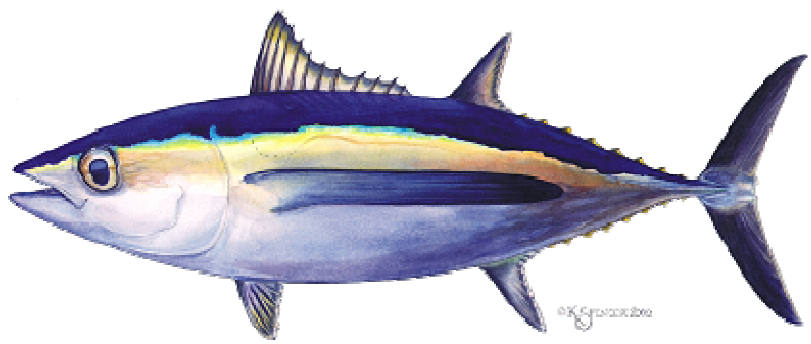
# STOCK ASSESSMENT OF ALBACORE TUNA IN THE NORTH PACIFIC OCEAN IN 2011



***REPORT OF THE ALBACORE WORKING GROUP STOCK ASSESSMENT WORKSHOP***

International Scientific Committee for Tuna and Tuna-like Species
in the North Pacific Ocean

4-11 June 2011

National Research Institute of Far Seas Fisheries
Shimizu, Shizuoka, Japan, 424-8633

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# EXECUTIVE SUMMARY

The current assessment of the status and future trends in the north Pacific albacore tuna (*Thunnus alalunga*) stock was completed in June 2011 using fishery data through 2009. This assessment was conducted using a seasonal, length-based, age-structured, forward simulation population model developed within the Stock Synthesis modelling platform (Version 3.11b) and is based on the assumption that there is a single well-mixed stock of albacore in the north Pacific Ocean. The model used quarterly catch-at-length data; sixteen age-aggregated fisheries defined by gear, location, season, and catch units (weight or number); eight abundance indices; a new growth curve estimated within the model; and conditional age-at-length (otoliths) data not previously available.

Analyses were carried out to assess the sensitivity of the results to assumptions including data weighting (both between data types and relative weightings within a data type), biology (stock-recruitment relationship, natural mortality, growth), and fishery selectivity patterns. Stochastic future projections of the stock were conducted to assess the impact of current F on future harvest and stock status and to estimate the probability that future spawning stock biomass (SSB) will fall below the average of the ten historically lowest estimated SSBs (SSB-ATHL) in at least one year of a 25-yr (2010-2035) projection period. The base-case scenario for projections assumed historical recruitment and constant F (at the current F level, $F_{2006\text{-}2008}$), but sensitivity of the results to alternative harvest scenarios (constant catch and constant $F_{2002\text{-}2004}$), two alternative recruitment scenarios (high and low historical levels), and alternative structural assumptions (down-weighting of the length composition data, stock recruitment relationship, growth) were investigated. Retrospective analyses were conducted to assess the level of bias and uncertainty in terminal year estimates of biomass, recruitment, and fishing mortality. A reference run of the VPA model configured as in the 2006 assessment, but with updated catch-at-age (to 2009) and six age-aggregated CPUE indices rather than age-specific indices, was conducted to compare important estimated quantities for model-related changes.

The SS3 base-case model estimates that SSB has likely fluctuated between 300,000 and 500,000 t between 1966 and 2009 and that recruitment has averaged approximately 48 million fish annually during this period. Fishing mortality (F-at-age) increases to its highest level on 3-yr old juvenile albacore and then declines to a much lower and stable level in mature fish. Current F (geometric mean of 2006 to 2008, $F_{2006\text{-}2008}$) is lower than $F_{2002\text{-}2004}$ (current F in the 2006 assessment). The Northern Committee (NC) of the Western and Central Pacific Fisheries Commission (WCPFC - one of the RFMOs managing the stock) established an interim reference point to limit fishing mortality such that future SSB is maintained above the SSB-ATHL threshold with a probability greater than 50% ($F_{SSB\text{-}ATHL\ 50\%}$). $F_{2006\text{-}2008}$ is approximately 30% below $F_{SSB\text{-}ATHL\ 50\%}$ and there is about a 1 % risk that future SSB will fall below the SSB-ATHL threshold in at least one year in the 25-yr projection period, assuming recruitment remains at average historical levels.

Sensitivity and retrospective analyses revealed uncertainty in absolute estimates of biomass (total and SSB) and, to a lesser extent, recruitment, but few differences in overall time series trends. Relative F-at-age patterns were not substantially affected by different assumptions, except when the growth curve parameters from the 2006 assessment (the Suda growth curve) were used, and

$F_{2006\text{-}2008}$ was consistently lower than $F_{2002\text{-}2004}$. Although terminal year estimates of biomass and recruitment are not strongly biased, there is a high level of uncertainty in the most recent recruitment estimates. Given these findings, the current parameterization of the base-case model is considered reasonable.

Both the SS3 base-case model and the VPA reference run estimated similar historical trends in SSB and recruitment, but with different scaling for biomass. The scaling difference is largely attributable to the different growth curves used in SS3 base-case model and the VPA reference run. A sensitivity run of the base-case model in which growth parameters were fixed to those used in the VPA, reduced the scaling of biomass to the level of the VPA reference run. Sensitivity analyses of future projections were conducted with respect to the interim reference point ($F_{SSB\text{-}ATHL\ 50\%}$) and the results show that stock status and conservation advice are relatively insensitive to the scaling differences. Based on these findings, the WG concludes that the growth curve used in the 2006 assessment is not representative of growth in north Pacific albacore.

The north Pacific albacore stock is considered to be healthy at the current level of fishing mortality, $F_{2006\text{-}2008}$, and average historical recruitment. Current $F_{2006\text{-}2008}$ is about 71% of $F_{SSB\text{-}ATHL}$, which means F is well below the fishing mortality that would lead SSB to fall below the SSB-ATHL threshold, estimates of $F_{2006\text{-}2008}$ expressed as a ratio relative to several potential F-based reference points ($F_{MAX}$, $F_{0.1}$, $F_{MED}$, $F_{20\text{-}50\%}$) are less than 1.0, and the stock is expected to fluctuate around the long-term median SSB (~400,000 t) in the foreseeable future given average historical recruitment levels and constant fishing mortality at $F_{2006\text{-}2008}$. Based on these findings, the WG concludes that overfishing is not occurring and that the stock likely is not in an overfished condition, although biomass-based reference points have not been established for this stock. However, recruitment is a key driver of the dynamics in this stock and a more pessimistic recruitment scenario increases the probability that the stock will not achieve the management objective of remaining above SSB-ATHL threshold with a probability of 50%. If future recruitment declines about 25% below the historical average and F remains constant at $F_{2006\text{-}2008}$, then the risk of future SSB falling below the SSB-ATHL threshold by the end of the projection period increases to 54%. Therefore, the Working Group recommends maintaining present management measure (no increase in effort beyond "current" levels (2002-2004)).

Research needs to improve the assessment were identified, prioritized and an appraisal of achievability by the next assessment was made. The priority areas for research are: (1) age and growth modelling to improve the model fit; (2) spatial pattern analysis to investigate regional differences in growth and movements; (3) CPUE analyses to investigate discrepancies among indices; (4) maturity research to develop a length-based maturity schedule; (5) investigation of several data issues, including size composition anomalies noted in model fit residual patterns; and (6) improvements to SS3 base-case model configuration and parameterization including weighting of different information sources, a stock-recruitment relationship, explicit spatial structure, accounting for environmental covariates.

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# 1.0 INTRODUCTION

The Albacore Working Group (ALBWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) is tasked with conducting regular stock assessments of north Pacific albacore tuna (*Thunnus alalunga*) to estimate population parameters, summarize stock status, and develop scientific advice on conservation needs for fisheries managers. There is a long history of cooperative research and stock assessment analyses on north Pacific albacore conducted by the *North Pacific Albacore Workshop*, which was established in 1974, and was integrated into the ISC as the Albacore Working Group in 2005. The Albacore Working Group consists of members from coastal states and fishing entities of the region (Canada, China, Chinese-Taipei, Japan, Korea, Mexico, USA) and members from relevant intergovernmental fishery and marine science organizations (Inter-American Tropical Tuna Commission, Secretariat of the Pacific Community).

This report presents the results of the current assessment of albacore tuna in the north Pacific Ocean and conservation advice to fisheries managers. The stock assessment was conducted 30 May to 11 June 2011 at the National Research Institute of Far Seas Fisheries, Shimizu, Shizuoka, Japan and supersedes the previous assessment completed in 2006 (ALBWG 2007). Members of the ALBWG who participated in the present stock assessment are listed in Appendix 1.

The objectives of the present assessment are to quantitatively understand the dynamics of north Pacific albacore fisheries by estimating population parameters such as recruitment, biomass and fishing mortality, and to determine stock status and fishing impacts on the stock. Stock status is summarized in terms of a variety of well-known biomass- and fishing mortality-based reference points used in contemporary fisheries management. Recent fishing mortality is also assessed relative to $F_{SSB\text{-}ATHL}$, a simulation-based reference point used to support the objective of maintaining spawning biomass (SSB) above the average of the ten historically lowest “observed” levels in the assessment time series (ATHL), as requested by the Northern Committee (NC) of the Western and Central Pacific Fisheries Commission (WCPFC). Lastly, biomass projections are estimated using both constant catch and constant fishing mortality scenarios in order to formulate advice to fisheries managers concerning future options. These projections were also used to estimate the probability that future SSB will fall below the ATHL threshold in at least one year of the projection period (see Ichinokawa et al. 2011a).

The results, conclusions and conservation advice recommended by the ALBWG are subject to approval by the ISC, after which they are transmitted to the Inter-American Tropical Tuna Commission (IATTC) and the WCPFC for review and management action. The relationship between the two Pacific regional fisheries management organizations and the ISC differs. A Memorandum of Cooperation between the ISC and IATTC provides a mechanism for data exchange between the two organizations and allows IATTC scientific staff to participate as members on ISC working groups. In contrast, an MOU with the WCPFC specifically provides for the WCPFC through the NC, to make requests to the ISC and its working groups for scientific information and advice on HMS stocks north of 20 °N latitude in the Pacific Ocean. The assessment documented in this report was approved by the ISC at the 11$^{th}$ Plenary Session in San Francisco, USA, 20-25 July 2011 (ISC 2011).

The ALBWG switched from the virtual population analysis (VPA) model used for the 2006 assessment to a length-based, age-structured, forward-simulation population model in this assessment. We used the Stock Synthesis (SS) Version 3.11b modeling platform (Methot 2011; http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm), which can implement either a size- or age-based population model, for this assessment. A length-based spatially structured population model was developed for the north Pacific albacore stock assessment after confirming that age-based modeling with SS worked effectively for north Pacific albacore (ALBWG 2008). In this assessment we compare a base-case run of the SS3 model with a VPA reference run in order to understand and explain model-related differences in outputs. Only outputs from the SS3 base-case model were used for the assessment and to formulate recommendations on conservation advice to managers.

# 2.0 BIOLOGY

## 2.1 Stock Structure

Albacore tuna in the Pacific Ocean consist of the north Pacific stock (focus of this assessment) and the south Pacific stock. The discreteness of these stocks is supported by fishery data in which catch rates are considerably lower in equatorial regions of the western Pacific between 10° N and 5° S than higher latitudes on either side of the equator (Suzuki et al. 1977), the lack of tag recoveries south of the equator of fish tagged in the north Pacific (Ramon and Bailey 1996), the rarity of albacore larvae during sampling surveys in equatorial waters (0-10°N; Ueyanagi 1969), and evidence of genetic differentiation between the north and south Pacific stocks (Takagi et al. 2001). Thus, the available evidence from tagging, ecological, fishery, and genetic studies support the hypothesis that these stocks are reproductively isolated with negligible movement of fish across the equator. At present, there is no strong evidence of structure within the north Pacific stock, i.e., subgroups or further stock differentiation.

## 2.2 Reproduction

Albacore are batch spawners, shedding hydrated oocytes in separate spawning events directly into the sea where fertilization occurs. Spawning frequency is estimated to be 1.7 d in the western Pacific (Chen et al. 2010a), and batch fecundity ranges between 0.17 and 2.6 million eggs (Ueyanagi 1957; Otsu and Uchida 1959; Chen et al. 2010a). Female albacore mature at lengths ranging from 83 cm fork length (FL) in the western Pacific (Chen et al. 2010a) to 90 cm in the central Pacific (Ueyanagi 1957), and 93 cm north of Hawaii (Otsu and Uchida 1959).

Spawning occurs in tropical and sub-tropical waters west of the Hawaiian Islands (155° W longitude) and between 10 and 25°N latitudes at depths exceeding 90 m (Ueyanagi 1957, 1969; Otsu and Uchida 1959; Yoshida 1968; Chen et al. 2010a). Although spawning probably occurs over an extended period from March through September in the western and central Pacific Ocean (WCPO), recent evidence based on a histological assessments of gonadal status and maturity (Chen et al. 2010a) found that spawning in the western Pacific Ocean (WPO) peaks between March-April, which is consistent with evidence from larval sampling surveys in the same region (Nishikawa et al. 1985). In contrast, studies of albacore reproductive biology in the central

Pacific Ocean (CPO) have concluded that there was a probable peak spawning period between June and August (Ueyanagi 1957; Otsu and Uchida 1959), but these studies are based on indirect methods and lack the verification of spawning activity provided by Chen et al. (2010a).

## 2.3 Growth

Growth among albacore is commonly modeled with a von Bertalanffy growth function, with rapid growth among immature fish and a slowing of growth rates at maturity and through the adult period of the life history. Growth in the first year of life is uncertain because these young fish are rarely captured in any of the active fisheries in the north Pacific Ocean (NPO). However, juvenile albacore recruit into intensive surface fisheries by age 2 in both the eastern Pacific Ocean (EPO) and the WPO and as a result, much better size-at-age and growth information is available. Estimated size at age-1 in north Pacific albacore ranges from 45 to 64 cm (Clemens 1961; Wells et al. 2011; Chen et al. 2011). Albacore are ~ 60 cm FL at age 2 when they recruit into surface fisheries and growth slows to about 10 cm per year for ages 2-4 and becomes even slower after 5-6 years of age when albacore are mature (Clemens 1961; Otsu and Uchida 1959; Yabuta and Yukinawa 1963; Wells et al. 2011; Chen et al. 2011). Maximum measured size of north Pacific albacore is 128 cm (Otsu and Uchida 1959; Clemens 1961) and the maximum recorded age is 15 years (Wells et al. 2011). Although Chen et al. (2011) reported sexual dimorphism in size-at-age and longevity, fishery data are not collected by sex so the use of sex-specific growth rates and age compositions are not viable options for assessment without the use of arbitrary sex ratio assumptions.

## 2.4 Movements

North Pacific albacore are highly migratory and these movements are influenced by oceanic conditions (e.g., Polovina et al. 2001; Zainuddin et al. 2006, 2008). The majority of the migrating population is believed to be composed of juvenile fish (i.e., immature animals that are less than 5 years old and 85 cm FL), which generally inhabit surface waters (0-50 m). Details of the migration remain unclear, but seasonal movements have been observed (Ichinokawa et al 2008a), especially among juvenile fish in the EPO (Childers et al. 2011). A portion of the juvenile fish are believed to move into the EPO and WPO in the spring and early summer, returning to the CPO in the late fall and winter where mixing among the eastern and western juvenile components of the stock probably occurs (Otsu and Uchida 1963). Some of juvenile albacore undergo a trans-Pacific movement from the WPO to the EPO where they display seasonal movements between the EPO and CPO (Childers et al. 2011). Recent estimates of seasonal migration rates (Ichinokawa et al. 2008a) are consistent with the pattern of movements proposed by Otsu and Uchida (1963), but show that westward movements are more frequent than eastward movements in the NPO. This differential westward movement appears to correspond to the recruitment of juvenile fish into fisheries in the WPO and EPO, followed by a gradual movement of maturing juveniles and mature fish to low latitude spawning grounds in the WCPO.

Trans-Pacific movements of juvenile albacore from west to east track the position of the transition zone chlorophyll front, a zone of sharp temperature fronts combined with high productivity, which is known to be an important migratory pathway for albacore and other species (Polovina et al. 2001; Zainuddin et al. 2006, 2008). Kimura et al. (1997) noted that

ENSO events and large eastward extensions of the Kuroshio current meanders affect albacore migration patterns, particularly trans-Pacific migration rates to the EPO through disruptions in prey movements. The migration rate increases when large meanders in the Kuroshio are evident because of increased prey availability in the transition zone.

### 2.5 Food Habits

Albacore undergo a size-related shift in diet as they grow, switching from microplankton to macroplankton, fish, and cephalopods (squids) (Young and Davis 1990; Watanabe et al. 2004; Pusineri et al. 2005; Consoli et al. 2008). Larval albacore (2.5 to 9.5 mm standard length) forage in epipelagic waters during the day and their diets are dominated by cyclopoid copepods (principally copepodites and nauplii), with cladoceran and calanoid copepods at the larger sizes (Young and Davis 1990; Catalán et al. 2007). Juvenile and adult albacore forage in epipelagic and mesopelagic waters and fish, crustaceans, and squid are the dominant components of the diet in terms of numbers and weight (Iversen 1962; Pinkas et al. 1971; Watanabe et al. 2004; Pusineri et al. 2005; Consoli et al. 2008). Epipelagic prey are consumed during the day and vertically migrating mesopelagic species that reach the surface layer are the primary prey at night (Pusineri et al. 2005). Small schooling pelagic species of sardine (*Sardina pilchardus, Sardinops sagax*), anchovy (*Engraulis* spp.), and mackerel (*Scomber* spp., *Trachurus* spp.) are the most common fish encountered in the diet of albacore in all oceans (Pinkas et al. 1971; Bernard et al. 1985; Watanabe et al. 2004). Although squids can be a common item in albacore diets, their importance in terms of numbers and weight varies with location and even season (Iversen 1962; Watanabe et al. 2004; Salman and Karakulak 2009; Goñi et al. 2011).

## 3.0 DATA

Four types of data were used in this assessment: fishery-specific catches, length compositions sampled from the catches, abundance indices derived from logbooks, and conditional age-at-length data. These data were compiled from 1966 through 2009 and frozen for the assessment as of 15 December 2010. Data sources (fisheries) and temporal coverage of the available datasets are summarized in Figure 1. Some of the 2009 data were considered preliminary for some fisheries at the time of the assessment and, as a consequence inferences should focus on results up to 2008.

### 3.1 Spatial Stratification

The geographic area encompassed in the assessment is the Pacific Ocean north of the equator from 10°N to 55°N latitude and from 120°E to 120°W longitude (Figure 2). This area includes all of the known catch of the north Pacific albacore stock from 1966 through 2009.

### 3.2 Temporal Stratification

The time period modeled in this assessment is 1966–2009. Within this period, catch and size composition data were compiled into quarters for analysis (Jan–Mar, Apr–Jun, Jul–Sep, Oct–Dec). Although some fisheries have catch data time series extending back to at least 1952, these data were not used because effort and size composition data are not consistently available prior to 1966 and the location information associated with these catches may not be reliable.

### 3.3 Fisheries

Albacore tuna is a valuable species with a long history of exploitation in the NPO. During the last decade (2000-2009), fisheries in Japan accounted for 65.4% of the total harvest on average annually, followed fisheries in the United States, which accounted for 16.7%, 7% by the Canadian fishery, and 6.5% by fisheries in Chinese Taipei. Other countries targeting north Pacific albacore during this period, including China, Korea, Mexico, Tonga, Vanuatu, Cook Islands, and Ecuador, accounted for 2.5% of the annual reported harvest on average (Figure 3).

Albacore in the NPO are harvested primarily by longline, pole-and-line, and troll gears (Figure 4). Surface fisheries, which capture the smaller, juvenile fish, include the USA and Canada troll (and USA pole-and-line) fisheries, and the Japan pole-and-line fisheries and have harvested 60% of the albacore taken since 1966. Longline fisheries, which fish deeper in the water and target the larger mature adult albacore, are responsible for harvesting 32% of the albacore during the same period. The major longline fisheries in the North Pacific include distant-water, offshore, and domestic fleets from Japan, Chinese Taipei, and the United States. Korea, Cook Islands and Vanuatu have minor longline fisheries harvesting albacore in the north Pacific Ocean. Purse seine, gillnet, and recreational gears combined account for about 8.5% of the total catch since 1966.

### 3.4 Fisheries Definitions

Sixteen fisheries were defined for the assessment on the basis of gear, location, season, and the unit of catch (numbers or weight) and all catch and effort data were allocated to these fisheries (Table 1). The aim was to define fisheries in which temporal changes in selectivity and catchability between years and within years (between seasons) were minimized. These fisheries consisted of one troll (CAN/USA, which included USA pole-and-line data), two pole-and-line (Japan offshore and distant water), nine longline (USA, JPN coastal, offshore, distant-water, TWN offshore and distant-water, KOR and other), two gillnet (JPN, TWN and KOR), and two miscellaneous (JPN and EPO including MEX). The operational areas of all sixteen fisheries are shown in Figure 5.

Fourteen fisheries were initially defined using the criteria described above, but further analysis of the size composition data revealed that there was a substantial seasonal change in selectivity in one longline fishery (F6) and temporal changes in the selectively of two other longline fisheries (F2, F12). Seasonality in selectivity was modeled by splitting the F6 longline fishery into two seasonal fisheries corresponding to quarters 1 and 2 of the calendar year (S1, S2). Since the selectivity of longline fishery F7 was mirrored to F6, this fishery was also split into two seasonal fisheries, resulting in the sixteen fisheries used in the assessment.

Temporal changes in the selectivity of the F2 and F12 time series were modelled by splitting the time series for these fisheries into discrete time periods or blocks. The USA longline fishery (F2) consists of both shallow-set (targeting swordfish, *Xiphias gladius*) and deep-set (targeting bigeye tuna, *Thunnus obesus*) components. A temporal change in selectivity occurred from 2001 to 2004 when the shallow-set component was shut down due to marine turtle conservation concerns and as a result a time block was used to estimate selectivity separately for this period. Qualitative differences in the early period (prior to 2003) and late period data (2003 to present) size composition data from the Taiwan longline fishery (F12) necessitated the use of two time periods to account for differences in selectivity (see Section 3.7 for details).

### 3.5 Catch and Effort

The total reported catch of north Pacific albacore for all nations combined (Figure 3) peaked at a 126,538 metric tonnes (t) in 1976 and then declined to the lowest observed catch in the time series (37,320 t) in 1991. Following this low point, total catch recovered by 1999 to a second peak of 125,542 t. Total catch declined through the 2000s to a low of 63,198 t in 2005 and has recovered slightly to between 70,000 and 92,000 t in recent years (2006-2009). Total catch has averaged 76,965 t annually for the 30 year period, 1971-2000.

Albacore catches by the three major gear types (troll, pole-and-line, longline) exhibit similar patterns over the 1966-2009 time series (Figure 4). Catches by all gears were relatively high in the 1970s, especially pole-and-line catch, and then declined to their lowest levels by the late 1980s. This decline was followed by a rebuilding phase ending with a second peak in catch by the late 1990s in all gears. Through the 2000s catches have either declined steadily (longline) or stabilized at lower levels than the peak in the 1990s (troll, pole-and-line). Pole-and-line catches in the 2000s exhibit greater year-to-year variability than catches by the other gear types. This variability is related to target switching between skipjack (*Katsuwonus pelamis*) and albacore by some vessels on the fishing grounds off the east coast of Japan (Kiyofuji and Uosaki 2010). High gillnet catches in the 1980s reflect data from a highseas driftnet fishery, which captured albacore as by-catch, beginning in 1978. This fishery ceased operating in January 1993 as a result of the adoption of United Nations General Assembly Resolution 44/225, which put in place a moratorium on the use of driftnets on the highseas (Uosaki et al. 2011).

The number of vessels fishing each of the major gears (Figure 6) has either decreased (longline, troll) or remained relatively stable (pole-and-line, purse seine) since the 1990s. Surface fisheries are highly seasonal, occurring mainly from May through October whereas longline fisheries operate throughout the year, although there is a strong seasonal trend in the catch distribution, with the first (Jan-Mar) and fourth quarters (Oct-Dec) producing the largest annual catches.

Time series of quarterly catch data from 1966 to 2009 were developed using logbook data so that the annual catch was consistent with the Category I data archived in the ISC-ALBWG database catalogue. Catch was reported in metric tons (t) for most fisheries, except for catches from the JPN OLLF1 and OLLF2 (F6s1, F6s2, and F8) and TWN LL (F12) fisheries, which were reported in 1,000s of fish. Catch was treated in the model as known with negligible error.

### 3.6 Indices of abundance - CPUE

Standardized annual indices of relative abundance were developed for eight fisheries (Table 2, Figure 7), consisting of four surface fishery indices (S1, S3, S4, S5) and four longline indices (S2, S6, S7, S8). Catch and effort data were aggregated into monthly 1° x 1° (surface fisheries) or 5° x 5° (longline fisheries) spatial blocks and a generalized linear model (GLM) approach with three main factors – year, quarter, area – was used to standardize most abundance indices. Details of the standardization procedures and sources of data used to derive these indices are described by the references cited in Table 2. Two indices (S4, S5) covering different time periods were created from the Japan pole-and-line fishery (F5) capturing smaller averaged-sized fish because strikingly different trends were observed in these time blocks.

Standardized annual CPUE values for each index are shown in Table 3. A season was assigned to each index based on the annual quarter in which the majority of catch is recorded. Visual inspection of all indices grouped by fishery type (surface or longline) showed that trends are generally consistent among indices, but there are differences in recent trends in surface fishery indices in the eastern Pacific Ocean (S1) and western Pacific (S3 and S5). These diverging trends appear to coincide with a retraction in the operational areas of these fisheries from the CPO towards their respective coastlines in the EPO and WPO. Longline indices also exhibit similar trends, although there is some variation in the magnitude of decline since the late 1990s and S2 exhibits a declining trend in the 2000s in contrast to all other longline indices. The anomalous trend in S2 since 2004 may be related to the relatively small operational area of fishery F2 (USA LL) and the impact of recent domestic regulatory changes in the USA affecting this fishery. This discrepancy was interpreted as a signal that the reliability of S2 as an indicator of overall abundance is low relative to other indices. The coefficients of variation (CVs) of these indices (i.e., the relative weightings) were fixed in the base-case model based on the WG's judgement concerning the reliability of each index as an indicator of overall albacore abundance (see Section 4.6 for details).

