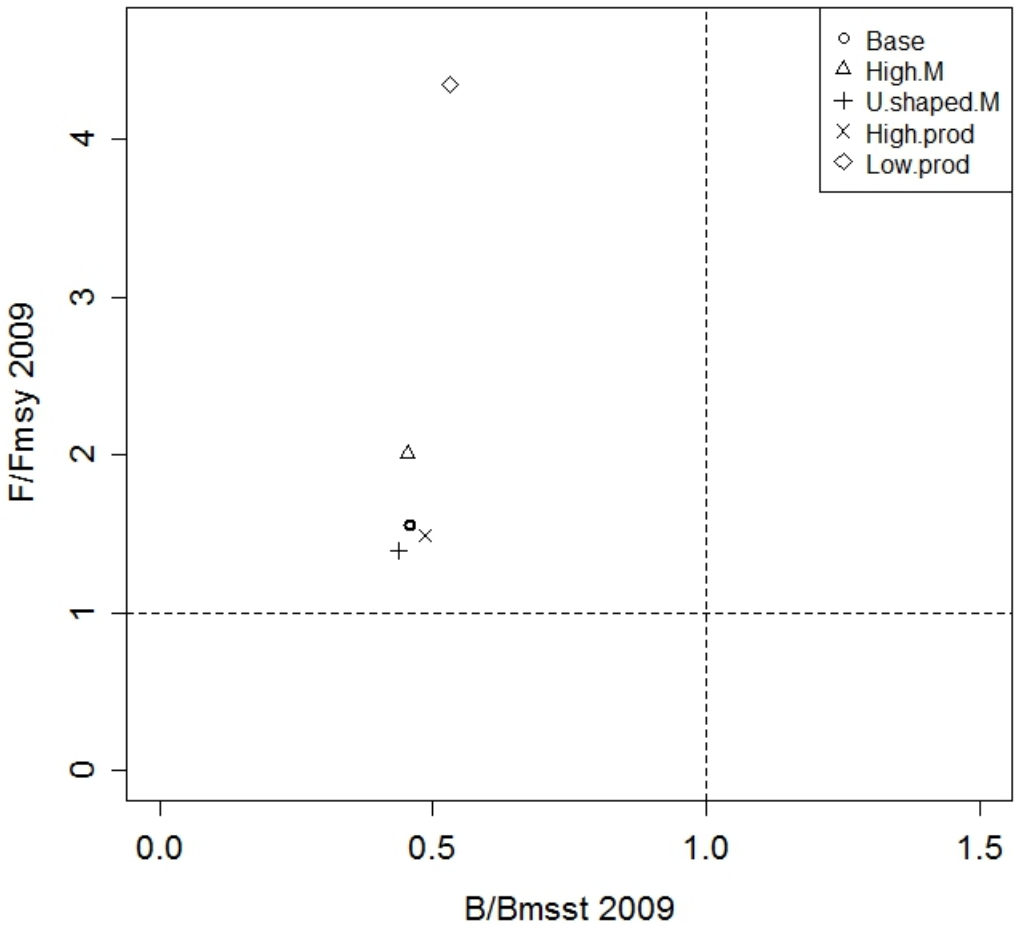


**Figure 5:** A phase plot summarizing stock status of dusky sharks in the terminal year of the assessment model according to various base and sensitivity runs selected by the Review Panel. Points to the left of the vertical dashed line indicate runs in which the stock is estimated to be overfished; points above the horizontal black line indicate runs in which overfishing is estimated to have occurred. (*Figure 6 from the Review Workshop Report*)

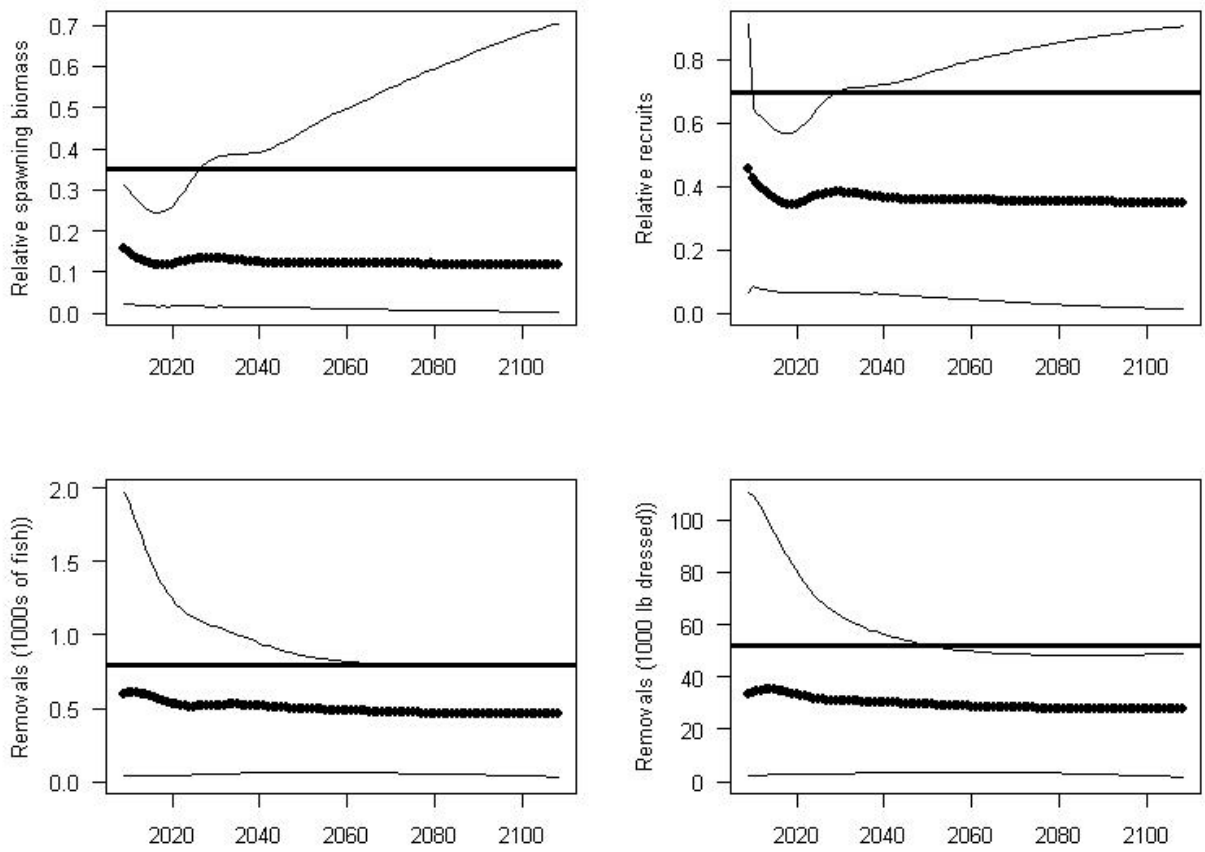


**Figure 6:** Results for the $F_{current}$ projection scenario, 2009-2108. The heavy dotted line gives the median projection, while thin solid lines give 95% uncertainty bounds. The horizontal line represents the corresponding value that would be anticipated at MSY. (*Figure 3.16 from the Assessment Workshop Report*)