Seasonally separated and annual CPUE indices for F6 were examined during the assessment workshop because the WG concluded that seasonal changes in the selectivity pattern of this fishery justified splitting it into two quarterly fisheries, F6s1 and F6s2. The S6 annual index is driven by the Q1 CPUE index in this fishery and it was noted that catch in Q1 of F6 is the largest component of the JPN LL catch and therefore it was important to include it in the base-case model. However, the catch and effort data for this fishery were not disaggregated to calculate separate Q1 and Q2 CPUE indices because there was no document supporting the development of a quarterly index at the assessment workshop and because it was not possible to calculate a quarterly index since the data were frozen for the assessment as per ISC policy before the WG noted the strength of the seasonal selectivity pattern. Thus, the S6 index used in this assessment is the annual CPUE index calculated using all F6 data (Q1 and Q2 combined) rather than a true Q1 index. Further research to document the development of a quarterly index for F6s1 and the characteristics of this index is a high priority recommendation to improve the next assessment.

### 3.7 Size Compositions

Quarterly length composition data from 1966 to 2009 were used in this assessment. Length frequency data were available for eight fisheries (Figure 8) and were compiled using 1-cm size bins up to 90 cm, 2-cm size bins from 90 to 100 cm, and 4-cm size bins from 100 to 140 cm, where the numerical labels mark the lower boundary of each bin as required by SS. Each length frequency observation consisted of the number or proportion of albacore measured for most fisheries and catch-at-size data for JPN PL and JPN LL fisheries. Most of these fisheries exhibit clear and relatively stationary modes for a given quarter throughout the time series (Figure 9).

Fork lengths of albacore for the JPN LL (F6s1, F6s2, and F8, 1966-2009), and JPN PL fisheries (F4 and F5, 1968-2009) were measured to the nearest cm at the landing ports or onboard fishing vessels from which catch-at-size data were derived (see Matsumoto and Uosaki 2011).

Fork lengths of albacore (to the nearest cm) for the UCLTN fishery (F1, 1966-2009), and the USA LL fishery (F2, 1994-2008) were collected through port sampling and longline observer programs, respectively (Teo et al. 2010). Length composition data from the CAN component of the UCLTN fishery were not used in this assessment because the data from the USA component were considered representative of the entire fishery. Length compositions for the USA LL fishery in 2009 were not used due to errors in the database for that year.

Fork lengths of albacore (to the nearest cm) for the TWN LL fishery (F12, 1995-2009) were measured by crew members onboard fishing vessels and compiled by the Overseas Fisheries Development Council (OFDC) of Taiwan (Chen et al. 2010b). The length composition data from several years (1995, 1999, 2000, 2002) were not considered representative of catches by the TWN LL fishery because the size data are sampled from a restricted geographic area and shorter annual time period than the spatial and temporal scope at which the fishery was operating (ALBWG 2011). In addition, length composition data were not available for 2001 nor during the historical period from 1966 to 1994. Previous analysis demonstrated that length compositions from 1996-1998 were substantially different from the length compositions from 2003-2009 due to changes in the fishing operations of this fishery (Chen et al. 2010b; Wu et al. 2011).

Length composition data from the early period of the TWN LL fishery (1996-1998) were combined into a single ‘super-year’ in order to reduce the influence of observed inconsistencies during this period (Wu et al. 2011). A super-year blends data across multiple years and causes the model to calculate an expected length composition for each time period in the super year sequence. Each year was weighted equally in the calculation of the expected super-year value.

### 3.8 Conditional Age-at-Length

Otolith-based ages and fish lengths (fork length, cm) in Wells et al. (2011) from four fisheries (F1, F2, F6s1, and F8) were used as conditional age-at-length data in the growth model. The SS model platform uses integer ages and assumes a birth date of 01 January. The otolith age data are reported assuming a birth date of 01 May and as a result fractional ages of fish sampled prior to 01 May were rounded up while those sampled after 01 May were rounded down to their integer ages. Otolith-based ages are assumed to have standard errors of ± 1 year for fish up to age-5 and ±2 years for fish older than 5 years (D. Wells, NOAA/NMFS, SWFSC, pers. comm).

## 4.0 MODEL DESCRIPTION

### 4.1 Stock Synthesis 3

A seasonal, length-based, age-structured, forward-simulation population model was used to assess the status of the north Pacific albacore stock. The model was implemented using Stock

Synthesis (SS) Version 3.11b (Methot 2011; http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm). Stock Synthesis is an age and size-structured model that projects the survival, growth and reproduction of individual age classes and can incorporate ageing errors and individual variation in growth. Subcomponents within SS include a population model, an observation model and a statistical model. The population model is used to simulate the size and age structure of the population and the observation model uses the data inputs and selectivity functions to fit the simulated population to the observed data. The statistical model uses a log-likelihood approach to estimate best-fit parameters for the model by minimising a log-likelihood objective function, consisting of both likelihood (data) and prior information components. The log-likelihood function is used to calculate the total log-likelihood value associated with the model and allows emphasis factors to control the weight of each type of data and parameter influencing the total likelihood. The likelihood calculation of our model assumed a multinomial error structure for the length compositions and log-normal error for the surveys. A convergence criterion of 0.0001 log-likelihood units was used for all runs of the model. All of the control, starter, and forecast files for the consensus base-case scenario are shown in Appendix 2.

In this section, the base-case model parameterization, data sources, structural uncertainties, and the context for key sensitivity analyses regarding fishery data, biological parameters, and other modeling assumptions are described.

## 4.2 Biological and Demographic Assumptions

### *4.2.1. Growth*

Preliminary modeling with SS (ALBWG 2011) supported the conclusion that the model outputs (biomass, recruitment) are sensitive to growth curve parameterization, i.e., fixed or estimated, and the functional form (von Bertalanffy, Richards) of the fitted growth curve. Additional modeling work demonstrated that estimating growth within the base-case model resulted in the best fit to the length data (ALBWG 2011) and the resulting growth parameter estimates were independently corroborated by newly available otolith data (Wells et al. 2011). Based on these findings, a von Bertalanffy growth function was used to model the relationship between fork length (cm) and age for north Pacific albacore within the base-case model:

$$L_A = L_\infty + (L_1 - L_\infty)e^{-K(1-A)},$$

where $L_A$ is the age-at-length $A$, $L_\infty$ is the theoretical maximum length, $K$ is the growth coefficient, and $L_1$ is the size of the youngest fish ($A_1$). The asymptotic length, $L_\infty$, is:

$$L_\infty = L_1 + \frac{L_2 - L_1}{1 - e^{-K(A_2 - A_1)}},$$

where $L_1$ and $L_2$ are the sizes associated with ages near the youngest $A_1$ and oldest $A_2$ ages in the data. In this assessment, $L_1$ and $L_2$ were chosen as size at age 1 and $L_\infty$, respectively. The growth parameters K, $L_1$, $L_\infty$ were estimated in the SS model and CVs for $L_1$ and $L_\infty$ were also estimated to account for the variability in size-at-age distributions. Conditional age-at-length data from Wells et al. (2011) were applied because preliminary modeling results (ALBWG 2011) also showed that these data stabilize the growth curve parameter estimates with respect to different base-case model configurations.

#### *4.2.2 Weight-at-Length*

Weight-length relationships are used to convert catch-at-length to weight-at-length data. A previous study (Watanabe et al. 2006) reported that there were seasonal differences in the relationship between weight (kg) and fork length (cm) of north Pacific albacore. The seasonal weight-at-length relationships used in this assessment are:

$$\text{Quarter 1 (Q1): } W_L(kg) = 8.7\times10^{-5}\, L(cm)^{2.67},$$
$$\text{Quarter 2 (Q2): } W_L(kg) = 3.9\times10^{-5}\, L(cm)^{2.84},$$
$$\text{Quarter 3 (Q3): } W_L(kg) = 2.1\times10^{-5}\, L(cm)^{2.99},$$
$$\text{Quarter 4 (Q4): } W_L(kg) = 2.8\times10^{-5}\, L(cm)^{2.92},$$

where $W_L$ is weight at length $L$. These seasonal weight-at-length relationships were applied as fixed parameters in the SS base-case model.

#### *4.2.3 Sex Ratio*

Males predominate in longline catches of mature albacore sampled scientifically while juveniles < 85 cm generally have a sex ratio of 1:1 (Otsu and Uchida 1959; Otsu and Sumida 1968; Foreman 1980). Chen et al. (2011) reported sex-specific growth after maturity in the western Pacific Ocean, with males achieving larger sizes than females. Both sexes are combined in the assessment model because the fishery data are not sex-specific.

#### *4.2.4 Natural mortality*

Natural mortality (M) is a difficult parameter to estimate in the model and estimation was not attempted during this assessment. M was fixed at 0.3 $yr^{-1}$ for all ages, i.e., there is no variation with age. This assumption has been used in previous assessments of north Pacific albacore (e.g., ALBWG 2007) and was taken from north Atlantic albacore assessments (e.g., ICCAT 2010) since productivities of the north Atlantic and north Pacific albacore stocks were similar based on previous assessment results. M cannot be reliably estimated from north Pacific albacore tagging data because tag return rates are low, especially in the WPO (Bertignac et al. 1999), and estimates of M are positively correlated with tag return rates (see Ichinokawa et al. 2008a).

#### *4.2.5 Recruitment and Reproduction*

North Pacific albacore are assumed to have one spawning and recruitment period in the second quarter of the year (Q2) based on recent histological assessments of gonadal status and maturity reported by Chen et al. (2010a). Ueyanagi (1957) estimated that 50% of the albacore at age-5 were mature and that all fish age-6 and older were mature. This maturity ogive was also used in the 2006 assessment (see Uosaki et al. 2006) and is used in the present assessment as no new information is available that would support a change in this assumption.

A standard Beverton and Holt stock-recruitment model was used in this assessment. Recruitment was defined as the number of age-0 fish and recruitment variability ($\sigma_R$; the standard deviation of log-recruitment) was fixed at 0.6. The log of the virgin recruitment level, $R_0$, and annual recruitment deviates were estimated by the SS base-case model. The offset for the initial recruitment relative to virgin recruitment, $R_1$, was assumed to be negligible and fixed at 0. Three eras are assumed for recruitment: early (1954-1968), main (1969-2007), and late (2008-09). Bias adjustment for recruitment was performed during the main era, but not during the early or late eras.

The steepness parameter (*h*) of the stock-recruitment relationship, which is a measure of the productivity of the stock at low stock size, is difficult to estimate because model derived estimates of SSB and recruitment commonly lack sufficient contrast in biomass levels, especially low biomass levels, to enable steepness to be reliably estimated (ISSF 2011). Two independent estimates of steepness for north Pacific albacore (Brodziak et al. 2011; Iwata et al. 2011), based on the first principles approach of Mangel et al. (2010), reported values of *h* ranging from 0.84 to 0.95. The steepness (*h*) of the stock-recruitment relationship was fixed at 1.0 in the present assessment. Although this assumption has low biological plausibility since it implies that there is an infinite amount of compensation in the stock-recruitment relationship at its origin (Mangel et al. 2010), it was used because preliminary modeling work showed that the likelihood profile of *h* was minimized at $h = 1.0$ in a base-case model. Furthermore, the external estimates of *h* (Brodziak et al. 2011; Iwata et al. 2011) are subject to considerable uncertainty due to the interpretation of ambiguously defined parameters in the methodology and the use of a growth curve in both studies that differed from the curve used in the base-case model (see Section 5.2.1). However, a sensitivity analysis was performed in which steepness (*h*) was assumed to be 0.85 based on the findings in Brodziak et al. (2011) and Iwata et al. (2011) and further research on plausible steepness values prior to the next assessment is a high priority recommendation.

#### *4.2.6 Maximum Age*

The maximum age of north Pacific albacore was assumed to be 15 years, which is the age of the oldest fish reported by Wells et al. (2011).

#### *4.2.7 Movement*

Albacore were assumed to be well mixed and distributed throughout the NPO and regional and seasonal movement rates were not explicitly modeled. Although the assessment modelling is not spatially explicit, the collection and pre-processing of data on which the assessment is based are fishery (i.e., country-gear) specific and therefore contain spatial inferences (see Section 3.4).

#### *4.2.8 Stock Structure*

The present stock assessment assumes a single stock of albacore in the north Pacific Ocean from 10°N to 55°N latitude and between 120°E and 120°W longitude (Figure 2). This assumption is supported by evidence from genetic, tagging, and seasonal fishing pattern studies (Suzuki et al. 1977; Chow and Ushima 1995; Takagi et al. 2001; Ichinokawa et al. 2008a).

### 4.3 Selectivity

Selectivity is fishery-specific and is assumed to be length-based. Selectivity affects the size distribution of the fish removed from the population and the expected length-frequency distribution and is, therefore, an influential component of the model given the relative importance of length-frequency data in the total log-likelihood function. Selectivity patterns were estimated for all fisheries with length composition data and the same selectivity patterns were applied to the associated CPUE indices (or surveys using SS nomenclature).

Selectivity patterns for all surface fisheries (F1, F4, F5) were assumed to be dome-shaped and time invariant. The initial and final parameters of the selectivity patterns were assigned values of -999, which causes SS to ignore the first and last size bins, i.e., these parameters were not estimated by the model. All other selectivity parameters were estimated in the SS base-case model. The robustness of the F4 selectivity pattern was improved by fixing the width between the ascending and descending limbs (the top) to a value of -4.

Selectivity patterns for the longline fisheries were either asymptotic (flat-topped) or dome-shaped, depending on the size of fish encountered by the fishery. Since the largest albacore were caught by F2 and F8, asymptotic selectivity was assumed for these fisheries. However, dome-shaped selectivity was assumed for F6 and F12 because inspection of their length data demonstrated that these fisheries caught smaller fish than F2 and F8. Two time-periods were implemented for selectivity in F2 (2001-2004, other years), F6s1 (1966-1992, 1993-2009), and F12 (1995-2002, 2003-2009) to account for time-varying selectivity observed in the length composition data from these fisheries. Sensitivity runs for selectivity assumptions were conducted in which the selectivity of F6s1 was assumed to be asymptotic and time blocks were removed one-by-one from the F2, F6s1, and F12 selectivity patterns.

Selectivity patterns of fisheries without length composition data were mirrored to the selectivity patterns of fisheries with similar operations, area, and season for which a selectivity pattern was estimated. Mirrored selectivity patterns were as follows:

1. F3 mirrored F1;
2. F7s1 and F13 mirrored F6s1;
3. F7s2 mirrored F6s2;
4. F9 mirrored F8; and
5. F10 , F11 and F14 mirrored F5.

**4.4 Catchability**

Catchability (Q) is estimated assuming that survey indices are proportional to vulnerable biomass with a scaling factor of Q and is assumed to be constant over time for all indices.

**4.5 Environmental Influences**

The base-case model does not explicitly capture the impact of environmental factors on the biology or population dynamics of albacore. However, environmental impacts are indirectly captured by the different recruitment scenarios used for future projections (see Section 4.11).

**4.6 Initial Conditions**

Initial fishing mortality was estimated for two surface (F1, F4) and one longline fishery (F7) and the initial equilibrium catch was calculated as the 14 year average of total catch (1952-1965) in these fisheries. The average catches for fisheries F1, F4, and F7 during this period were 19,499 t for F1, 28,575 t for F4, and 18,180 t for F7.

### 4.6 Data Weighting

Two types of weighting were used in the base-case model: (1) weighting of the different data types (sources of information, e.g., length compositions, abundance indices, and conditional age-at-length) relative to each other using lambda (λ) values, and (2) relative weighting among CPUE indices based on CV values. Length composition and conditional age-at-length data from all fisheries were down-weighted using lambda values of 0.01 and 0.1 respectively, relative to the abundance indices with a lambda of 1.0. Sensitivity runs were conducted in which the length composition data were up-weighted and down-weighted relative to the base-case using lambda values of 0.025 and 0.001, respectively. An additional sensitivity run was conducted to assess the impacts when conditional age-at-length data are not down-weighted (lambda = 1.0).

There is no objective method of establishing weightings (lambda) for different information sources in the SS model. The WG compared SSB estimates from preliminary base-case model runs with values reported for other tuna stocks, particularly south Pacific albacore (Table 4) and on this basis down-weighted the length composition data (lambda = 0.01). This choice resulted in the scaling of the estimated quantities within a range that was considered biologically plausible relative to productivity reported in other tuna assessments.

The WG considered S6 (CPUE index of F6s1) to be the most reliable indicator of albacore abundance and tuned the base-case model to S6 by assuming a fixed CV of 0.2 for this index. The CV is a measure of the weighting of these data in the model, with a lower CV (higher weighting) forcing the model to fit the index more tightly than an index with a higher CV value (lower weighting). The relative weightings (CVs) used for the other CPUE indices in this assessment, based on a judgement of their reliability as indicators of overall abundance, were:

1. S1 = 0.4 (1966-1999),
   = 0.5 (2000-2009);
2. S2 = 0.5;
3. S3 = 0.3;
4. S4 = 0.3;
5. S5 = 0.4 (1985-2003),
   = 0.5 (2004-2009);
6. S7 = 0.4; and
7. S8 = 0.5.

Two weightings were used for both S1 (from F1 – UCLTN) and S5 (from F5 – JPN PLSF), depending on the time block. Both of these indices are surface fishery indices and the down-weighting of these indices in recent years (CV = 0.5) relative to the earlier periods (CV = 0.4) reflects reductions in the operational area of each fishery from broad areas of the NPO early in the time series towards the coasts of North America and Japan, respectively, in recent years. A sensitivity analysis was run to check all weightings by fixing the CV of S6 at 0.2 and estimating the CVs of the other indices in the model, i.e., allowing the data to determine the weightings.

Effective sample sizes for length composition data of all fisheries were scaled to the average number of trips for the UCLTN fishery (N ~ 113.65), such that the average effective sample size for each fishery is equal to 113.65.

## 4.7 Convergence

Jitter analysis was conducted as a quality control procedure to ensure that the model was not converging on a local minimum. Jitter values of 0.1, 0.2, and 0.3 were randomly added to all parameters, 50 trials were run for each jitter value, and plots of SSB and recruitment were inspected. Substantial differences in the scaling or trends in the time series of these quantities was interpreted as evidence that the model was caught on a local rather than global minimum in log-likelihood space.

## 4.8 Retrospective Analysis

Retrospective analysis was conducted to assess the consistency of stock assessment results by sequentially eliminating one year of data while using the same base-case model parameterization and assumptions. Retrospective analyses were conducted by removing one year (2009), two years (2009, 2008), three years (2009, 2008, 2007) and four years (2009, 2008, 2007, 2006) of data and examining changes in SSB and recruitment time series as more data were incrementally removed from the model. The results of this analysis are useful in assessing bias and uncertainty in terminal year estimates of these quantities.

## 4.9 Sensitivity to Alternative Assumptions

Sensitivity analyses examine the effects of plausible alternative assumptions on the base-case model results. The sensitivity analyses conducted in this assessment (Table 5) are categorized into three themes, including (1) data weighting, (2) biology, and (3) selectivity. For each sensitivity run, comparisons of spawning stock biomass and recruitment trajectories, as well as F-at-age for two temporal periods (2002-2004 and 2006-2008) and likelihood profiles, were completed.

## 4.10 Ancillary Analyses

Two additional analyses were conducted in order to assist in the interpretation of the stock assessment results for management purposes.

### *4.10.1 Fishery Impact Analysis*

The impact of three fishery types (surface, longline, other) on the spawning stock biomass was evaluated. The fishery impact analysis was conducted using base-case model parameterization and assumptions and dropping the annual (1966-2009) and initial equilibrium catches for longline (USA, JPN, TWN, KO), surface (UCLTN and JPN PL), and "other" fisheries (the remaining miscellaneous fisheries) from the SS base-case data file one-by-one and calculating the SSB time series for each scenario. The magnitude of differences in the simulated spawning biomass trajectories with and without fishing indicates the impact of the major fishery types on the spawning biomass of north Pacific albacore.

#### *4.10.2 Yield Analysis*

Yield-per-recruit (Y/R) and spawning potential ratio (SPR) were calculated conditional on natural mortality (M), mean weight-at-age (i.e., growth), maturation, and age-specific selectivity (the age-at-first entry in the fishery). Equilibrium yield and SPR are expressed as multiples of current fishing mortality ($F_{MULT} = F/F_{2006\text{-}2008}$), where the $F_{MULT}$ for $F_{2006\text{-}2008}$ is 1.0. These analyses avoid the need to fit a stock-recruitment relationship and all of the parameters except $F_{MULT}$ are available from the base-case model as fixed or estimated values.

Yield-per-recruit and spawning potential ratio provide two ways to examine the effect of fishing mortality on a stock through the equilibrium yield (catch) that can be attained for a given level of F and the spawning ability of a stock for a given level of F relative to the spawning ability of the stock in an unfished condition. The results should be used with caution since neither approach accounts for the effect of changes in stock size on recruitment or environmental effects on the stock and both methods assume that overall selectivity is time invariant. However, if the age-at-first entry to the fishery changes as a result of a change in the proportions of catch by gears fishing a stock, then Y/R and SPR estimates will change.

### 4.11 Future Projections

Stock projections were used to assess the impact of current F on future harvest and stock status. In addition, the probability that future SSB will fall below a threshold defined as the average of the ten historically lowest SSB estimates (SSB-ATHL) in at least one year of a 25-yr (2010-2035) projection period was estimated (see Ichinokawa 2011a) in response to an NC request to include this information in future assessments (Northern Committee 2008). The base-case configuration assumes current fishing mortality ($F_{2006\text{-}2008}$) and random resampling of estimated historical recruitment (1966-2007) during the stock assessment period.

The stochastic future projections are based on an age-structured population dynamics model identical to SS base-case model in principle, but implemented in R with coding that was used in the assessment of Pacific bluefin tuna (see Ichinokawa et al. 2008b). Each projection is based on 200 bootstrap replicates to estimate parameter uncertainty followed by 10 stochastic simulations of future trends. Detailed algorithms for conducting the projections with options for future scenarios, and reference points, including $F_{SSB}$, are described in Ichinokawa (2011b), which is available electronically at: http://cse.fra.affrc.go.jp/ichimomo/

A constant F scenario using current fishing mortality ($F_{2006\text{-}2008}$) was used as the base-case of the future projection analysis. Projections with $F_{2002\text{-}2004}$ were also conducted for comparative purposes because the 2006 assessment defined current fishing mortality as the geometric mean of apical F for 2002-2004, $F_{2002\text{-}2004}$. Although a constant catch scenario was conducted, the WG considered it unrealistic for this stock because catch is largely dependent on annual recruitment, and hence, this scenario is treated as a sensitivity run. The constant catch sensitivity run was based on average quarterly catches between 2006 and 2008, assuming that total quarterly catch weights are constant in the future, but not partial catches by fleet. The total catch in weight assumed in the constant catch scenario is 75,224 t (average for 2006-2008). Because the total weights are derived from SS estimates, they are not exactly equal to the officially reported catch weights (see Table 14-1 in ISC 2011).

Recruitment for future projections was randomly resampled from the historical recruitment time series estimated by the base-case model and a low recruitment phase (1978-1987) and high recruitment phase (1988-2004) were identified in the time series and used as sensitivity runs.

Structural sensitivity runs of the base-case scenario included future projections in which: (1) growth curve parameters were fixed to the Suda (1966) estimates; (2) length composition data were down-weighted using lambda = 0.001; and (3) the steepness parameter of the stock-recruitment relationship (*h*) was assumed to be 0.85. Since sensitivity analyses results showed that up-weighting the length composition data resulted in more optimistic SSB trends, the WG chose to focus on future projections with down-weighted length composition data. All future projection scenarios and associated sensitivity runs are summarized in Table 6.

The $F_{SSB\text{-}ATHL\text{-}50\%}$ reference point was estimated for several recruitment scenarios and structural sensitivity runs to assess the robustness of the scientific advice to plausible alternative assumptions. Runs in which reference point calculations were made include:

- base-case;
- low recruitment;
- high recruitment;
- fixing the growth curve to the Suda growth parameters;
- down-weighting length composition data (lambda = 0.001);
- steepness; h = 0.85; and
- current F from the 2006 assessment ($F_{2002\text{-}2004}$).

The projections begin 1 January 2008 for consistency with the base-case recruitment scenario. Sensitivity runs conducted with projections beginning 1 January 2009 or 1 January 2007 (Ichinokawa 2011a) confirmed that the starting year is not influential to short- and long-term future projection results. Known catches for 2008, 2009 and 2010 were used for future projections. Total catch weights for 2008 and 2009 were estimated by the SS base-case model, while total catch in 2010 was based on preliminary reported catch weights. The catch data used for the future projections (Table 7) differ slightly from those reported in the updated catch table in ISC (2011: Table 14-1) because they were taken from an earlier version of this catch table.

### 4.12 Virtual Population Analysis

The 2006 assessment of north Pacific albacore (ALBWG 2007) was based on virtual population analysis modeling using VPA-2BOX software (Uosaki et al. 2006), which follows the ADAPT framework (Gavaris 1988, Conser and Powers 1990), and PRO-2BOX software (Porch 2002) for future projections. The VPA model is a backward-estimation method using catch-at-age data and ancillary information from indices of relative abundance, size compositions, and other information sources. VPA assumes that the observed catch-at-age data are known without error and that the fishing selectivity pattern varies from year-to-year, whereas the SS base-case model assumes that the selectivity pattern is fixed within time periods and that differences between observed and model-predicted catch-at-length data reflect process and observation errors. A reference run of the VPA model used in 2006 was repeated in the present assessment with the model configured as closely as possible to the SS base-case model. The VPA results were compared to the base-case model results in order to understand and explain model-related differences in important management quantities (e.g., biomass, spawning biomass, recruitment) during the transition from the VPA to the SS model. A more detailed description of the VPA reference run is provided by Kiyofuji et al. (2011).

#### *4.12.1 Data*

The VPA-2BOX platform uses a 'one zone' hypothesis which requires a single catch-at-age (CAA) matrix. The CAA matrix updated to 2009 was produced by combining fishery-specific matrices and was assumed to accurately reflect the overall catch-at-age from all surface and longline fisheries for albacore in the north Pacific Ocean. Errors in the catch-at-length data for the Taiwan longline fishery and the submission of a truncated CAA matrix (1995-2009) resulted in the development of a new CAA matrix for the Taiwan longline fishery (1987-2008), assuming that the age composition for this fishery is the same as that for the USA longline fishery. The 2006 VPA model defined 17 age-specific fisheries, in contrast to the present VPA reference run which uses six age-aggregated fisheries (Table 8). Six CPUE indices were prepared from five fisheries (UCLTN, JPN PL (1972-1984, 1985-2009), JPN LL, USA LL and TWN LL) by individual nations (Table 9, Figure 10). Partial catch vectors were used to estimate selectivity-at-age for each index.

#### *4.12.2 Parameterization*

The VPA reference run used the same parameterization as the previous assessment in 2006, with updated catch-at-age and new abundance indices between 1966 and 2009. Natural mortality was assumed to be constant over time and across all ages at $M = 0.3\ yr^{-1}$ and maximum age was set at 15 years. Recruitment was defined as the total number of age-1 fish and steepness of the stock-recruitment relationship (*h*) was fixed at 1.0. Following Ueyanagi (1957) it was assumed that the median age of albacore maturity was age-5 (50% probability) and that all fish age-6 or older are mature (100% probability).

Total stock biomass and exploitable biomass as of January 1st were estimated by converting age-at-length to weight-at-age data using the following weight-length model (Watanabe et al. 2006):

$$W(kg) = 0.87 \times 10^{-4} * L^{2.67}\ (cm).$$

Spawning biomass as of May 1st was converted from length-at-age to weight-at-age data using (Watanabe et al. 2006):

$$W(kg) = 2.20 \times 10^{-4} * L^{2.48} (cm).$$

Weight-at-age matrices were developed in two stages: for the spawning stock biomass time series, estimates for ages 1.33-8.33 were assumed to be constant over time and were calculated with the growth model of Suda (1966) and the weight-length model used to estimate SSB biomass (above), and for the 9+ age-group, a time-varying weight-at-age vector was estimated (see Kiyofuji et al. 2011 for details).

Growth was modeled internally, using a von Bertalanffy growth curve which was parameterized as $L_1$ = 40.2 cm, $L_\infty$ = 146.46 cm, and K = 0.149 $yr^{-1}$ and weight-length parameters based on the equations shown above. The growth curve parameter estimates were taken from Suda (1966) and are based on scale-aged samples from Japanese fisheries operating in the WPO in the 1950s and early 1960s. Since the maximum age in these samples was 6 years, the curve was extrapolated to older ages to estimate the mean length-at-age of mature albacore. The use of the Suda (1966) growth model differs from the growth model used in the SS base-case model, but is consistent with parameterization in the 2006 assessment.

# 5.0 Results

## 5.1 Model Fit Diagnostics

The performance of the base-case model is assessed by comparing input data with predictions for three data types: abundance indices, length composition, and conditional age-at-length. Total log-likelihood for the base-case model was 67.4 units.

### *5.1.1 Abundance Indices*

The model captured trends in most CPUE indices well and fits to the indices were considered acceptable given the relative weightings (CVs) on these indices (Figure 11). The fit to S1 (F1 - UCLTN) was poor from 2005-2009 when trends in this index conflict with trends in S4 (F5 - JPN PLSF). The model does not fit S2 (F2 – USA LL) well, exhibiting positive residuals early in the series and negative residuals in recent years. This poor fit may be related to the limited area of this index relative to the area of the stock and standardization may not have accounted for changes in catchability related to regulatory changes associated with a 2001-2004 closure of the shallow-set swordfish component of this fishery. Trends in S7 are reflected by the model, but the magnitude of change in this index in the late 1990s early 2000s is not captured well during a period when catches were high (Figure 3). This lack of fit between the mid 1990s and 2000s may be due to a poor fit to the length composition data (see Figure 13 below). Although the model did not fit the S8 index (F12 – TWN LL) particularly well, this index is not informative in the model as preliminary work in which it was removed from a run did not alter the magnitude nor trends in important model outputs.

### *5.1.2 Length Composition*

The model fits the length modes in data aggregated by fleet fairly well considering that the length composition data were down-weighted in the model with lambda = 0.01, but the magnitudes of some modes are not estimated well (Figure 12). These fits may be the result of the clear and relatively stationary modes in the data (Figure 8). Some relatively strong residual trends remain in the length-frequency data of some of the longline fisheries, including the Japanese offshore longline fisheries (F6s1 and F8) (Figure 13). Positive residuals for large fish from the mid-1980s to early 1990s in F6s1 and from the 1980s to mid-1990s in F8 may represent changes in catchability or selectivity. However, attempts to account for selectivity changes in F6s1 using one, two, and three time blocks found that the best model fit and lowest maximum residual for this fishery were obtained using two blocks, i.e., adding a third block to address the positive residual pattern resulted in a poorer model fit to these data. The positive residuals in F8 between the mid-1980s and mid-1990s are unexplained at present, but research to resolve this issue will be a high priority for the next assessment.

#### *5.1.3 Conditional Age-at-Length*

The estimated growth model fits the conditional age-at-length data relatively well, but estimated variability in age-at-length increases with age and there are some misfits for the youngest fish (age-1), older fish (ages 8-11), and the largest fish (ages 14 and 15) (Figure 14). It is not clear at present how much of the observed variability in these data is true variability, and how much variability is related to (1) small sample sizes ranging between 1 and 34 for all ages except 3 and 4 (where N = 67 and 121, respectively), and (2) regional differences in growth rates that are assumed to be negligible in the base-case model. Most of the age-at-length data in Wells et al. (2011) are from EPO samples. If there are regional differences in growth, then there is no simple way to deal with area-growth interactions in the present assessment, but this issue is a high priority recommendation for research in the period between assessments.

### 5.2 Model Parameter Estimates

#### *5.2.1 Growth*

The parameters estimated for the von Bertalanffy growth model in this assessment (Figure 14) were $L_1$ = 44.4 cm, $L_\infty$ = 118.0 cm, K = 0.2495 $yr^{-1}$, $CV_1$ = 0.0599, and $CV_2$ = 0.0339. A von Bertalanffy growth model fitted to the otolith data (Wells et al. 2011) had parameter estimates of $L_\infty$ = 120.0 cm, K = 0.184 $yr^{-1}$, and $t_0$ = -1.945 yr, respectively, providing some corroboration of the base-case model estimates. These estimates differ from the Suda (1966) growth model parameters used in the 2006 assessment, which were $L_1$ = 40.2 cm, $L_\infty$ = 146.46 cm, and K = 0.149 $yr^{-1}$. The most noticeable differences are that Suda estimates a substantially larger $L_\infty$ (146.46 cm) than this assessment and the Suda growth model does not fit the conditional age-at-length data for fish less the age-3 or older than age-6 well (Figure 14).

#### *5.2.2 Selectivity*

All selectivity parameters were relatively well estimated and within their boundaries, although the selectivity curve for F5 had a wider and flatter top than expected (Figure 15). Surface fisheries (F1, F4 and F5) principally exploit fish less than 90 cm in size (ages 2-4), although there is some variation in this selectivity, and the selectivity of larger sizes is low. Two of the longline fisheries (F2 and F8) were modelled with asymptotic selectivity because they consistently harvest the largest fish. The other longline fisheries, particularly F6s1, capture smaller fish and were modelled with dome-shaped selectivity. There is temporal variation in the selectivity of these fisheries as captured by the time blocks employed for F2 and F6s1.

### 5.3 Stock Assessment Results

#### *5.3.1 Biomass*

Total biomass of north Pacific albacore estimated by the base-case model exhibits different trends at the beginning, middle and end of the model period (Figure 16A). Biomass declines from approximately 1.0 million t around 1971 to about 500,000 t by the late 1980s, followed by a steady increase to the highest estimated level (1.2 million t) in 1996. Stock biomass has steadily declined since the mid-1990s to around 800,000 t by 2009 (Figure 16A).

Spawning stock biomass (SSB) estimated by the base-case model has gone through three phases during the modeled time period (Figure 16B): (1) an early phase from the 1966 to the mid-1970's when estimated SSB was relatively high around 400,000 t, (2) a middle phase during the 1980's during which SSB declined to approximately 300,000 t, and (3) a recent period of higher SSB from the 1990's to 2009. During this recent phase, estimated SSB increased and reached its highest level in 1999 (about 504,000 t). The estimated SSB in 2009 is near the historical median of about 400,000 t (Table 10).

#### *5.3.2 Recruitment*

Average estimated recruitment was approximately 48 million fish annually and the estimated CV of the recruitment time series is 0.24 (Table 10). Three periods were apparent in the estimated historical recruitment time series (Figure 16C): (1) a low recruitment period (1978-1987), and (2) two high recruitment periods (1966-1977, 1988-2009). These periods may reflect the influence of changing ocean conditions on stock dynamics, but existing research supporting this hypothesis is limited at present.

#### *5.3.3 Fishing Mortality*

Since retrospective analysis of the assessment model did not reveal any specific bias in estimates of terminal year fishing mortality (see Section 5.5), current fishing mortality for this assessment was defined as the age-specific geometric mean of the estimated annual instantaneous rate of fishing mortality from 2006 to 2008, ($F_{2006\text{-}2008}$). Juvenile albacore experience the highest fishing mortality while adult albacore experience a lower, but relatively stable level of fishing mortality (Figure 17). $F_{2006\text{-}2008}$ increases to a maximum at age-3 and then declines to a relatively low, but stable level through ages 7 to 15 (Figure 17). In addition, $F_{2006\text{-}2008}$ is consistently lower than $F_{2002\text{-}2004}$ (current fishing mortality in the 2006 assessment) up to age-6, after which both measures of F are similar.

### 5.4 Model Convergence

Jitter values of 0.1, 0.2, and 0.3 were randomly added to all parameters and 50 trials were run for each jitter value (Figure 18). Five of 50 trials failed to converge when jitter values of 0.2 and 0.3 were added. Visual inspection of SSB plots shows that trends and absolute scaling are consistent with the base-case model, regardless of the jitter value applied. As jitter values increase, confidence intervals increase, possibly due to changes in selectivity curves, but total model likelihood does not change, remaining at approximately 67 units. Based on these results, the WG concluded that the base-case assessment model is relatively stable and is probably converging on a global minimum.

### 5.5 Retrospective Analysis

Retrospective analyses provide insight into the consistency of stock assessment results and show the same relative trends in the estimates of SSB (Figure 19), i.e., there is no pattern of differences consistent with bias in terminal estimates of SSB. Some uncertainty is present in terminal year point estimates of SSB, but the magnitude of this uncertainty is minimal relative to the confidence intervals around SSB estimates. In contrast, the retrospective analyses show that recent recruitment estimates tend to exhibit much higher uncertainty than SSB, but are not consistently biased (Figure 19). Based on these results, the WG did not use recruitment estimates for 2008 and 2009 in the future projection analysis (see Section 5.8).

## 5.6 Sensitivity to Alternative Assumptions

Sensitivity analyses examined the effects of plausible alternative assumptions on the base-case model results. The sensitivity analyses (Table 5) are categorized into three themes, including (1) data weighting, (2) biology, and (3) selectivity. For each sensitivity run, comparisons of spawning stock biomass and recruitment estimates and trajectories, as well as F-at-age for two temporal periods (2002-2004 and 2006-2008) and likelihood profiles, were completed.

### *5.6.1 Dropping Each CPUE Index*

The purpose of sequentially dropping each CPUE and re-running the base-case model was to assess which CPUE indices were most influential in determining the scaling, trends and trajectories of estimated quantities in the base-case model. Dropping individual indices (setting lambda = 0 for that index in the SS control file) revealed that S7 was the most influential index for scaling and trends in SSB and recruitment (Figure 20). When other indices are removed, the scaling of SSB and to a lesser degree, recruitment, change, but the pattern of trends or trajectory remained consistent with the base-case model. Dropping S1 and S2 scaled SSB up relative to the base-case while dropping all other indices, including S7, scaled SSB down relative to the base-case. S7 had the largest scaling effect on biomass and is the only long term index with asymptotic selectivity. Since S7 covers a the majority of the spawning grounds and spawning seasons of the stock, it is likely highly informative with respect to SSB trends in the model. Furthermore, when CVs were estimated for all indices except S6 (see Section 5.6.3), S2, the other index with asymptotic selectivity, is relatively short term at 19 years in length and covers a small area around the Hawaiian Islands. When S7 is removed, the model has less information on SSB trends and scales estimates down accordingly. For these reasons, the scenario in which S7 is dropped is not unrepresentative of the north Pacific albacore biology because this index is a reliable indicator of adult abundance (see Section 5.6.3).

### *5.6.2 Changing Length Composition Data Weighting*

Up-weighting the length composition data (lambda = 0.025) relative to the base-case weighting (lambda = 0.01) scales SSB and recruitment up, while down-weighting length composition data (lambda = 0.001) relative to the base-case estimates of SSB and recruitment (Figure 21). Changing lambda does not alter trends or trajectories in either quantity. In addition, the F-at-age pattern scales up and down with lambda, but $F_{2006\text{-}2008}$ is consistently lower than $F_{2002\text{-}2004}$.

### *5.6.3 Estimating CVs for CPUE indices*

The weighting (CV) for S6 was fixed = 0.2 in this run because this index is considered to be the most reliable indicator of north Pacific albacore abundance, and the CVs for all other indices were estimated by the model. Although estimating the CVs resulted in more pessimistic SSB and recruitment scenarios (lower absolute estimates) than the base-case model, the trends and trajectory of these quantities did not change (Figure 22). The estimated CVs are:

S1 – 0.387,
S2 – 0.827,

S3 – 0.282,
S4 – 0.309,
S5 – 0.453,
S6 – 0.2 (fixed),
S7 – 0.200, and
S8 – 0.305.

Most of the estimated CVs are similar to the CVs used in the base-case scenario (see Section 4.6), except for S2, which was much greater than assumed in the base-case model, and S7. The estimated CV for S7 indicates that the model considers this index to be a highly dependable abundance indicator. The pattern of F-at-age from this run was similar to the pattern produced by the base-case model and $F_{2006\text{-}2008}$ was consistently lower than $F_{2002\text{-}2004}$.

#### *5.6.4 Growth Parameters Fixed to Suda Estimates*

When the growth parameters were fixed to the Suda (1966) estimates, SSB and recruitment decreased 60% or more relative to the base-case model and F-at-age was much higher for all age classes, with a different pattern and substantially higher F at older ages than in the base-case model (Figure 23). Despite the different F-at-age pattern, $F_{2006\text{-}2008}$ was consistently lower than $F_{2002\text{-}2004}$. Total likelihood of the base-case model was more than 100 units better than the Suda sensitivity run (Figure 23). Examination of historical length frequency data for the stock shows that the largest fish do not exceed 135 cm FL (see Figures 8 and 9). Based on these findings the WG concluded that the von Bertalanffy growth curve parameterization estimated by Suda (1966) is not representative of growth in the north Pacific albacore stock. The Suda (1966) growth curve was based on scale ageing of a limited size range of fish (maximum size was 100 cm FL), which likely compromises its applicability for larger fish since it is extrapolated beyond lengths of 100 cm. The longline fishery from which the aged fish were sampled was operating only in the WPO, but the largest fish are found in the CPO. Thus, regionally biased sampling from the outset was a contributing factor, although this wasn't likely known by Suda (1966) at the time.

Since the 2006 assessment used the Suda growth curve parameters, this sensitivity run was also conducted as a future projection scenario (see Section 5.8.2) to assess the robustness of management advice to this important change in the assessment model.

#### *5.6.5 Steepness (h) = 0.85*

Reducing steepness ($h$) from 1.0 (base-case) to 0.85 increased the scaling of SSB and recruitment and decreased F-at-age relative to the base-case model (Figure 24). Total likelihood of the base-case model is slightly better than the total likelihood for $h$ = 0.85 (Figure 24). The increases in SSB and recruitment, although counterintuitive, are probably related to the model increasing recruitment to compensate for catches removed from the stock due to the absence of information on virgin biomass and recruitment to anchor the stock-recruitment relationship (Figure 25).

#### *5.6.6 Up-weighting Conditional Age-at-Length Data*

Up-weighting the conditional age-at-length data (increasing lambda from 0.1 in the base-case to 1.0) results in slightly higher SSB and recruitment estimates, but the general trends remain unaltered relative to the base-case model results (Figure 26). F-at-age patterns are consistent with the base-case, as is the finding that $F_{2006\text{-}2008}$ is lower than $F_{2002\text{-}2004}$.

### *5.6.7 Natural Mortality = 0.4 $yr^{-1}$*

Changing the assumed natural mortality (M) for all ages from 0.3 $yr^{-1}$ (base-case) to 0.4 $yr^{-1}$ led to higher scaling of SSB and recruitment and a decrease in F-at-age, although $F_{2006\text{-}2008}$ was consistently lower than $F_{2002\text{-}2004}$ (Figure 27). Total likelihood favours the base-case model.

### *5.6.8 Length-based Maturity Schedule*

A sensitivity run assuming a length-based maturity schedule was considered important because the base-case model is length-based, rather than age-based. Using a length-based maturity schedule (length of 50% maturity was 85 cm FL) rather than the age-based maturity schedule in the base case model resulted in a higher scaling of SSB relative to the base-case estimates, but no change in recruitment levels or trends (Figure 28). These results are interpreted as an indication that the maturity schedule may be influential in scaling SSB because the length-based schedule used in this sensitivity run caused age 4 fish to be included in SSB estimates, contrary to the age-based schedule (age-5 and older). Further research is needed between assessments to develop an appropriate length-based maturity schedule.

### *5.6.9 Asymptotic Selectivity for F6*

Assuming asymptotic (logistic) selectivity for F6 rather than the dome-shaped selectivity pattern applied in the base-case model results in substantially lower SSB and recruitment relative to the base-case model results, but no changes in the trends for either quantity (Figure 29). F-at-age is higher and importantly, F-at-age for large fish caught by longline is higher relative to F-at-age of younger fish caught by surface fisheries. The impact on total likelihood is substantial, increasing likelihood by more than 10 units relative to the base-case model, i.e., the assumption of asymptotic selectivity for F6 leads to a poorer fitting model.

### *5.6.10 Removal of Selectivity Time-blocks*

Removing time blocks one-by-one for selectivity on fisheries F2, F6, and F14 lowered the scaling of SSB relative to the base-case model results for all time blocks removed, but did not have much impact on recruitment levels or trends (Figure 30). F-at-age patterns were identical to the base-case model and $F_{2006\text{-}2008}$ was consistently lower than $F_{2002\text{-}2004}$, regardless of which time-block was removed. Selectivity patterns in other fisheries did not change (Figure 31). These findings support the conclusion that the use of time blocks in the base-case model is consistent with the available data. Removal of time-blocks also led to a poorer overall fit to the data as reflected by higher total log-likelihood values.

### *5.6.11 Summary of Sensitivity Analyses*

The scaling of SSB estimated by the base-case model is substantially affected by (1) the relative weighting of abundance indices and length composition data; (2) removing the S7 abundance index, (3) the selectivity assumption for fishery F6; (4) a length-based maturity schedule; and (5) the growth curve. Although recruitment estimates were also affected by these alternative assumptions, the magnitude of change was less than observed for SSB estimates. The pattern of F-at-age was affected only by fixing the growth curve to the Suda (1966) parameter estimates and the selectivity assumption for fishery F6 and for both runs F-at-age for adult fish (age-5 and older) was higher relative to F-at-age in other sensitivity runs. $F_{2006\text{-}2008}$ is consistently lower than $F_{2002\text{-}2004}$ regardless of the pattern of F-at-age in all sensitivity runs, and SSB and recruitment trajectories remain relatively consistent with the base-case model. Sensitivity runs examining the impacts of higher natural mortality and up-weighting of the conditional age-at-length data had relatively little impact on model estimated quantities. Although there is uncertainty in absolute estimates of SSB and recruitment, $F_{SSB}$ calculations are relatively less affected because the pattern of trends in SSB and recruitment were robust to alternative assumptions. Collectively these sensitivity runs point to uncertainty in the absolute estimates of biomass and fishing mortality while the trends in these parameters are remained relatively robust to the different assumptions that were tested. The F-at-age patterns for the Suda growth curve and the F6 asymptotic selectivity runs are exceptions to the pattern robustness: both runs produced F-at-age patterns consistent with the previous assessment, particularly the Suda growth curve run.

## 5.7 Ancillary Analyses

### *5.7.1 Fishery Impact Analysis*

The magnitude of differences in the simulated spawning biomass trajectories with and without fishing indicates the impact of the major fishery types on the SSB of north Pacific albacore (Figure 32). Surface fisheries, which harvest the smaller immature juvenile fish, had the largest impact on SSB for almost the entire modeled period, especially during 1970s and 1980s. The impact of longline fisheries on the stock increased after the mid-1990s and in recent years is closer to the impact of surface fisheries. The increased longline impact may be related to a concurrent decline in surface fishery effort at the same time. The impact of “other” fisheries was usually minimal relative to the surface and longline categories. However, the impact of these fisheries was marginally greater during late 1980s and 1990s when high seas driftnet fishing was occurring prior to the implementation of a ban in 1993, although their overall influence on SSB remained small relative to the impact of the surface and longline fisheries.

### *5.7.2 Yield Analysis*

The yield and spawning potential curves were calculated for the longline, surface, and other fisheries categories (Figure 33). Most of the yield is achieved from the surface fisheries and is maximised at $F_{MULT}$ = 7.29 for an equilibrium yield of 185,913 t per year, but an equilibrium spawning biomass of only 11,186 t. At $F_{MULT}$ = 1.0 (current $F_{2006\text{-}2008}$), the equilibrium yield is approximately 93,326 t while spawning potential ratio (SPR) is about $F_{52\%}$ or 443,775 t SSB in 2009, which is much higher than $F_{17\%}$ estimated in the 2006 assessment (ALBWG 2007). The $F_{SSB\text{-}ATHL}$ reference point occurs at an $F_{MULT}$ = 1.41, meaning that the fishing mortality to reach this point is 41% greater than $F_{2006\text{-}2008}$. Increasing $F_{2006\text{-}2008}$ by 41% to $F_{SSB\text{-}ATHL}$ would provide a 24% increase in yield and result in a 23% decrease in SPR. Little of the increased yield is would be attainable from longline fisheries, most of the increase would occur in the surface fisheries (Figure 33) and achieving these increases in F and yield would require an even higher increase in fishing effort.

## 5.8 Future Projections

The base-case model configuration for future projections of albacore population dynamics assumes current fishing mortality ($F_{2006\text{-}2008}$) and random resampling of historically estimated recruitment (1966-2007) during the stock assessment period (Figure 34). A 25-yr projection period from 2010 to 2035 was used. Retrospective analysis of the base-case model (Figure 19) demonstrated that although recruitment estimates in 2008 and 2009 were not biased, these estimates were relatively uncertain. As a result these years were removed from the time series for future projections. In addition, low recruitment (1978-1987) and high recruitment (1988-2004) phases in the estimated historical recruitment time series were identified and used for independent sensitivity runs. Recruitment scenarios and average recruitment levels are:

1. Base-case: 1966 to 2007, average R = 47,895,000, CV = 0.24;
2. Run 2: low recruitment, 1978 to1987, average R = 35,171,000, CV = 0.16; and
3. Run 3: high recruitment, 1988-2004, average R = 54,373,000, CV = 0.22.

### *5.8.1 Base-case Scenario Projections*

Box plots of projected recruitment, SSB, and total catch for the base-case scenario using $F_{2006-2008}$, and $F_{2002-2004}$ are shown in Figure 35. Under the base-case scenario ($F_{2006-2008}$), SSB is expected to fluctuate around the historical median SSB, while harvesting at $F_{2002-2004}$ would result in a decrease of future median SSB to below the base-case scenario. Because $F_{2006-2008}$, is lower than $F_{2002-2004}$ (Figure 17), future SSB is higher than the $F_{2002-2004}$ harvesting scenario. The median SSB in the constant catch scenario increases relative to the constant $F_{2006-2008}$ scenario (Figure 36), but the increase is moderate and does not represent a viable future scenario in the judgement of the WG.

### *5.8.2 Alternative Recruitment and Sensitivity Run Projections*

Alternative recruitment scenarios and structural sensitivity runs produced future median SSB trajectories, after scaling the results to $SSB_{2008}$, that were similar to the base-case model (Figure 37). $SSB_{2008}$ was used to scale these results because it is approximately equal to the historically observed median SSB level in the base-case model (~400.000 t). Only the low recruitment and $F_{2002-2004}$ harvesting scenarios resulted in forecasts in which SSB declines relative to $SSB_{2008}$. All other sensitivity runs resulted in future SSB about 15% above $SSB_{2008}$. The low recruitment scenario led to the largest decrease in future SSB, with the median SSB stabilizing at about 70% of $SSB_{2008}$ and was the only scenario in which the probability that future median SSB would fall below SSB-ATHL by the end of the projection period was greater than 50% (Table 11). Future SSB levels relative to current SSB in 2008 were relatively insensitive to alternative structural assumptions and recruitment scenarios. If the average historical recruitment and fishing mortality ($F_{2006-2008}$) do not change, then SSB is expected to fluctuate around the historical median level in the short-term and over the 25-yr projection period.

## 5.9 Biological Reference Points

An interim management objective to maintain SSB of north Pacific albacore above the average of the ten historically lowest estimated points (ATHL) with a probability greater than 50% was established in 2008 (Northern Committee 2008). The NC requested that the ALBWG evaluate the status of the north Pacific albacore stock against $F_{SSB\text{-}ATHL\ 50\%}$ for a 25-yr projection period. $F_{SSB\text{-}ATHL\ 50\%}$ is the fishing mortality, F, that will lead to future minimum SSB falling below the SSB-ATHL threshold level with a probability of 50% at least once during the projection period (2010-2035).

The $F_{SSB-ATHL}$ reference point is one of a group of simulation-based biological reference points (BRP) using SSB thresholds proposed by Conser et al. (2005) for north Pacific albacore. Unlike other BRPs used in fisheries management, $F_{SSB}$ is not based on an equilibrium concept and therefore does not assume that future SSB or yield will remain constant at some specified level. As a simulation-based BRP, $F_{SSB-ATHL}$ can incorporate non-equilibrium dynamics, uncertainty in stock size estimates and other parameters, as well as uncertainty in future recruitment.

The SSB-ATHL threshold can be derived from point estimates of SSB or bootstrap estimates of ATHL. Uncertainty in the estimated SSB time series was evaluated with parametric bootstrap analysis (Figure 38) and the results demonstrated that point estimates of SSB are subject to high uncertainty and are negatively biased relative to the median of the bootstrap estimates for the time series. Based on these findings, an SSB-ATHL threshold level was estimated in each bootstrap iteration and these estimates were used in calculating $F_{SSB-ATHL}$ since using a point estimate does not properly reflect the effect of future harvesting strategies (Ichinokawa 2011a). Using the bootstrap estimates of SSB-ATHL captures some of the uncertainty in the historical spawning biomass estimates and may, therefore, be a conservative estimate of this quantity.

### *5.9.1 $F_{SSB-ATHL-50\%}$ Reference Point*

The sensitivity of $F_{SSB-ATHL}$ estimates to different recruitment scenarios and structural assumptions described in Section 5.8 is shown in Table 12 using the ratio of $F_{2006-2008}/F_{SSB-ATHL}$ (F-ratio). The F-ratio in the base-case projection is estimated to be 0.71, which means that $F_{2006-2008}$, i.e., current F, is about 30% lower than the F that will result in future SSB falling below the SSB-ATHL threshold level at least once during the 2010-2035 projection period. Although the estimated $F_{SSB-ATHL}$ depends on future projection scenarios, the F-ratios of most $F_{SSB-ATHL}$ estimates are well below 1.0, except in the low recruitment and Suda growth curve runs, where the ratio is approximately 1.0. However, the Suda growth curve run is not a plausible scenario because the Suda growth curve is not representative of growth in this stock (see Section 5.6.4). Consequently, the WG concluded that $F_{SSB-ATHL}$ and the resulting advice based on this reference point is probably robust to alternative structural assumptions in the base-case model. Some caution is needed when interpreting these results since the projections over 25 years assume recruitment fluctuates around the historical average while the data show that recruitment for this stock is quite variable during the modeled period (Figure 34). For example, if future recruitment is lower than the historical average level by 25% on average (low recruitment scenario), then the risk that future SSB could fall below SSB-ATHL increases to 54% (Table 11). Therefore, developing a better understanding of environmental factors affecting recruitment is an important research recommendation.

### *5.9.2 Other Candidate Reference Points*

No other reference points are currently used in north Pacific albacore management. A suite of candidate reference points and their associated estimates from the base-case model are presented when discussing stock status (Section 6.1).

## 5.10 VPA Results

The VPA reference run in which the model was configured similar to the SS base-case model reproduces the SSB and recruitment time series estimated in the 2006 assessment well up to

2000 (Figure 39). Biomass trends since 2000 are on average higher, at approximately 115,000 t, and flatter in the current reference run than the 2006 model results (Figure 39A) probably as a result of four additional years of data and changes in the model configuration to six age-aggregated fisheries. The estimated SSB in 2009 (about 143,500 t) was 40% above the overall estimated time series average (102,300 t). Recruitment declined from 1970 to 1988 and has remained between 20 and 45 million fish since 1994, near the middle of the range for the entire time series (Figure 39B).

Overall trends in F-at-age were similar for all ages in the reference run and the 2006 assessment (Figure 40). One important difference is that F-at-age for the oldest fish has decreased while F-at-age 4 has increased since 2005 in the reference run, relative to the 2006 assessment results. The reduction in F-at-age on mature fish may account for the more optimistic SSB trends since 2000 in the reference run relative to the 2006 assessment results. Overall, $F_{2006\text{-}2008}$ is lower than $F_{2002\text{-}2004}$, which is consistent with the SS base-case model results.

### 5.11 SS3 Base-case Model and VPA Reference Run Comparison

Both the base-case model and the VPA reference run estimated similar historical trends in SSB and recruitment but a comparison of these trends shows there is uncertainty in the absolute estimates of these quantities, especially biomass (Figure 41). Both the base-case model and the VPA reference run estimate that $F_{2006\text{-}2008}$ is lower than $F_{2002\text{-}2004}$ (Figures 17 and 40) and that the pattern of F-at-age has shifted from being highest on mature age classes to highest on juvenile age classes. This shift in F-at-age is consistent with results of fishery impact analysis, which shows that the surface fisheries capturing juveniles have the largest impact on biomass levels in this stock historically and in recent years (Figure 32).

A sensitivity run of the base-case model in which growth parameters were fixed to Suda (1966) parameter estimates used in the VPA reference run reduced the scaling of SSB to the level of the VPA reference run (Figure 41) and produced an F-at-age pattern in which F is highest on mature age classes and lowest on juvenile age classes, consistent with the 2006 assessment results (ALBWG 2007). Freeing the growth parameters in the base-case model improved the fit to the age and length data by about 100 likelihood units relative to fixing the growth parameters to the externally estimated Suda values, primarily through the effect of reducing $L_\infty$ and increasing $L_1$ in order to better fit to the length-at-age information. The Suda growth curve predicts much higher mean length-at-age for mature fish, especially the oldest ages, than observed in size composition data and as a result, the model imposes high fishing mortality on older age groups to account for the difference between expected and observed, resulting in the similar F-at-age patterns produced by the sensitivity run (Figure 23) and the VPA reference run (Figure 40). However, the WG does not consider the Suda (1966) growth model to be plausible for the north Pacific albacore stock (see Section 5.6.45). Recent sampling for otolith ageing (Wells et al. 2011; Chen et al. 2011; see Figure 14) supports the conclusion that the Suda (1966) growth curve parameters used in the 2006 assessment are not representative of growth in the north Pacific albacore stock. Based on the agreement in trends of estimated quantities between the VPA reference run and the SS base-case model and the ability to explain the scaling differences between models, the WG concluded that the SS base-case model is representative of the population dynamics and abundance of north Pacific albacore and that this model will replace the VPA as the principal model for north Pacific albacore assessments.

# 6.0 Current Stock Status and Conservation Advice

## 6.1 Stock Status

The SS base-case model estimates that SSB has fluctuated between 300,000 and 500,000 t between 1966 and 2009 (Figure 16) and that recruitment has averaged 47.9 million fish annually during this period (Table 10). Although the sensitivity analyses reveal uncertainty in absolute estimates of biomass and recruitment, stock status and conservation advice are relatively insensitive to these uncertainties as trends in SSB and recruitment are robust to the different plausible assumptions that were tested. Given the model fits to the data and sensitivity analyses based on conservative parameters, the base-case model is considered to be relatively stable and to produce a reasonable representation of the history of stock abundance and F-at-age (Figures 16 and 17). Actual stock parameters may be higher so estimated quantities such as biomass probably are not substantial over estimates of true abundance. The current assessment results confirm that $F_{2006\text{-}2008}$ has declined relative to $F_{2002\text{-}2004}$, which is consistent with the intent of previous conservation advice (i.e., no increase in F beyond the current level defined as $F_{2002\text{-}2004}$ - ALBWG 2007).

Estimates of $F_{2006\text{-}2008}$ (current F) relative to several F-based reference points used in fisheries management are presented in Table 13. These estimates are expressed as the ratio of $F_{2006\text{-}2008}/F_{\text{ref point}}$, which means that when the ratio is less than 1.0, $F_{2006\text{-}2008}$ is below the reference point estimate. The $F_{MAX}$, $F_{MED}$ and $F_{0.1}$ reference points are based on yield-per-recruit analysis while the $F_{20\text{-}50\%}$ reference points are spawning biomass-based proxies of $F_{MSY}$. Since the steepness of the base-case model is 1.0, $F_{MAX}$ is mathematically equivalent to $F_{MSY}$ for the base-case model. The F-ratio for $F_{SSB\text{-}ATHL}$ is 0.71 and based on yield analysis results (Figure 33) a 41% increase in current F would be required to achieve $F_{SSB\text{-}ATHL}$ (F-multiplier = 1.41 in Figure 33). The SPR at $F_{2006\text{-}2008}$ is $F_{52\%}$ (see Section 5.7.2, Figure 33) which is about three times higher than $F_{17\%}$ estimated in the 2006 assessment (ALBWG 2007) using the implausible Suda (1966) growth model. Increasing $F_{2006\text{-}2008}$ by 41% to $F_{SSB\text{-}ATHL}$ results in a 24% increase in yield and 23% decrease in SPR. Most of the yield increase would occur in the surface fisheries (Figure 33) and achieving these increases in F and yield would probably require a greater proportionate increase in fishing effort. Since $F_{2006\text{-}2008}$ is close to $F_{MED}$ and well below $F_{SSB\text{-}ATHL}$ and the MSY proxies ($F_{20\text{-}50\%}$), the WG concludes that overfishing of the north Pacific albacore stock is unlikely to be occurring at present.

Spawning biomass is currently around the long-term median for the north Pacific albacore stock (~400,000 t) and is expected to fluctuate around the historical median SSB in the future, assuming average recruitment levels continue and fishing mortality remains at $F_{2006\text{-}2008}$ levels. The probability that SSB will fall below the SSB-ATHL threshold at least once during the projection period (2010-2035) is about 1% (Table 11). The WG concludes that overfishing is not occurring and that the stock likely is not in an overfished condition, although biomass-based reference points have not been established for this stock. However, the risk that SSB will fall below the SSB-ATHL threshold by the end of the projection period increases to 54% if recruitment declines substantially (about 25%) below the current average historical recruitment level (Table 11).

### 6.2 Conservation Advice

The north Pacific albacore stock is considered to be healthy at current levels of recruitment and fishing mortality. The sustainability of the stock is not threatened by overfishing as current $F_{2006-2008}$ is about 71% of $F_{SSB-ATHL}$ and the stock is expected to fluctuate around the long-term median SSB (~400,000 t) in the short- and long-term future given average historical recruitment levels and constant fishing mortality at $F_{2006-2008}$ (Figure 36). However, a more pessimistic recruitment scenario increases the probability that the stock will not achieve the management objective of remaining above the SSB-ATHL threshold with a probability of 50%. Thus, if future recruitment declines about 25% below average historical recruitment levels due either to environmental changes or other reasons, then the impact of $F_{2006-2008}$ (current F) on the stock is unlikely to be sustainable. The current assessment results confirm that F has declined relative to the 2006 assessment, which is consistent with the intent of the previous recommendations (ALBWG 2007). Therefore, the working group does not recommend changes to the present management measures.

## 7.0 Research Recommendations

The 2011 assessment of north Pacific albacore is based on the best available biology, fishery data, and modeling techniques at this time. Nevertheless, several research recommendations were identified during the assessment process that could improve the assessment model. These recommendations are categorized into six areas and for each recommendation priorities and achievability by the next assessment were assigned. The research recommendations are:

### 7.1 Age and growth modeling

i. Improved sampling from all regions, particularly focusing on fish < 60 cm and fish greater than 85 cm FL (**high priority, achievable by next assessment**)
ii. Validation of aging procedures (annulus) and comparison of aging by multiple readers (**high priority, achievable by the next assessment**)
iii. Daily growth ring analysis of otoliths from young albacore to validate aging, especially time of annulus formation, and investigate growth patterns in young fish (**high priority, achievable**)
iv. Further investigation into regional differences in growth rates in central, eastern and western Pacific (**high priority, achievability by next assessment uncertain**)
v. Combine results of Chen et al. (2011) and Wells et al. (2011) (**high priority, achievability by next assessment uncertain**)
vi. Further investigation into the appropriate growth model for albacore (Richards, von Bertalanffy, Gompertz, etc.) after enhanced sampling (**high priority, achievability for next assessment uncertain since it depends on the sampling time frame**)

vii. Document currently available samples on sampling plan to determine where further effort is needed (**low priority, achievable by next assessment**)

### 7.2 Spatial Patterns Analysis

i. Explore existing tagging data to determine if further effort is needed and design statistically justified program, e.g., to estimate natural mortality, estimate growth in different regions, ground-truth abundance estimates (**high priority, achievability by next assessment uncertain**)
ii. Investigate spatial and temporal distribution by size to assist in fishery definitions (**high priority, achievable by next assessment)**
iii. Investigate spatial and temporal changes in size composition of JPN LL fisheries to support the use of appropriate selectivity (**high priority, achievable by next assessment)**
iv. Investigate spatial and temporal changes in size composition of TWN LL fisheries to support the use of appropriate selectivity (**high priority, achievable by next assessment**)
v. Cooperative tagging (pop-up satellite, archival) of large albacore to understand movement patterns of mature fish and bring movement into the model **(medium priority, achievability long-term beyond next assessment)**
vi. Cooperative tagging (pop-up, archival) of young albacore in the western Pacific to understand their movement patterns and bring movement into the model **(medium priority, achievability long-term beyond next assessment)**
vii. Cooperative sampling for otolith microchemistry (stable isotopes, trace elements) across regions **(medium priority, achievability long-term beyond next assessment)**

### 7.3 CPUE Analysis

i. F8 (JPN LL south) increases and decreases in 1990s, the model cannot explain these trends so further exploration is needed (**high priority, uncertain if complete resolution achievable for next assessment**)
**ii.** Document the development and trends of the F6s1 quarterly CPUE index (**high priority, achievable by next assessment)**
iii. Split the USA LL fishery into shallow-set and deep-set fisheries (**high priority, achievable by next assessment)**
iv. Investigate different CPUE trends in surface fisheries in EPO (UCLTN) and WPO (JPN PL) since 2005 (**high priority, achievable by next assessment**)
v. Investigate CPUE standardization procedures, GLM vs. Delta log-normal, etc. to improve indices. Should take advice developed at ISC11 plenary session, into account (**low priority, achievable by next assessment**)

### 7.4 Maturity

i. Samples of maturity by length are required to determine length at which 50% are mature (**medium priority, achievability uncertain by next assessment as depends on new sampling**)

ii. Improved sampling of large fish in central and eastern Pacific is needed to determine if spawning occurs, when it occurs, and fecundity by length (**low priority, achievability long-term beyond next assessment**)

### 7.5 Data Issues

i. Investigate length composition anomalies in USA LL fishery with respect to very large fish (**high priority, achievable by next assessment)**
ii. Document historical socio-economic factors of fisheries to understand changes in fishing grounds, fishing strategies, market developments that may influence CPUE (**high priority, achievable by next assessment)**
iii. Provide information on targeting practices and effort in all fisheries (**high priority, achievable by next assessment**)
iv. Document existing national sampling programs (**high priority, achievable by next assessment)**

### 7.6 SS3 Model Improvements

i. Explore scaling in the model, including weighting of different information sources (**high priority, achievability uncertain by next assessment)**
ii. Explore the stock-recruitment relationship, especially steepness estimate **(high priority, achievable by next assessment)**
iii. Explore the incorporation of explicit spatial structure and sex-specific growth in the model (**medium priority, achievability long-term beyond the next assessment**)
iv. Incorporate existing conventional tagging data into the model (**high priority, achievable by next assessment**)
v. Explore the impact of environmental covariates on abundance indices, movement patterns, etc. (**medium priority, achievable by next assessment**)

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**Table 1.** Descriptions and numbers of fisheries defined for the SS3 base-case assessment model.

| Fishery | Fishery Description | Boundaries and Seasonal Coverage |
|---|---|---|
| F1 | USA/Canada troll & pole-and-line (UCLTN) | • 10-55°N latitude by 160°E-120°W longitude |
| F2 | USA longline (USA LL) | • 10-45°N latitude by 170°E-130°E longitude |
| F3 | EPO miscellaneous (EPOM) | • EEZ waters along the coasts of USA, Canada and Mexico |
| F4 | Japan pole-and-line (south) – large average-sized fish (JPN PLLF) | • 25-35°N latitude by 130°E-180° longitude in Q2 |
| F5 | Japan pole-and-line (north) – small average-sized fish (JPN PLSF) | • 35-45°N latitude by 140°E-180° longitude in Q2 and Q3 |
| F6s1 | Japan offshore longline (north / season 1 / numbers of fish) – smaller average-sized fish (JPN OLLF1S1 | • 25-40°N latitude by 120°W-180° longitude in Q1 |
| F6s2 | Japan offshore longline (north / season 2 / numbers of fish) – smaller average-sized fish (JPN OLLF1S2) | • 25-40°N latitude by 120°E-180° longitude in Q2 |
| F7s1 | Japan coastal longline (north / season 1 / weight) – smaller average-sized fish (JPN CLLF1S1) | • 25-40°N latitude by 120°E-180° longitude in Q1 |
| F7s2 | Japan coastal longline (north / season 2 / weight) – smaller average-sized fish (JPN CLLFS2) | • 25-40°N latitude by 120°E-180° longitude in Q1 |
| F8 | Japan offshore longline (south / north s3-4 / numbers of fish) – larger average-sized fish (JPN OLLF2) | • 25-40°N latitude by 120°E-180° longitude in Q3 and Q4<br>• 25-40°N latitude by 120°W-180° longitude in Q2-Q4<br>• 10-25°N latitude by 120°E-120°W longitude all year round |
| F9 | Japan coastal longline (south / north s3-4 / weight) – larger average-sized fish (JPN CLLF2) | • 25-40°N latitude by 120°E-180° longitude in Q3 and Q4<br>• 10-25°N latitude by 120°E-120°W longitude all year round |
| F10 | Japan gill net (JPN GN) | • 20-55°N latitude by 120°E-160°E longitude |
| F11 | Japan miscellaneous (JPN M) | • E.E.Z. along Japan coasts |
| F12 | Taiwan longline (TWN LL) | • 10-55°N latitude by 120°E-120°W longitude |
| F13 | Korea and Others longline (KO LL) | • 10-55°N latitude by 120°E-120°W longitude |
| F14 | Taiwan and Korea gill net (TK GN) | • 20-55°N latitude by 120°E-180° longitude |

**Table 2.** Standardized indices (CPUE) of relative abundance used in the SS3 base-case assessment model. See Table 1 for fishery numbers and acronyms.

| Index | Fishery description | Time series | Reference |
|---|---|---|---|
| S1 | USA/CAN troll and pole-and-line (F1 - UCLTN) | 1966-2009 | Teo et al. (2010) |
| S2 | USA longline (F2 - USA LL) | 1991-2009 | |
| S3 | Japan pole-and-line (F4 - JPN PLLF) | 1972-2009 | Kiyofuji and Uosaki (2010) |
| S4 | Japan pole-and-line (F5 - JPN PLSF) | 1972-1984 | |
| S5 | Japan pole-and-line (F5 - JPN PLSF) | 1985-2009 | |
| S6 | Japan longline (F6 - JPN OLLF1 and F7 - JPN CLLF1) | 1972-2009 | Matsumoto (2010) |
| S7 | Japan longline (F8 - JPN OLLF2 and F9 - JPN CLLF2) | 1972-2009 | |
| S8 | Taiwan longline (F12 – TWN LL) | 1995-2009 | Chen et al. (2010b) |

**Table 3.** North Pacific albacore annual abundance indices developed for the SS3 base-case model. Units are weight (JPN PL fisheries) and number of fish (all other indices). Main season refers to annual quarters where 1 = Jan-Mar, 2 = Apr-June, 3 = July-Sept, and 4 = Oct-Dec.

| | **UCLTN** | **USA LL** | **JPN PL2 - larger fish** | **JPN PLL3 - smaller fish (early period)** | **JPN PL3 - smaller fish (late period)** | **JPN LL (Fishery I- smaller fish)** | **JPN LL (Fishery II- larger fish)** | **TWN LL** |
|---|---|---|---|---|---|---|---|---|
| Index | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
| Main season (quarter) | 3 | 3 | 2 | 3 | 3 | 1 | 1 | 1 |
| 1966 | 90.8459 | | | | | | 1.4360 | |
| 1967 | 138.7865 | | | | | | 1.3868 | |
| 1968 | 112.9091 | | | | | | 1.2618 | |
| 1969 | 99.6598 | | | | | | 1.0029 | |
| 1970 | 127.4874 | | | | | | 1.1782 | |
| 1971 | 95.9675 | | | | | | 0.8721 | |
| 1972 | 80.0587 | | 0.0370 | 0.0528 | | 4.1144 | 1.1120 | |
| 1973 | 86.6313 | | 0.0394 | 0.0499 | | 4.6954 | 1.5249 | |
| 1974 | 108.1492 | | 0.0453 | 0.0553 | | 4.9615 | 1.6459 | |
| 1975 | 116.1248 | | 0.0471 | 0.0447 | | 3.1809 | 1.6475 | |
| 1976 | 77.8496 | | 0.0381 | 0.0485 | | 3.8288 | 1.5381 | |
| 1977 | 55.8463 | | 0.0298 | 0.0236 | | 3.1139 | 1.7913 | |
| 1978 | 82.3323 | | 0.0286 | 0.0531 | | 2.9052 | 1.1290 | |
| 1979 | 54.7658 | | 0.0393 | 0.0464 | | 2.8797 | 1.1446 | |
| 1980 | 42.1214 | | 0.0408 | 0.0504 | | 2.6038 | 1.0934 | |
| 1981 | 59.3827 | | 0.0325 | 0.0152 | | 2.7981 | 1.0418 | |
| 1982 | 49.3858 | | 0.0345 | 0.0388 | | 3.1905 | 1.5286 | |
| 1983 | 60.3264 | | 0.0324 | 0.0313 | | 2.8958 | 1.6136 | |
| 1984 | 64.5650 | | 0.0389 | 0.0362 | | 3.1064 | 1.2419 | |
| 1985 | 79.0365 | | 0.0404 | | 0.0172 | 2.7365 | 1.1721 | |
| 1986 | 47.0426 | | 0.0352 | | 0.0287 | 2.8996 | 1.2760 | |
| 1987 | 34.0500 | | 0.0316 | | 0.0179 | 2.5192 | 1.1635 | |
| 1988 | 71.1995 | | 0.0428 | | 0.0093 | 2.7794 | 1.0149 | |
| 1989 | 32.5861 | | 0.0432 | | 0.0152 | 3.0032 | 1.0240 | |
| 1990 | 46.2233 | | 0.0436 | | 0.0342 | 3.9338 | 1.0364 | |
| 1991 | 44.0167 | 1.7392 | 0.0385 | | 0.0555 | 3.3750 | 1.2123 | |
| 1992 | 69.1531 | 2.1348 | 0.0678 | | 0.0365 | 3.0558 | 1.0655 | |
| 1993 | 58.7956 | 2.4073 | 0.0333 | | 0.0259 | 5.1161 | 1.4425 | |
| 1994 | 94.5308 | 3.0313 | 0.0411 | | 0.0714 | 4.7830 | 1.6906 | |
| 1995 | 55.5957 | 4.3978 | 0.0868 | | 0.0519 | 4.0916 | 2.3395 | 29.4674 |
| 1996 | 85.5895 | 5.8160 | 0.0420 | | 0.0289 | 5.1974 | 2.6887 | 49.8742 |
| 1997 | 49.1973 | 6.5153 | 0.0658 | | 0.0746 | 5.6403 | 3.5928 | 45.7498 |
| 1998 | 146.1602 | 4.4589 | 0.0374 | | 0.0709 | 5.3485 | 4.3474 | 21.2906 |
| 1999 | 54.2124 | 5.8205 | 0.0616 | | 0.0473 | 4.0164 | 4.0053 | 20.3758 |
| 2000 | 65.5909 | 2.3632 | 0.0416 | | 0.0386 | 4.0671 | 4.3854 | 21.4379 |
| 2001 | 95.8247 | 3.3225 | 0.0336 | | 0.0506 | 3.5976 | 3.9174 | 12.9967 |
| 2002 | 145.2481 | 1.0681 | 0.0599 | | 0.0918 | 4.3971 | 3.4494 | 12.3165 |
| 2003 | 134.3242 | 0.8901 | 0.0426 | | 0.0450 | 3.4019 | 2.4393 | 13.7703 |
| 2004 | 166.2718 | 0.9744 | 0.1051 | | 0.0253 | 2.4395 | 1.8594 | 8.2501 |
| 2005 | 82.6032 | 0.6818 | 0.0463 | | 0.0381 | 4.3689 | 1.7994 | 8.7805 |
| 2006 | 180.3983 | 0.5378 | 0.0436 | | 0.0352 | 3.9390 | 2.3460 | 13.5438 |
| 2007 | 106.0199 | 0.4105 | 0.0705 | | 0.0409 | 3.3796 | 2.4588 | 13.8258 |
| 2008 | 110.3124 | 0.6077 | 0.0352 | | 0.0134 | 3.3634 | 2.0355 | 16.4724 |
| 2009 | 122.7863 | 0.4537 | 0.0440 | | 0.0296 | 3.1821 | 2.0127 | 14.0754 |

**Table 4.** Estimated spawning stock biomass for several tuna species and stocks at the beginning and end of the assessment time period used to determine a down-weighting value (lambda) for length composition data in the 2011 assessment of north Pacific albacore.

| Species | Stock | Assessment Year | Assessment period | Reference | Spawning biomass estimates (x 1000's t) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Start | High | Low | End |
| albacore | North Pacific | 2006 | 1966-2005 | ALBWG (2007) | 60 | 160 | 60 | 115 |
| albacore | North Pacific | 2004 | 1975-2003 | Stocker (2005) | 60 | 120 | 50 | 110 |
| albacore | South Pacific | 2006 | 1960-2005 | Langley and Hampton (2006) | 390 | 500 | 270 | 270 |
| albacore | South Pacific | 2009 | 1960-2008 | Hoyle and Davies (2009) | 460 | 506 | 253 | 274 |
| albacore | North Atlantic | 2009 | 1930-2007 | ICCAT (2010) | 150 | 170 | 20 | 40 |
| albacore | South Atlantic | 2007 | 1956-2005 | ICCAT (2008) | 290 | 290 | 70 | 80 |
| Pacific bluefin | Pacific | 2006 | 1952-2005 | PBFWG (2006) | 100 | 170 | 20 | 80 |
| Atlantic bluefin | Eastern Atlantic | 2008 | 1970-2006 | ICCAT (2009) | 250 | 300 | 100 | 100 |
| Atlantic bluefin | Western Atlantic | 2008 | 1970-2007 | ICCAT (2009) | 45 | 45 | 7 | 8 |
| Southern bluefin | Southern bluefin | 2009 | 1931-2009 | CCSBT (2009) | 1,000 | 1,000 | 45 | 45 |
| bigeye | WCPO | 2009 | 1952-2007 | Harley et al. (2009) | 600 | 600 | 100 | 100 |
| bigeye | EPO | 2010 | 1975-2009 | Aires-da-Silva and Maunder (2011) | 210 | 230 | 80 | 100 |
| yellowfin | WCPO | 2009 | 1952-2008 | Langley et al. (2009) | 5,000 | 7,500 | 1,500 | 1,500 |

**Table 5.** Sensitivity analyses of the north Pacific albacore base-case model in 2011.

**Data weighting**

- Dropping each CPUE one-by-one by setting lambda = 0
- Up-weight and down-weight length composition data relative to the base-case model with lambda = 0.025 and 0.001, respectively
- Fix CV for S6 = 0.2, estimate CVs for all other CPUE indices

**Biological assumptions**

- Replace estimated growth curve with fixed Suda growth curve (continue to use ageing data)
- Reduce steepness (h) from 1.0 (base case) to 0.85
- Increase weighting of conditional age-at-length data from lambda = 0.1 (base-case) to lambda = 1.0
- M = 0.4 for all ages
- Use length-based maturity schedule in place of age-based schedule in the base-case

**Selectivity**

- Assume F6 selectivity is asymptotic using logistic form (flat-topped)
- Remove time blocks for selectivity one-by-on on fisheries F2, F6, and F14

**Table 6.** Summary of future projections for the base-case, low and high recruitment scenarios, and sensitivity runs performed during the stock assessment of north Pacific albacore.

| | Fssb scenario | | | | | | | Sensitivity scenarios | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base case | Run 1 (Previous current F) | Run 2 (Low recruit) | Run 3 (High recruit) | Run 4 (growth curve) | Run 5 (Length lambda) | Run 6 (Steepness=0.85) | Starting year = 2009 | Starting year =2007 | Current F definition | CC scenario |
| SS scenario | Base case | | | | Using suda's growth | Length lambda= 0.001 | Steepness=0.85 | | | | |
| Recruitment | Random sampling from 1966-2007 | | Random sampling from 1978-1987 | Random sampling from 1988-2004 | | | | | | | |
| Harvesting scenario | constant F with current F | | | | | | | | | | constant catch with current average catch |
| Starting year | 1st Jan, 2008 | | | | | | | 1st Jan, 2009 | 1st Jan, 2007 | | |
| Current F definition | 2006-2008 | 2002-2004 | | | | | | | | 2005-2007 | |
| Fssb need | yes | yes | yes | yes | yes | yes | yes | no | no | no | no |

**Table 7.** Assumed quarterly catch weights from 2008-2010 used for future projections. Quarterly catch in 2010 is estimated from the average quarterly catch ratio and preliminary catch weights while total quarterly catches for 2008 and 2009 are derived from estimates in the assessment model. None of these weights are identical to the quarterly totals calculated from the catch table in ISC (2011).

| Quarter | Quarterly Catch Ratio (2000-2010) | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| Qt1 | 0.14 | 13,178 | 9,901 | 9,839 |
| Qt2 | 0.33 | 23,393 | 37,359 | 22,804 |
| Qt3 | 0.40 | 21,100 | 21,928 | 27,469 |
| Qt4 | 0.13 | 7,594 | 8,474 | 8,943 |
| **Total** | | **65,265** | **77,662** | **69,056** |

**Table 8.** Fisheries definitions used for the VPA-based assessment in 2006 and the reference run for comparison in 2011.

| 2006 assessment (age-specific) | 2011 Assessment (age area aggregated) |
|---|---|
| F1 USA/Canada Troll (age2) | Japan pole-and-line (1972 – 1984) |
| F2 USA/Canada Troll (age3) | Japan pole-and-line (1985 – 2009) |
| F3 USA/Canada Troll (age4) | Japan longline (1972– 2009) |
| F4 USA/Canada Troll (age5) | USA/Canada troll (1966-2009) |
| F5 USA longline (age6-9+) | USA longline (1991 – 2009) |
| F6 Japan pole-and-line (age2) | Taiwan longline (1995 – 2009) |
| F7 Japan pole-and-line (age3) | |
| F8 Japan pole-and-line (age4) | |
| F9 Japan pole-and-line (age5) | |
| F10 Japan longline (age3) | |
| F11 Japan longline (age4) | |
| F12 Japan longline (age5) | |
| F13 Japan longline (age6) | |
| F14 Japan longline (age7) | |
| F15 Japan longline (age8) | |
| F16 Japan longline (age9+) | |
| F17 Taiwan longline (age6-9+) | |

**Table 9.** Age-aggregated abundance indices developed for the VPA reference run. Units are weight (JPN PL fisheries) and number of fish (all other indices).

| | JPN PLSF-A | JPN PLSF-B | JPNLL | UCLTN | USALL | TWNLL |
|---|---|---|---|---|---|---|
| 1966 | | | | 90.8 | | |
| 1967 | | | | 138.8 | | |
| 1968 | | | | 112.9 | | |
| 1969 | | | | 99.7 | | |
| 1970 | | | | 127.5 | | |
| 1971 | | | | 96.0 | | |
| 1972 | 0.0449 | | 2.09 | 80.1 | | |
| 1973 | 0.0446 | | 2.31 | 86.6 | | |
| 1974 | 0.0503 | | 2.37 | 108.1 | | |
| 1975 | 0.0459 | | 1.90 | 116.1 | | |
| 1976 | 0.0433 | | 2.24 | 77.8 | | |
| 1977 | 0.0267 | | 1.56 | 55.8 | | |
| 1978 | 0.0408 | | 1.53 | 82.3 | | |
| 1979 | 0.0429 | | 1.48 | 54.8 | | |
| 1980 | 0.0456 | | 1.38 | 42.1 | | |
| 1981 | 0.0239 | | 1.81 | 59.4 | | |
| 1982 | 0.0367 | | 1.96 | 49.4 | | |
| 1983 | 0.0319 | | 1.60 | 60.3 | | |
| 1984 | 0.0376 | | 1.60 | 64.6 | | |
| 1985 | | 0.0288 | 1.60 | 79.0 | | |
| 1986 | | 0.0319 | 1.54 | 47.0 | | |
| 1987 | | 0.0247 | 1.34 | 34.1 | | |
| 1988 | | 0.0260 | 1.41 | 71.2 | | |
| 1989 | | 0.0292 | 1.47 | 32.6 | | |
| 1990 | | 0.0389 | 1.81 | 46.2 | | |
| 1991 | | 0.0470 | 1.57 | 44.0 | 1.74 | |
| 1992 | | 0.0522 | 1.80 | 69.2 | 2.13 | |
| 1993 | | 0.0296 | 2.44 | 58.8 | 2.41 | |
| 1994 | | 0.0562 | 2.87 | 94.5 | 3.03 | |
| 1995 | | 0.0694 | 3.00 | 55.6 | 4.40 | 29.5 |
| 1996 | | 0.0354 | 3.94 | 85.6 | 5.82 | 49.9 |
| 1997 | | 0.0702 | 4.63 | 49.2 | 6.52 | 45.7 |
| 1998 | | 0.0542 | 4.30 | 146.2 | 4.46 | 21.3 |
| 1999 | | 0.0544 | 4.30 | 54.2 | 5.82 | 20.4 |
| 2000 | | 0.0401 | 3.95 | 65.6 | 2.36 | 21.4 |
| 2001 | | 0.0421 | 3.48 | 95.8 | 3.32 | 13.0 |
| 2002 | | 0.0759 | 2.87 | 145.2 | 1.07 | 12.3 |
| 2003 | | 0.0438 | 2.20 | 134.3 | 0.89 | 13.8 |
| 2004 | | 0.0652 | 1.94 | 166.3 | 0.97 | 8.3 |
| 2005 | | 0.0422 | 2.79 | 82.6 | 0.68 | 8.8 |
| 2006 | | 0.0394 | 2.78 | 180.4 | 0.54 | 13.5 |
| 2007 | | 0.0557 | 2.33 | 106.0 | 0.41 | 13.8 |
| 2008 | | 0.0243 | 2.31 | 110.3 | 0.61 | 16.5 |
| 2009 | | 0.0368 | 2.97 | 122.8 | 0.45 | 14.1 |

**Table 10.** Spawning stock biomass and recruitment time-series estimated by the base-case model for the 2011 north Pacific albacore assessment

| Year | Spawning biomass (t) | Recruitment (x1000 fish) |
|---|---|---|
| Virgin | 857,138 | 55,381.1 |
| 1966 | 416,016 | 50,133.3 |
| 1967 | 398,986 | 49,155.9 |
| 1968 | 389,813 | 51,323.5 |
| 1969 | 389,303 | 54,464.1 |
| 1970 | 409,518 | 44,200.7 |
| 1971 | 436,472 | 60,480.4 |
| 1972 | 436,742 | 55,089.0 |
| 1973 | 426,010 | 52,093.3 |
| 1974 | 408,849 | 37,136.4 |
| 1975 | 383,956 | 43,313.2 |
| 1976 | 363,717 | 53,538.9 |
| 1977 | 350,553 | 43,672.4 |
| 1978 | 341,099 | 32,625.9 |
| 1979 | 317,859 | 36,766.9 |
| 1980 | 298,930 | 35,993.5 |
| 1981 | 298,225 | 38,812.7 |
| 1982 | 293,942 | 42,563.6 |
| 1983 | 279,693 | 34,156.1 |
| 1984 | 267,377 | 29,383.4 |
| 1985 | 263,935 | 30,581.1 |
| 1986 | 264,530 | 43,678.8 |
| 1987 | 277,001 | 27,152.4 |
| 1988 | 281,203 | 49,385.9 |
| 1989 | 278,347 | 58,132.8 |
| 1990 | 276,500 | 65,216.3 |
| 1991 | 290,250 | 47,235.2 |
| 1992 | 298,809 | 69,277.8 |
| 1993 | 315,771 | 54,879.0 |
| 1994 | 364,731 | 68,726.6 |
| 1995 | 425,450 | 38,831.3 |
| 1996 | 459,003 | 68,999.6 |
| 1997 | 482,592 | 42,322.1 |
| 1998 | 495,364 | 41,296.7 |
| 1999 | 504,284 | 78,060.9 |
| 2000 | 476,738 | 51,007.6 |
| 2001 | 461,486 | 46,990.1 |
| 2002 | 446,178 | 55,507.1 |
| 2003 | 417,903 | 41,311.2 |
| 2004 | 428,487 | 61,036.6 |
| 2005 | 432,963 | 40,499.7 |
| 2006 | 413,820 | 41,381.5 |
| 2007 | 406,885 | 45,194.6 |
| 2008 | 397,088 | 44,970.5 |
| 2009 | 405,644 | 55,381.1 |

**Table 11.** Probability of future spawning stock biomass falling below the bootstrap estimate of SSB-ATHL in future projection scenarios and structural sensitivity runs.

| | Base case | Run 1 ($F_{2002\text{-}2004}$) | Run 2 (Low recruit) | Run 3 (High recruit) | Run 4 (growth curve) | Run 5 (Length lambda) | Run 6 (Steepness=0.85) |
|---|---|---|---|---|---|---|---|
| 2012 | 0.0 | 0.0 | 0.0 | 0.0 | 10.8 | 0.0 | 0.0 |
| 2013 | 0.0 | 0.0 | 0.0 | 0.0 | 25.1 | 0.0 | 0.0 |
| 2014 | 0.0 | 0.0 | 0.0 | 0.0 | 29.8 | 0.1 | 0.0 |
| 2015 | 0.1 | 0.3 | 0.8 | 0.0 | 30.9 | 0.2 | 0.3 |
| 2016 | 0.3 | 0.5 | 1.9 | 0.0 | 31.8 | 0.4 | 0.9 |
| 2017 | 0.4 | 0.9 | 3.8 | 0.0 | 32.7 | 0.7 | 1.5 |
| 2018 | 0.5 | 1.5 | 8.3 | 0.0 | 33.4 | 1.1 | 2.1 |
| 2019 | 0.5 | 2.0 | 12.7 | 0.0 | 34.4 | 1.2 | 2.6 |
| 2020 | 0.6 | 2.6 | 16.7 | 0.0 | 35.2 | 1.2 | 3.3 |
| 2021 | 0.7 | 3.1 | 20.9 | 0.0 | 36.0 | 1.4 | 4.1 |
| 2022 | 0.7 | 3.6 | 24.7 | 0.0 | 37.0 | 1.5 | 5.3 |
| 2023 | 0.8 | 4.2 | 27.6 | 0.0 | 38.0 | 1.6 | 5.7 |
| 2024 | 0.9 | 4.8 | 30.6 | 0.0 | 38.8 | 1.6 | 6.3 |
| 2025 | 0.9 | 5.3 | 33.6 | 0.0 | 39.6 | 1.9 | 6.8 |
| 2026 | 0.9 | 5.8 | 36.0 | 0.0 | 40.3 | 2.0 | 7.3 |
| 2027 | 0.9 | 6.5 | 38.9 | 0.0 | 41.0 | 2.2 | 8.1 |
| 2028 | 1.0 | 7.0 | 41.3 | 0.0 | 41.9 | 2.4 | 8.9 |
| 2029 | 1.0 | 7.4 | 43.4 | 0.0 | 42.4 | 2.5 | 9.5 |
| 2030 | 1.1 | 7.9 | 45.5 | 0.1 | 43.4 | 2.8 | 10.1 |
| 2031 | 1.1 | 8.4 | 47.0 | 0.1 | 43.8 | 3.0 | 10.9 |
| 2032 | 1.2 | 8.9 | 48.8 | 0.1 | 44.3 | 3.1 | 11.6 |
| 2033 | 1.2 | 9.2 | 50.1 | 0.1 | 44.6 | 3.1 | 12.2 |
| 2034 | 1.3 | 9.8 | 51.6 | 0.1 | 44.8 | 3.2 | 12.5 |
| 2035 | 1.3 | 10.3 | 52.9 | 0.1 | 45.2 | 3.5 | 13.2 |
| 2036 | 1.3 | 10.7 | 53.9 | 0.1 | 45.7 | 3.5 | 14.2 |

**Table 12.** Estimates of $F_{SSB\text{-}ATHL}$ 50% for a 25-yr projection period (2010-2035) for the base-case model, two harvest scenarios ($F_{2006\text{-}2008}$, $F_{2002\text{-}2004}$), two recruitment scenarios, and three alternate structural assumptions. Relative estimates of F as the F-ratio are shown rather than absolute estimates. F-ratio = $F_{2006\text{-}2008}/F_{SSB\text{-}ATHL}$ run estimate.

| Projection Run | F-ratio |
|---|---|
| Base case | 0.71 |
| Run 1 (F2002-2004) | 0.83 |
| (Current F in 2006 assessment) | |
| Run 2 (Low recruit) | 1.01 |
| Run 3 (High recruit) | 0.60 |
| Run 4 (growth curve) | 0.99 |
| Run 5 (Length lambda) | 0.77 |
| Run 6 (Steepness=0.85) | 0.71 |

**Table 13.** Potential reference points and estimated F-ratio using Fcurrent $F_{2006\text{-}2008}$ (Fcurrent), associated spawning biomass and equilibrium yield for north Pacific albacore. Median SSB and yield are shown $F_{SSB\text{-}ATHL}$ as this simulation-based reference point is not an equilibrium concept.

| Reference Point | $F_{2006\text{-}2008}/F_{RP}$ | SSB (t) | Equilibrium Yield (t) |
|---|---|---|---|
| $F_{SSB\text{-}ATHL}$ | 0.71 | 346,382 | 101,426 |
| $F_{MAX}$ | 0.14 | 11,186 | 185,913 |
| $F_{0.1}$ | 0.29 | 107,130 | 170,334 |
| $F_{MED}$ | 0.99 | 452,897 | 94,080 |
| $F_{20\%}$ | 0.38 | 171,427 | 156,922 |
| $F_{30\%}$ | 0.52 | 257,140 | 138,248 |
| $F_{40\%}$ | 0.68 | 342,854 | 119,094 |
| $F_{50\%}$ | 0.91 | 428,567 | 99,643 |

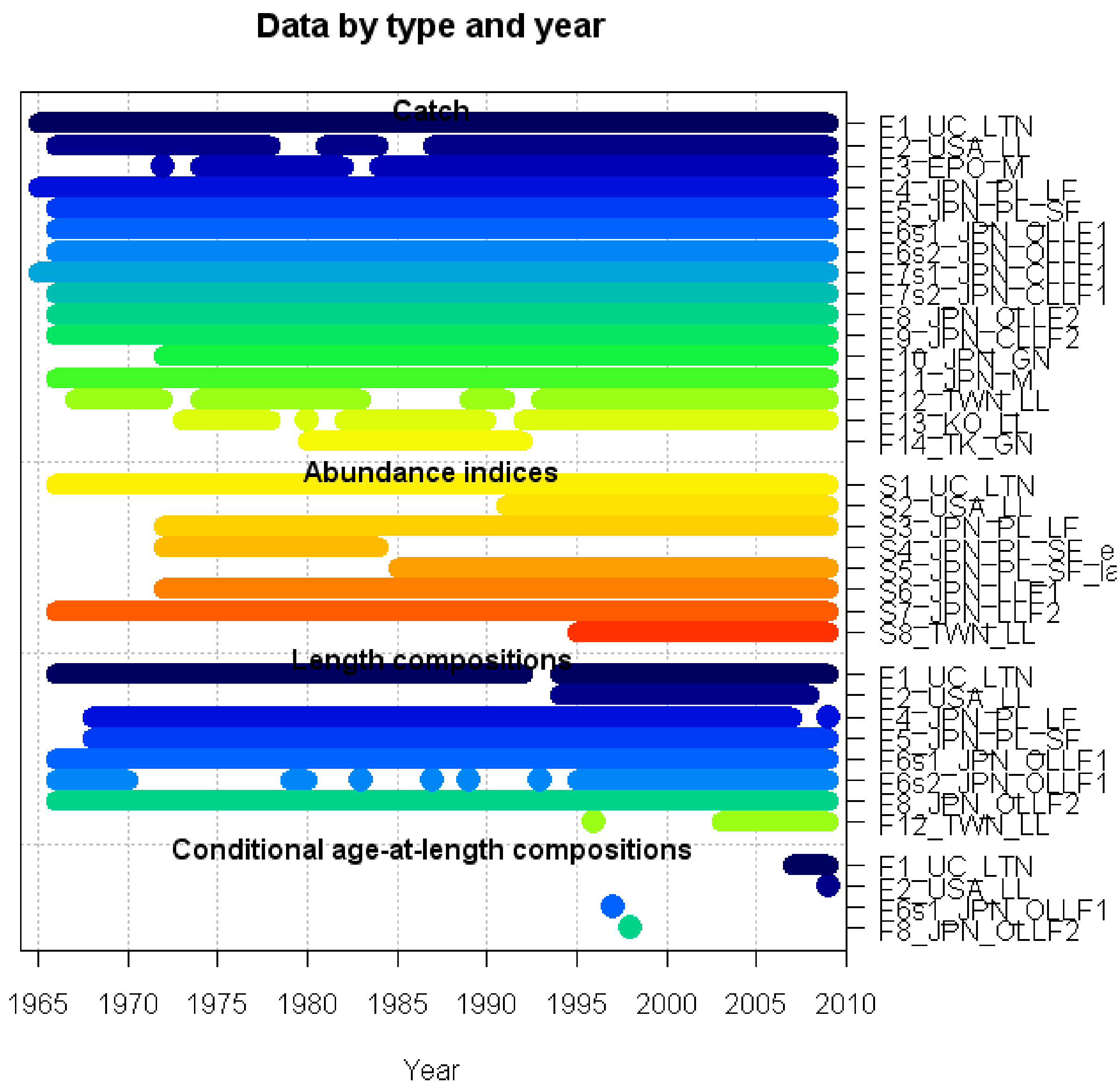



**Figure 1.** Temporal coverage and sources of catch, CPUE, length composition and ageing data used in the 2011 assessment of north Pacific albacore.

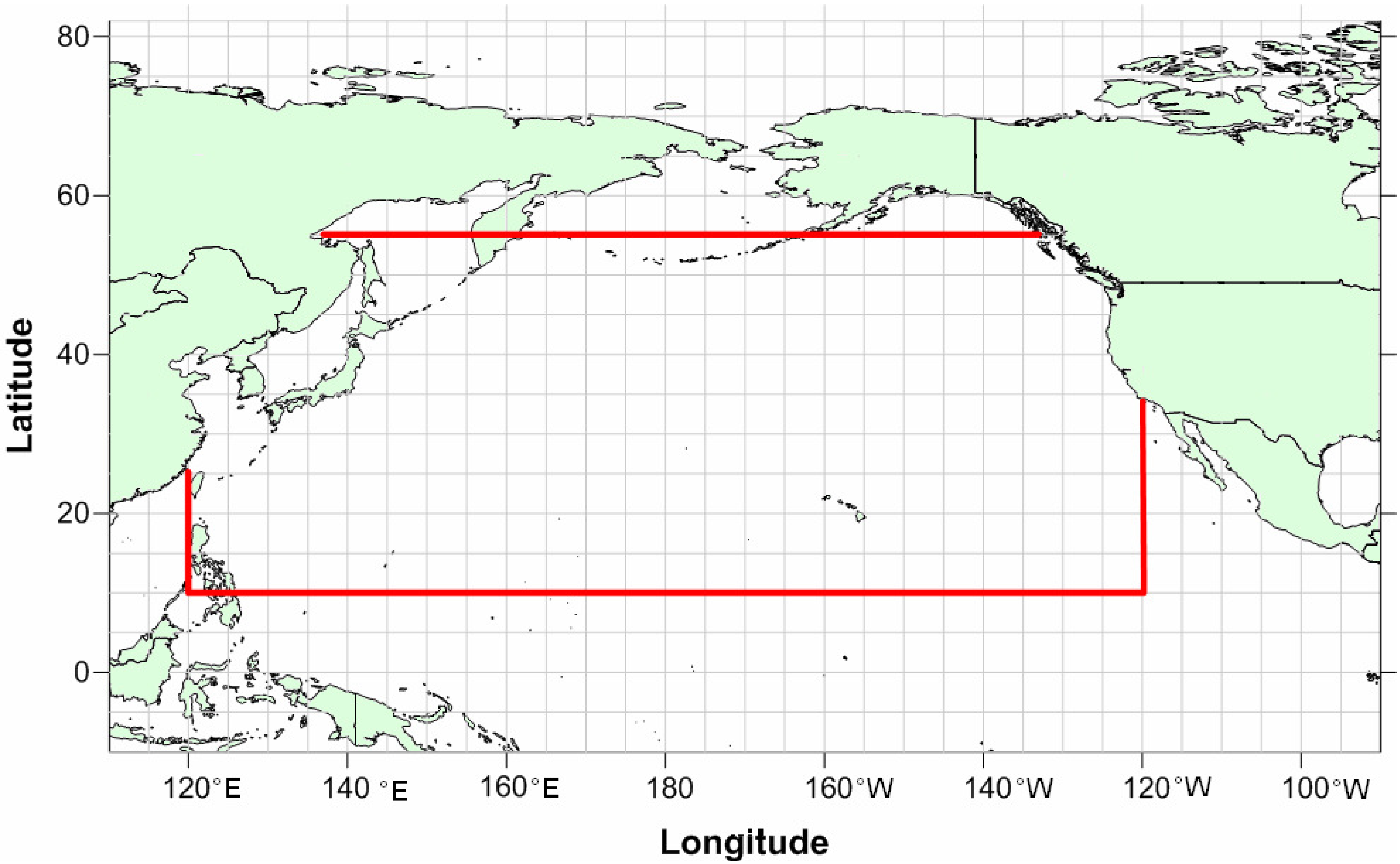



**Figure 2.** Spatial domain (red box) of the north Pacific albacore stock (*Thunnus alalunga*) and the 2011 stock assessment.

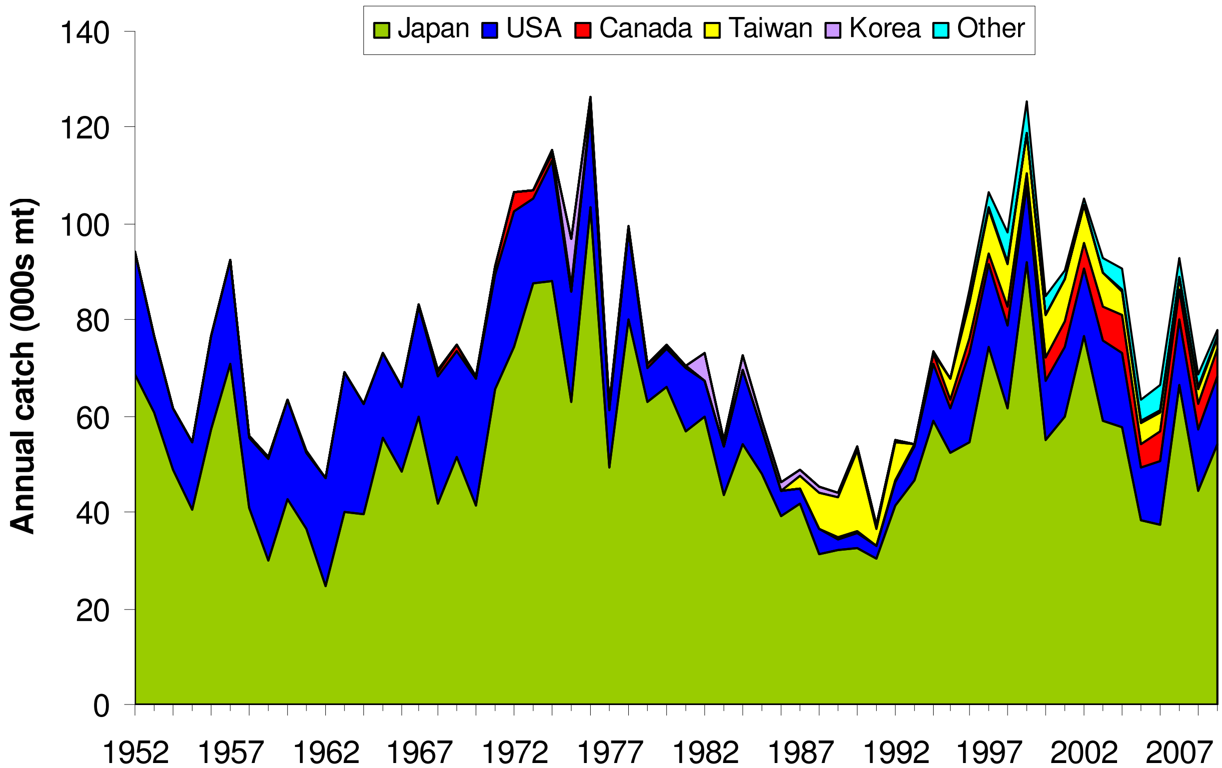



**Figure 3.** Total annual catch of north Pacific albacore (*Thunnus alalunga*) by all countries harvesting the stock, 1952-2009. The Other category includes Mexico, Tonga, Belize, Cook Islands, Ecuador and longline catches from vessels flying flags of convenience.

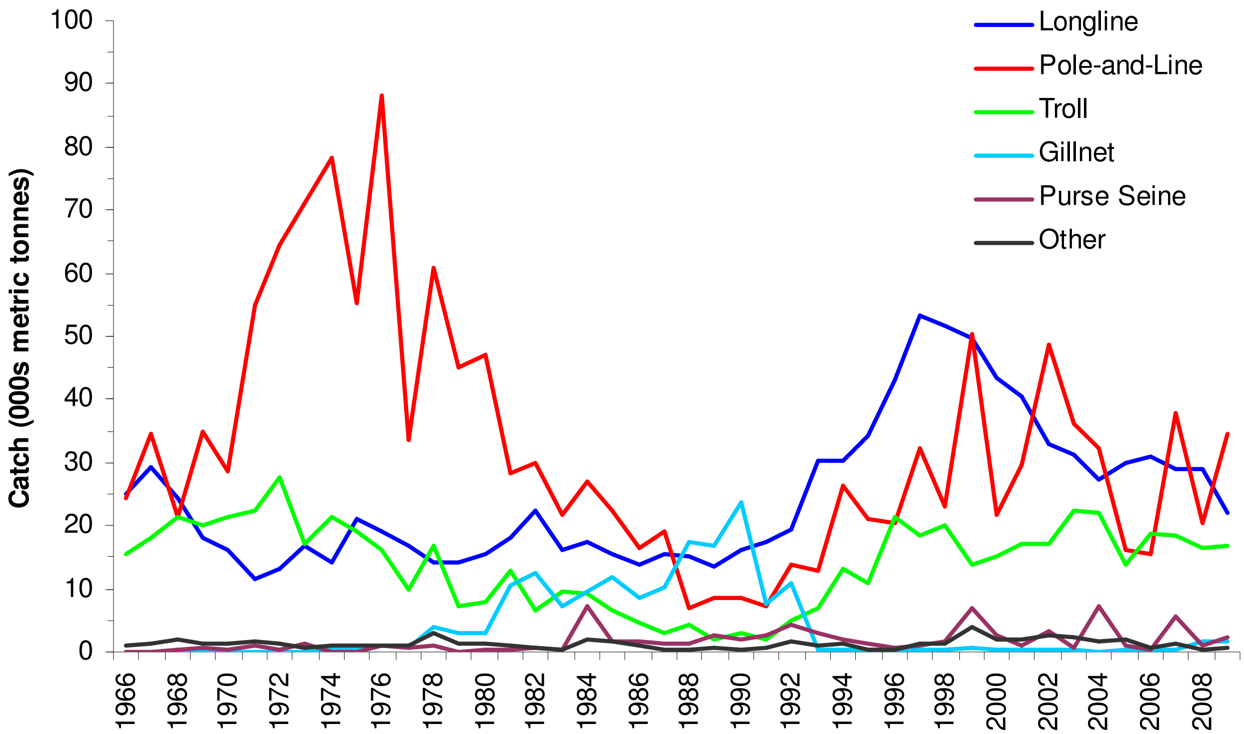



**Figure 4**. Catches of north Pacific albacore by major gear types, 1966-2009. The Other category refers to miscellaneous gears including recreational, handline, and harpoon.

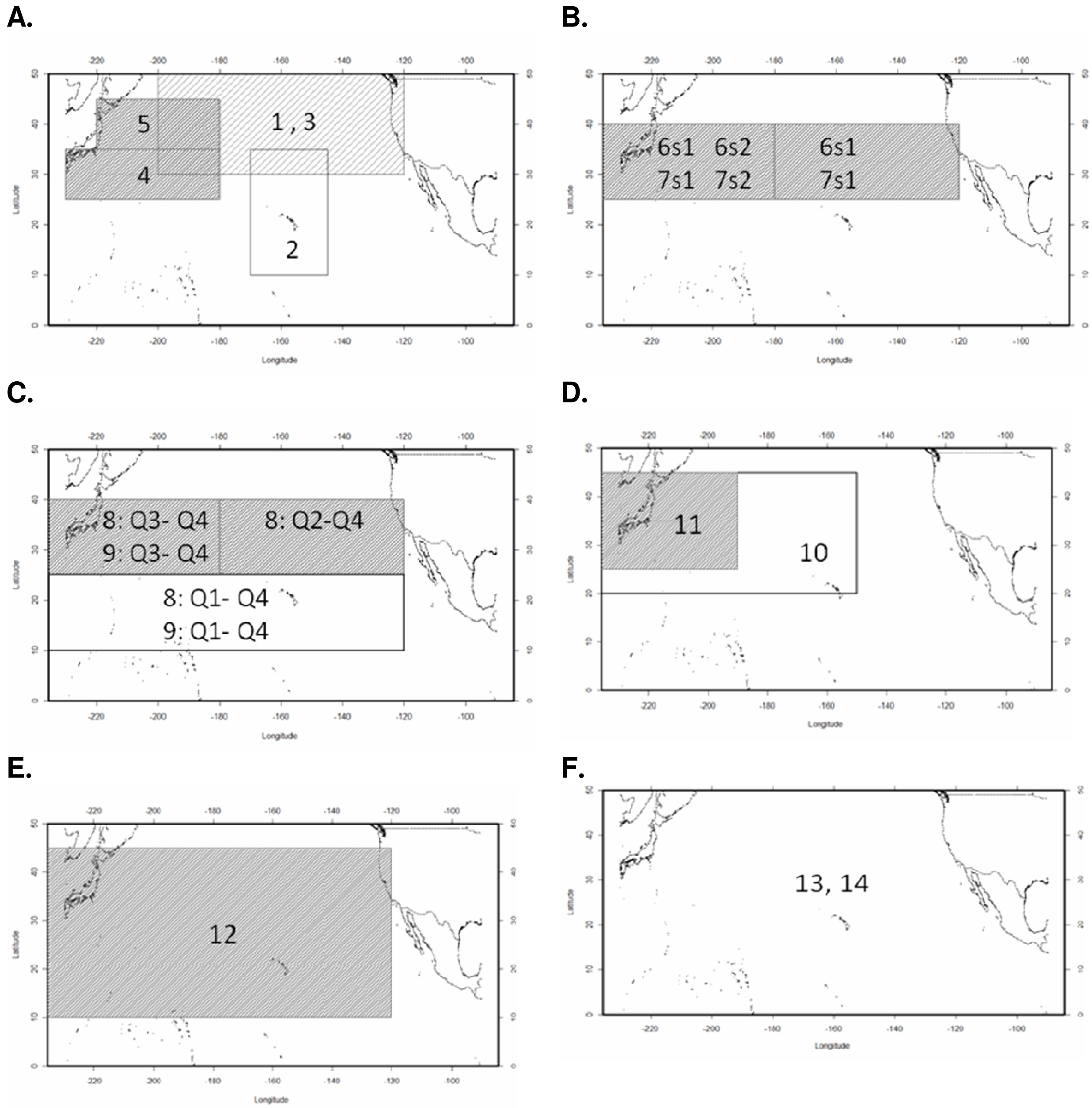



**Figure 5.** Maps showing main seasons and areas of operation of (A) EPO surface fisheries (F1 & F3), JPN PL fisheries (F4 and F5) and USA LL fishery (F2); (B) JPN OLLF1 and CLLF1 fisheries (F6s1, F6s2, F7s1, F7s2), where F6s1 and F7s1 operate during the first quarter and F6s2 and F7s2 operates in the second quarter; (C) JPN OLLF2 and CLLF2 fisheries (F8 & F9); (D) JPN GN (F10) and JPN M (F11) fisheries; (E) TWN LL fishery (F12); and (F) the KO longline fishery (F13) and TWN and KOR GN fishery (F14).

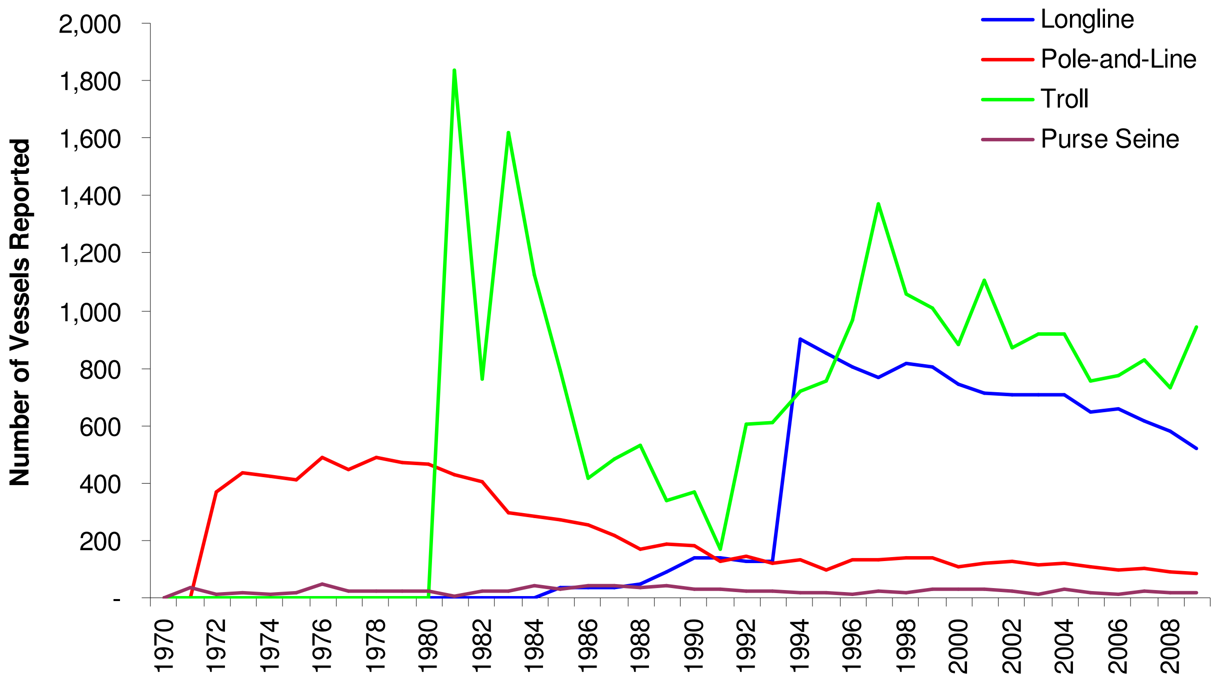



**Figure 6**. Reported number of vessels targeting north Pacific albacore by major gear types, all nations combined, 1970-2009.

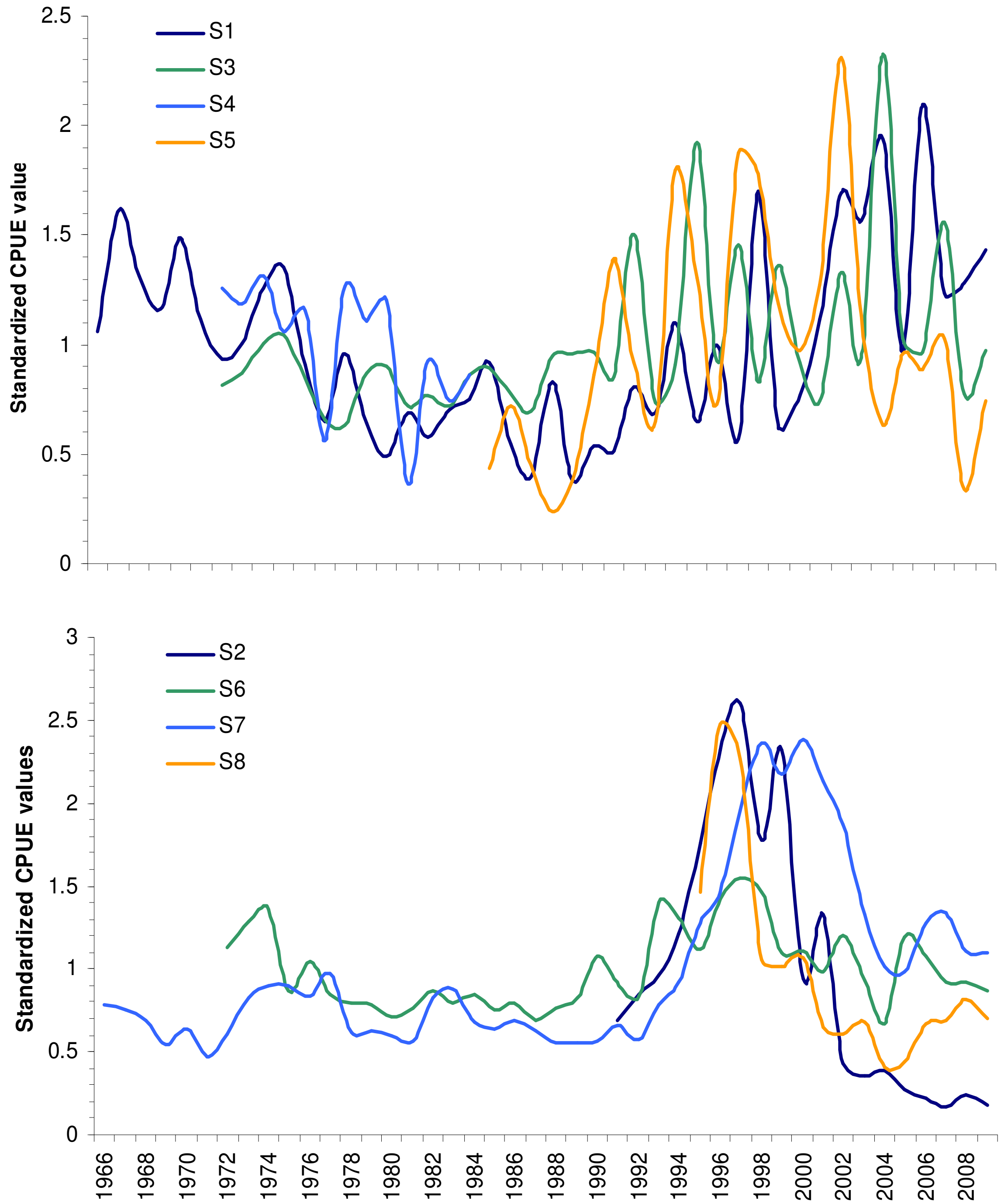



**Figure 7**. Time series of annual standardized CPUE indices for the major surface (top panel) and longline (bottom panel) fisheries for north Pacific albacore described in Table 1. Time series lengths vary from 15 years for the S8 (F12 - TWN LL) to 44 years for S1 (F1 - UC LTN). Index values in the figures are re-scaled by the mean of each index for comparison purposes. See Table 2 for index descriptions.

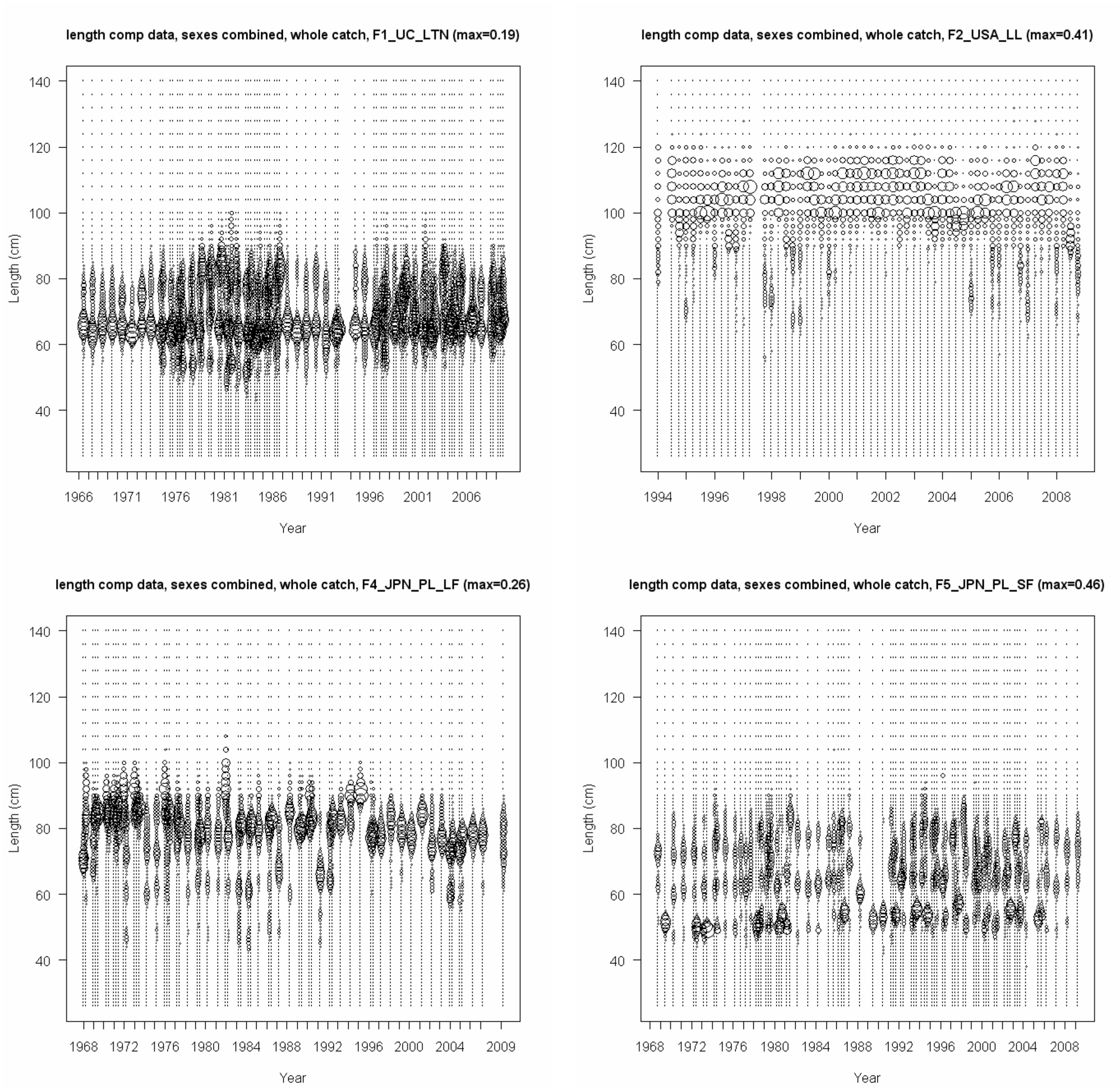



**Figure 8.** Annual length compositions of fisheries used in the assessment (F1, F2, F4, F5, F6s1, F6s2, F8, and F12 – see Table 1). Size of circles is proportional to the number of observations. Length composition data from other fisheries are not available for the assessment and selectivity patterns for these fisheries are mirrored to fisheries with length composition data.

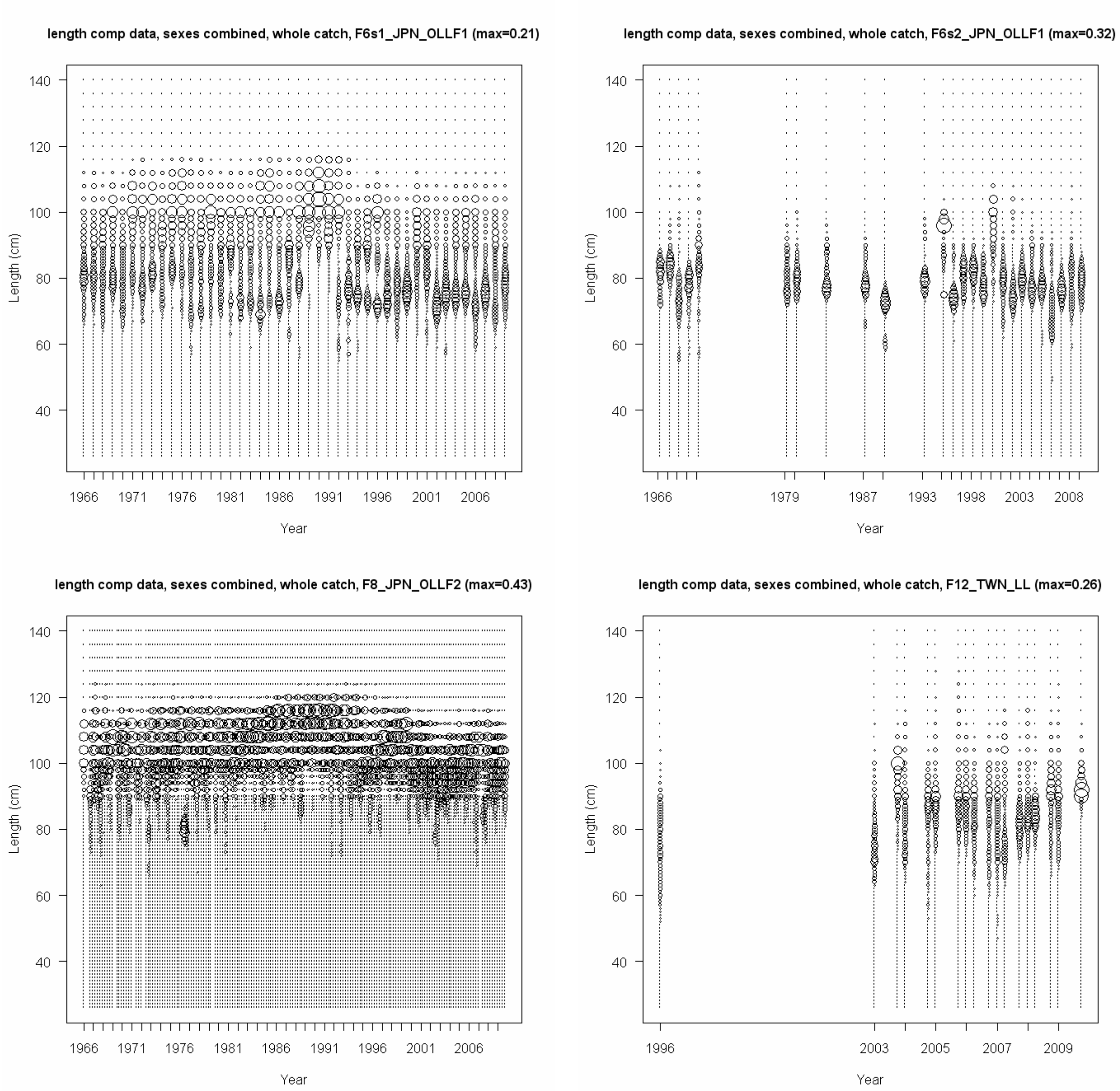



**Figure 8.** Continued.

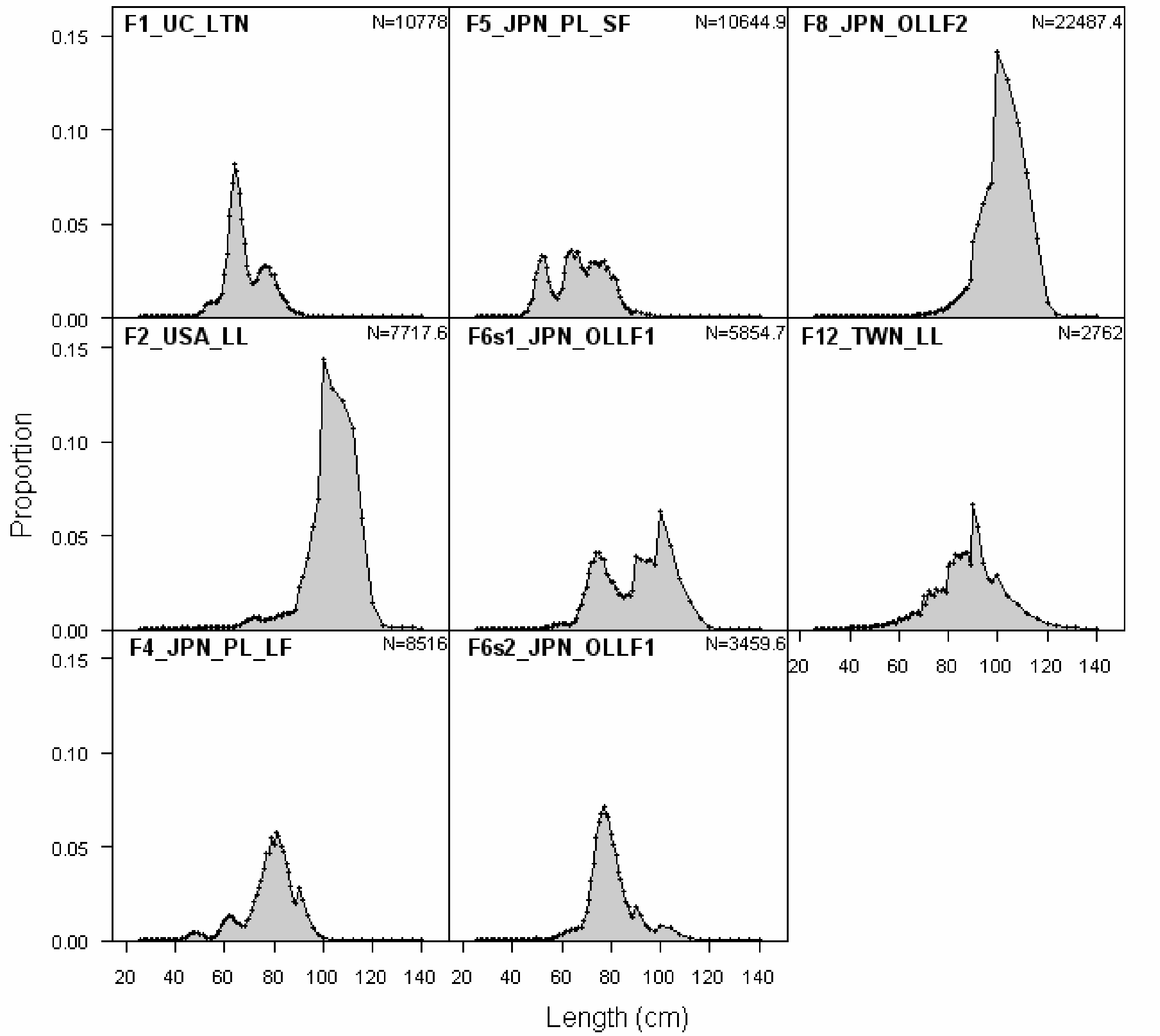



**Figure 9.** Aggregated annual length compositions used in the assessment (F1, F2, F4, F5, F6s1, F6s2, F8, and F12) showing clear modes. Length compositions from other fisheries are not available for the assessment and length selectivity for these fisheries are mirrored to one of the fisheries in this figure.

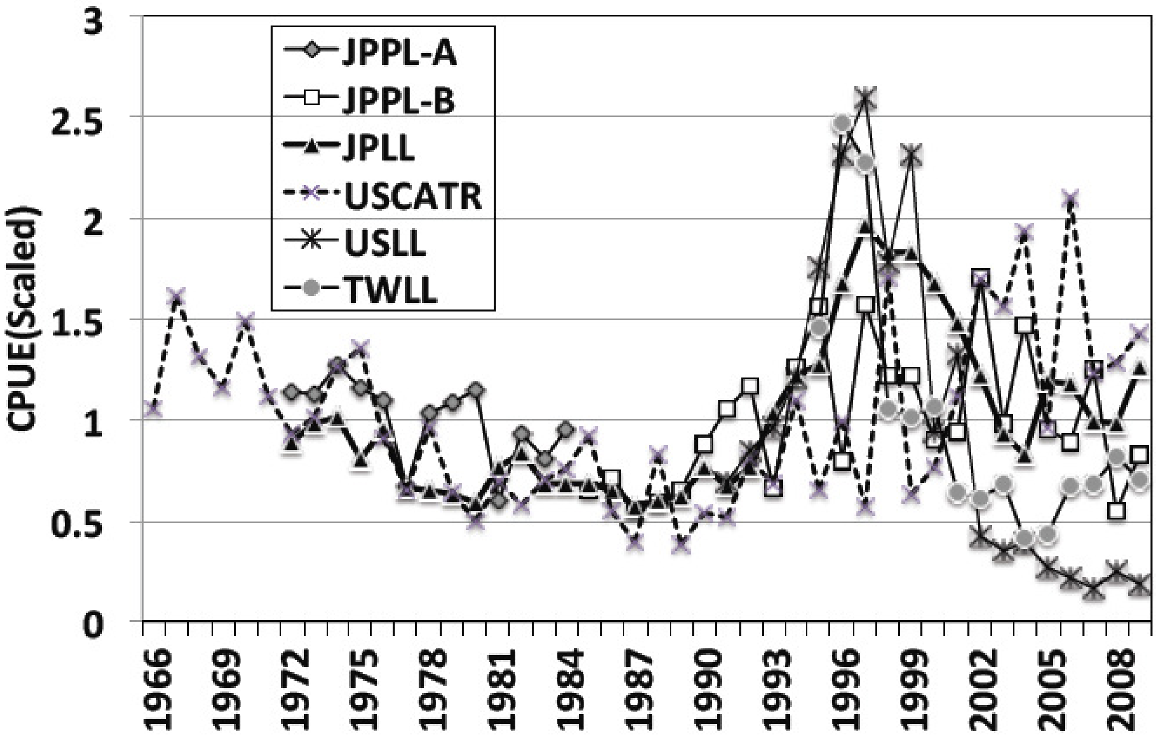



**Figure 10.** CPUE indices for north Pacific albacore used in the VPA reference run. JPN PL fishery A-1972-1984 and B-1985-2009, JPN LL fishery (1966-2008), USA LL (1991-2009), UCLTN fishery (1966-2009) and TWN LL fishery (1995-2008).

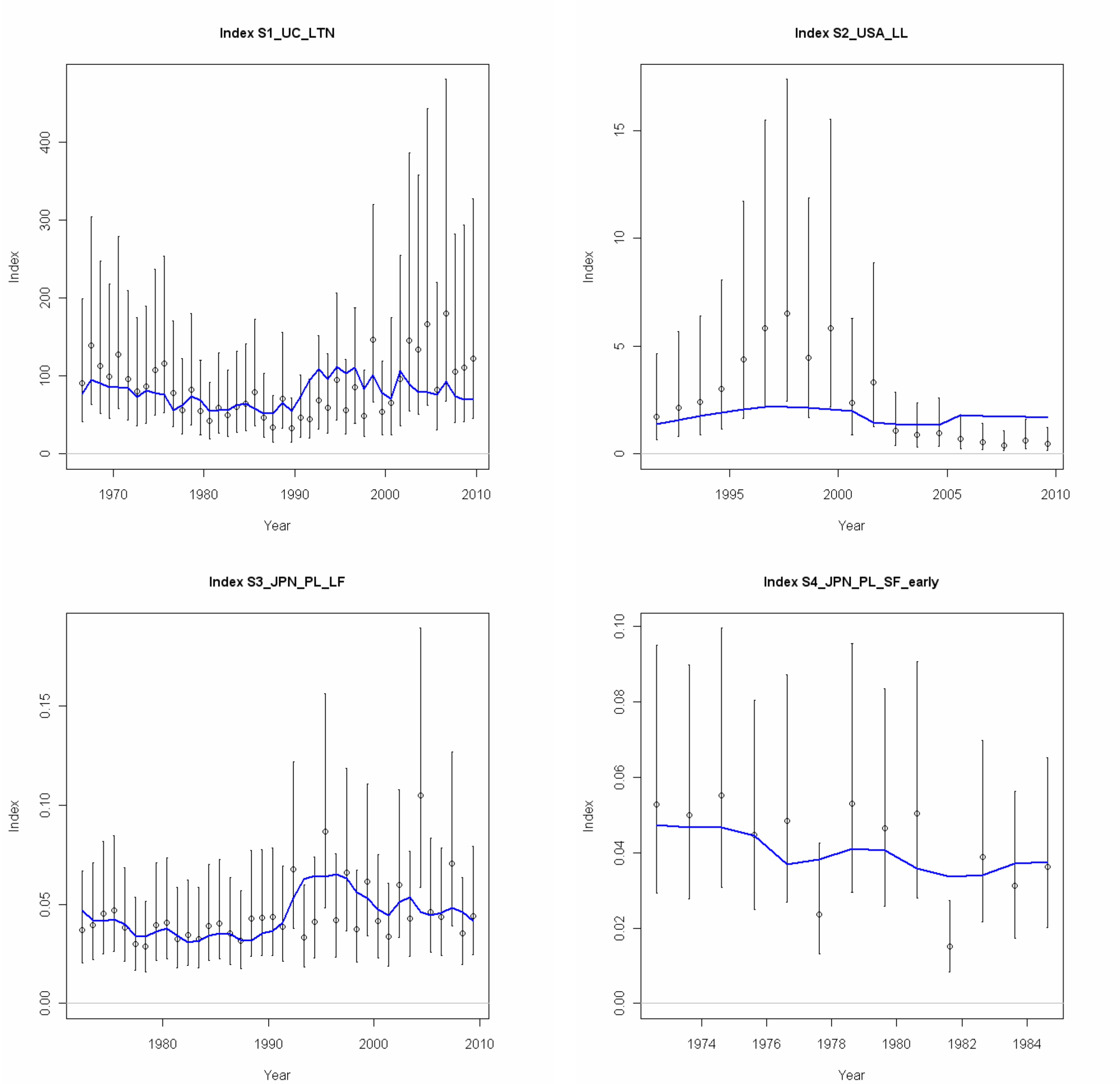



**Figure 11.** Model fits to the standardized CPUE data from different fisheries used in the assessment. The blue line is the model predicted value and the open circles are observed (data) values. The vertical lines represent the estimated confidence intervals (± 2 standard deviations) around the CPUE values. The numbers in the panels correspond to the index numbers in Table 2.

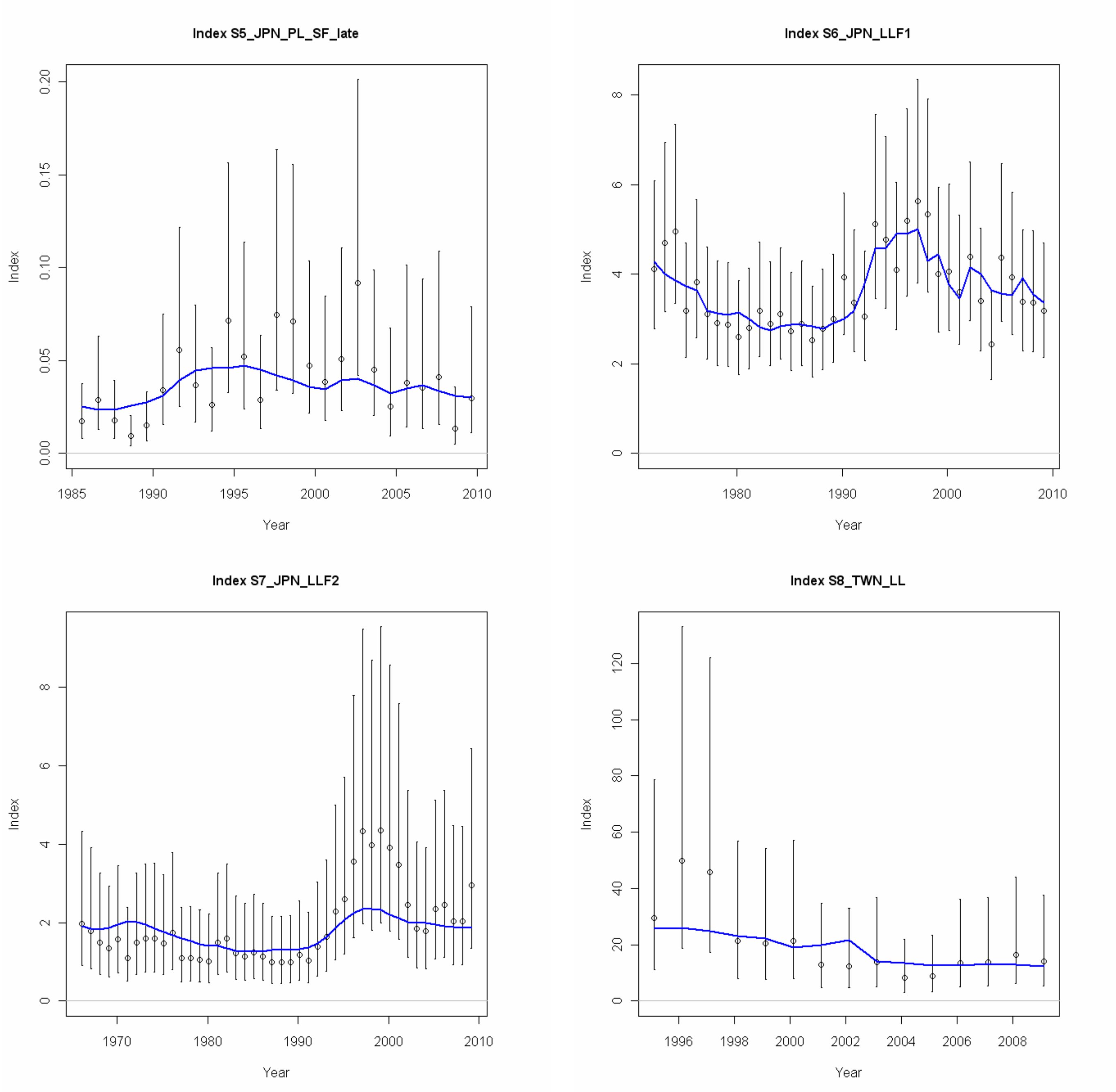



**Figure 11.** Continued.

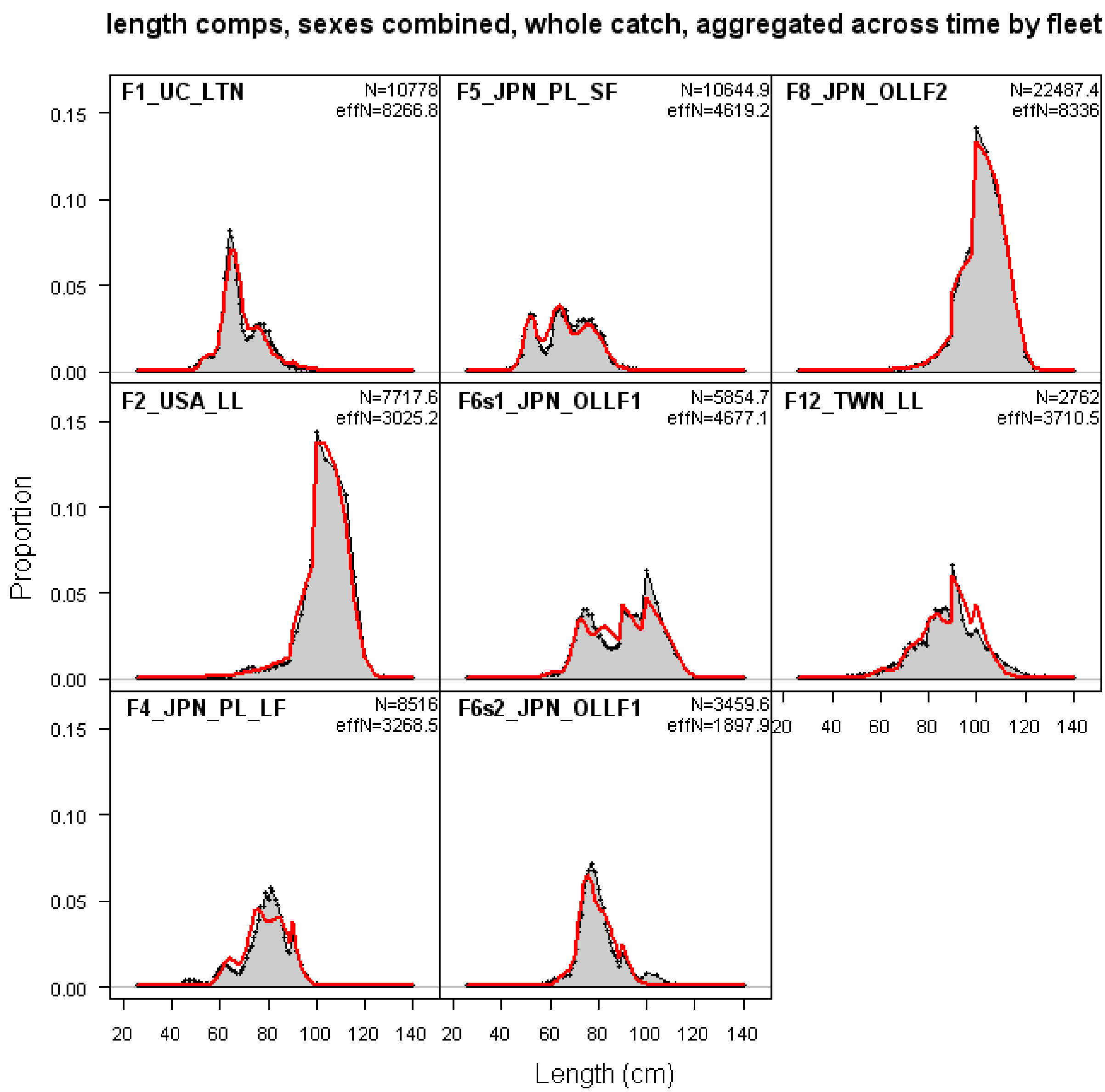



**Figure 12.** Comparison of observed (gray shaded area) and model predicted (red line) length compositions for fisheries used in the north Pacific albacore stock assessment (F1, F2, F4, F5, F6s1, F6s2, F8, and F12 – see Table 1 and Figure 2 for spatial and temporal boundaries of these fisheries).

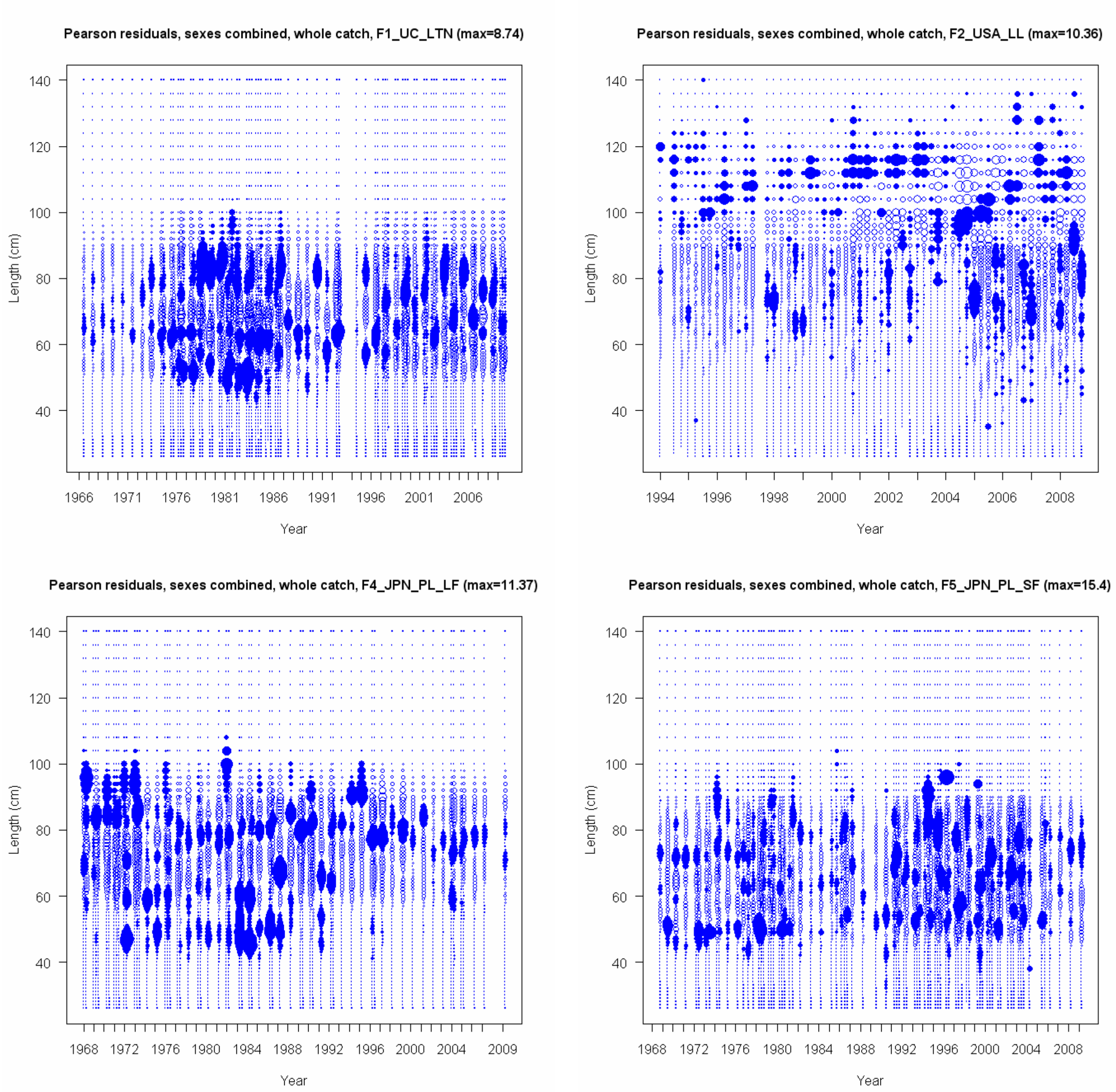



**Figure 13.** Pearson residual plots of model fits to the length-composition data for the albacore fisheries used in the assessment model (F1, F2, F4, F5, F6s1, F6s2, F8, and F12 – see Table 1 and Figure 2 for spatial and temporal boundaries of these fisheries). The filled and hollow blue circles represent observations that are higher and lower than the model predictions, respectively. The areas of the circles are proportional to the absolute values of the residuals.

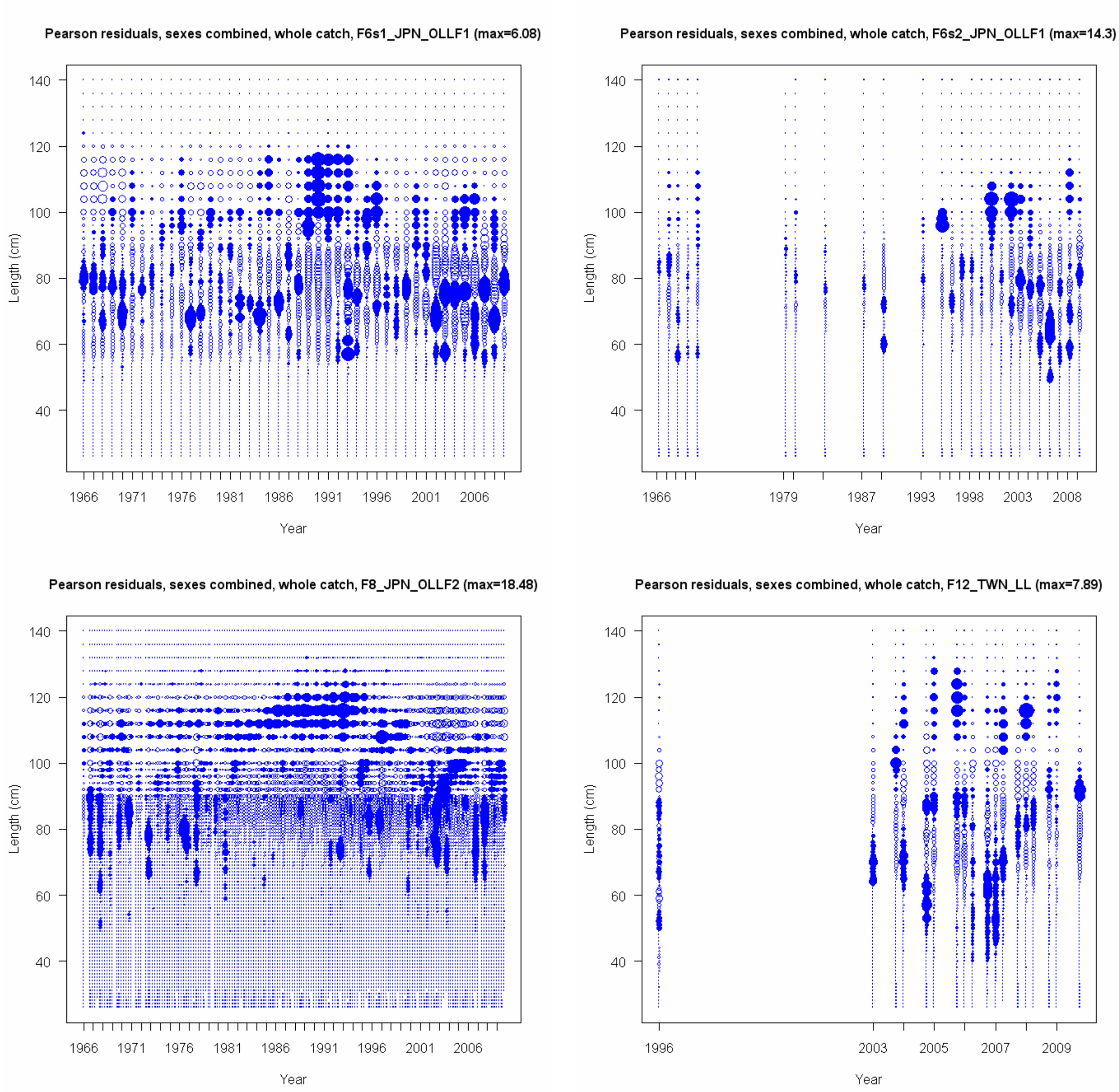



**Figure 13.** Continued.

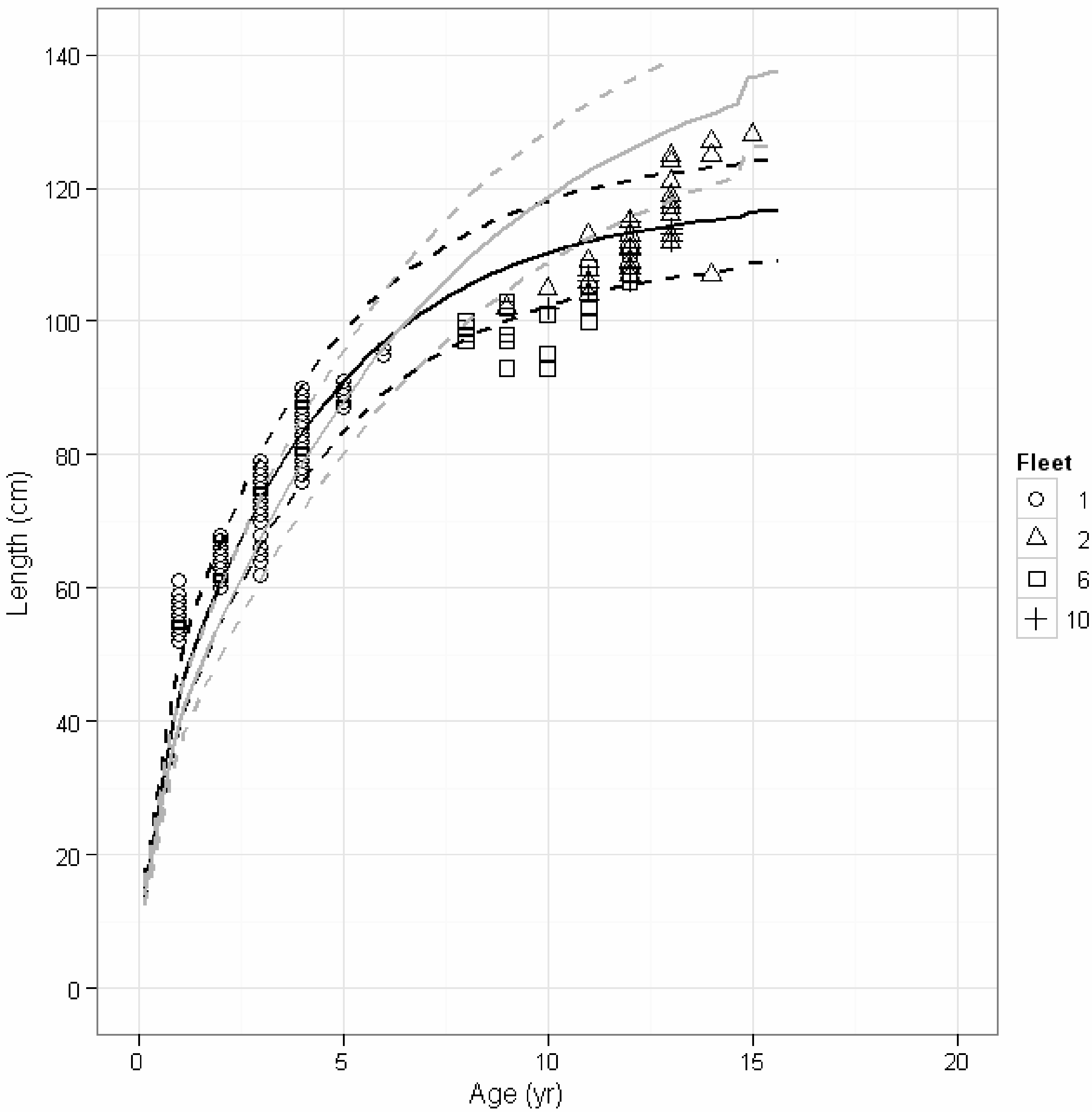



**Figure 14.** Comparison of the model estimated von Bertalanffy growth curve in the 2011 assessment (black) and the Suda (1966) growth curve used in the 2006 assessment of north Pacific albacore (grey). Model estimated limits for 2011 and 2006 are black and grey dashed lines, respectively. Points represent conditional age-at-length data from four fleets in the eastern (F1), central (F2) and western Pacific (F6, F10) Ocean reported by Wells et al. (2011).

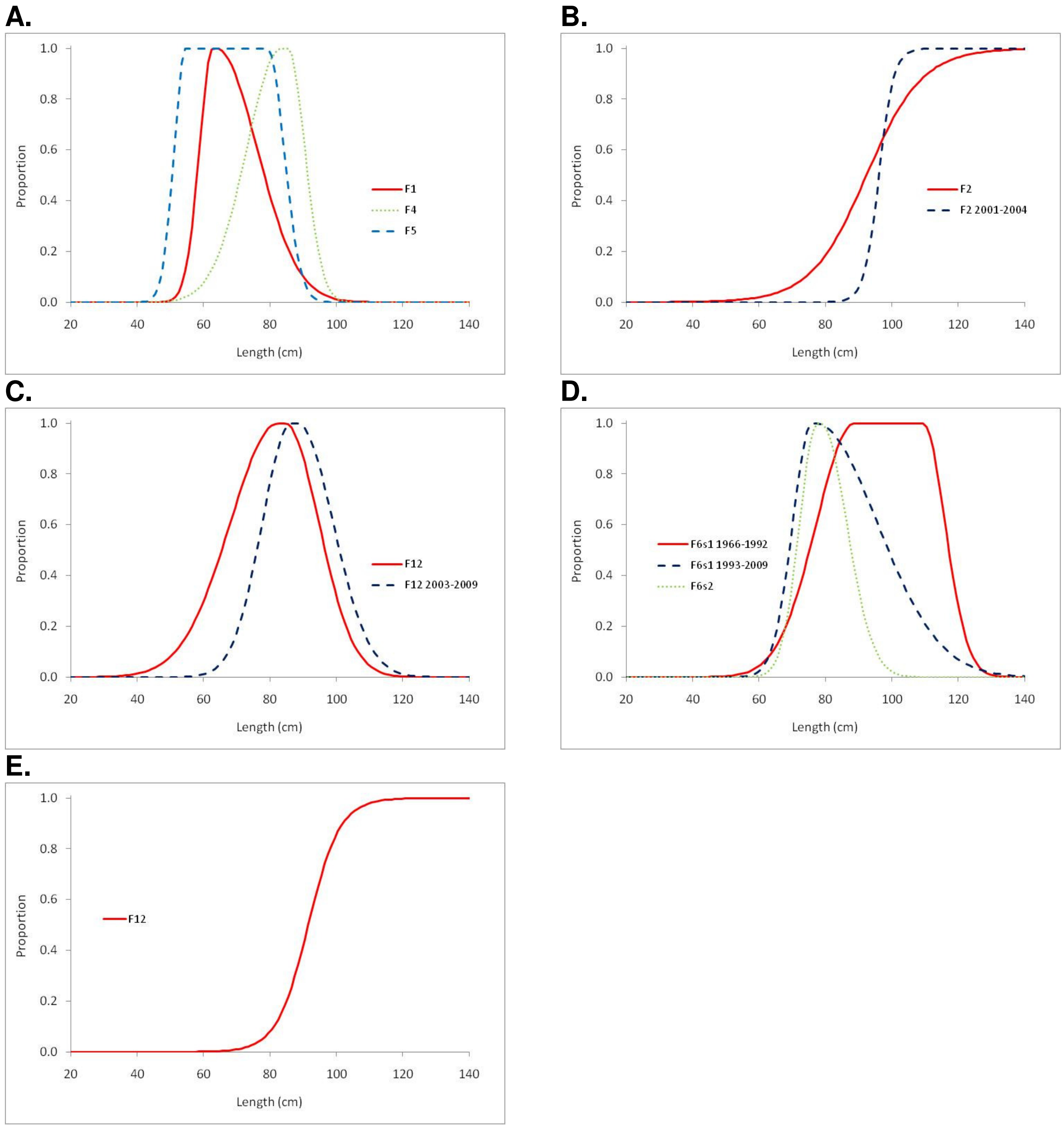



**Figure 15.** Length selectivity of fisheries estimated by the north Pacific albacore assessment model: (A) surface fisheries - F1 (red solid line), F4 (green dotted line), and F5 (blue dashed line); (B) US longline fishery (F2) during 2001-2004 (blue dashed line) and the remaining period (red solid line); (C) TWN LL fishery (F12) 1995-2002 (red solid line) and 2003-2009 (blue dashed line); (D) JPN OLLF1 and CLLF1 fisheries: F6s1 during 1966-1992 (red solid line) and 1993-2009 (blue dashed line), and F6s2 (green dotted line); and (E) JPN OLLF2 and CLLF2 fisheries (F8). See Table 1 for fishery definitions.

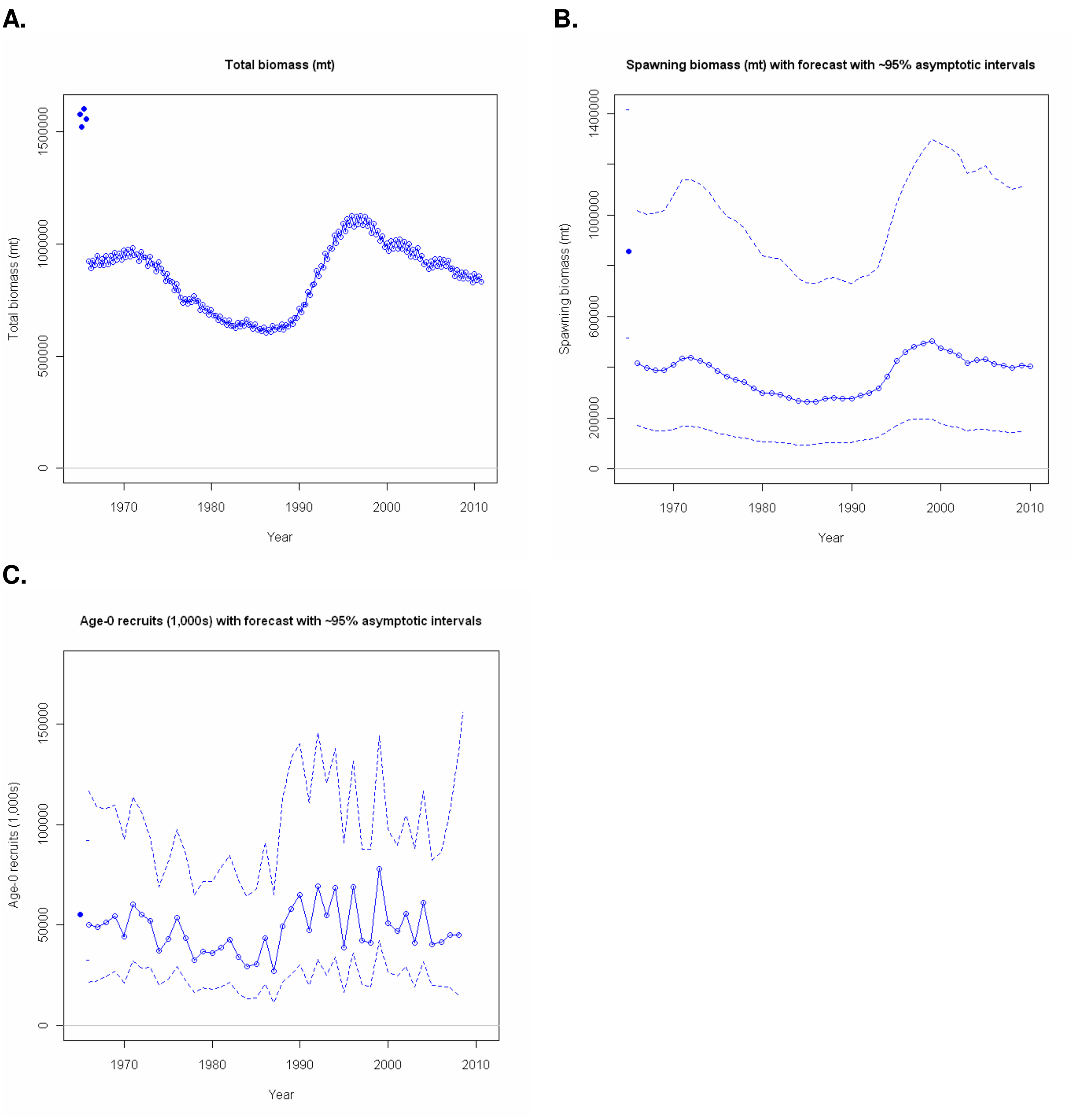



**Figure 16.** Estimated total biomass (A), spawning biomass (B), and age-0 recruitment (C) of albacore tuna in the north Pacific Ocean. The open circles represent the maximum likelihood estimates of each quantity and the dashed lines in the SSB (B) and recruitment (C) plots are the 95% asymptotic intervals of the estimates (± 2 standard deviations) in lognormal (SSB – B) and arithmetic (recruitment – C) space. Since the assessment model represents time on a quarterly basis, there are four estimates of total biomass for each year, but only one annual estimate of spawning biomass and recruitment.

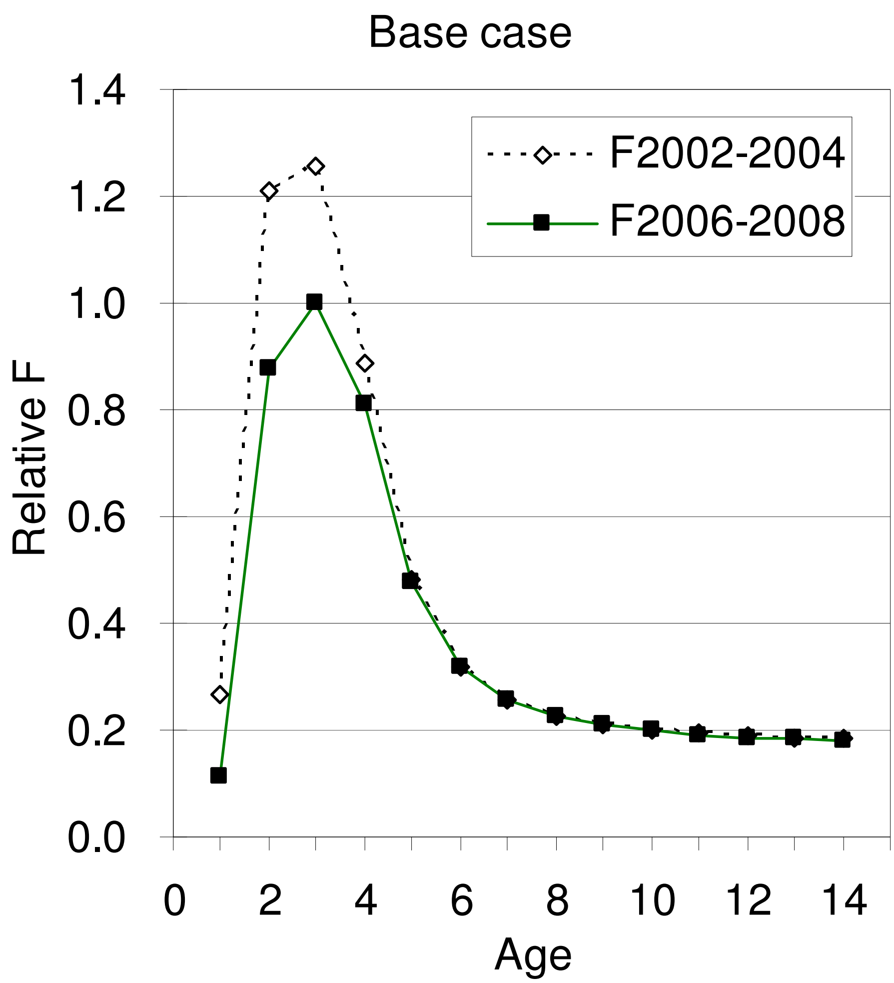



**Figure 17.** Estimated fishing mortality-at-age for the base-case scenario ($F_{2006\text{-}2008}$) and $F_{2002\text{-}2004}$ (current F in the 2006 assessment). Results are scaled to the highest F-at-age in the $F_{2006\text{-}2008}$ series, which was 0.16 $yr^{-1}$.

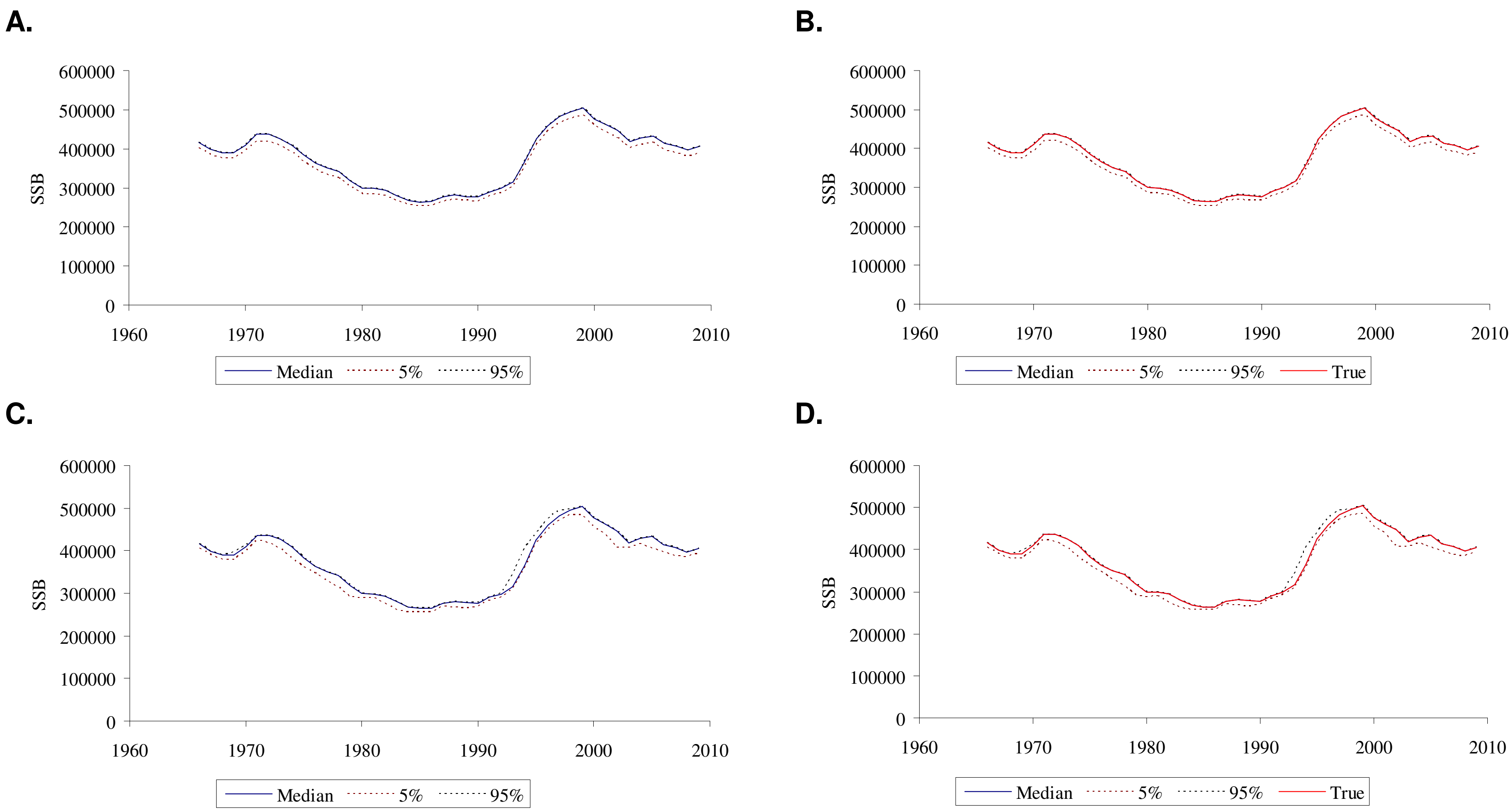
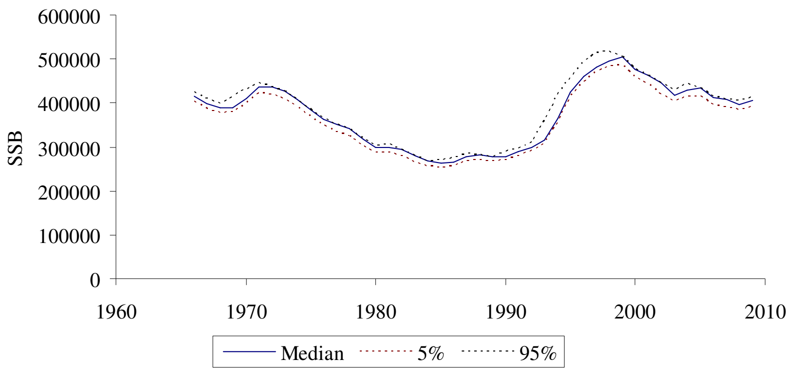



**Figure 18.** Model convergence analysis results showing spawning biomass time series estimated when jitter values of 0.1 (A) and 0.2 (B) were randomly added to parameters (blue lines) and base-case estimates of the SSB time series (C,D – red lines). Dotted lines are 5% and 95% confidence limits.

**E.**




**F.**

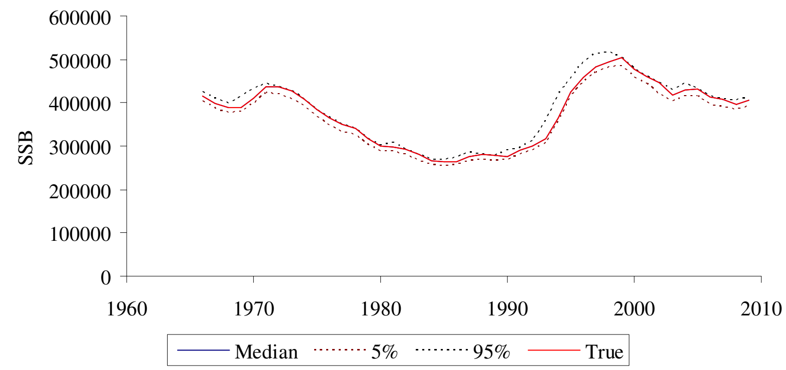



**Figure 18.** Continued. Spawning biomass (t) time series estimated when jitter values of 0.3 (E) were randomly added to parameters (blue lines) and base-case estimates of the SSB time series (F – red lines). Dotted lines are 5% and 95% confidence limits.

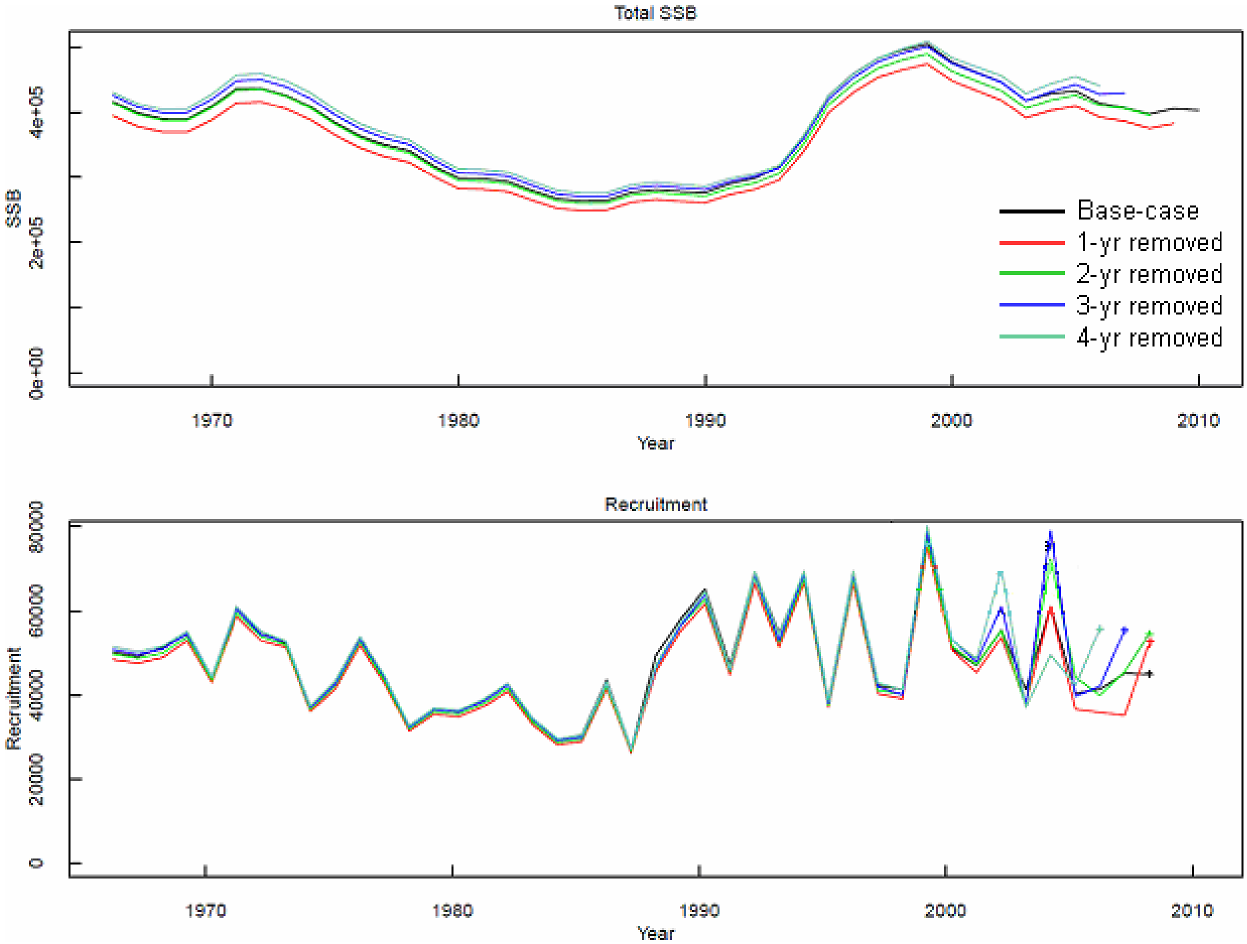
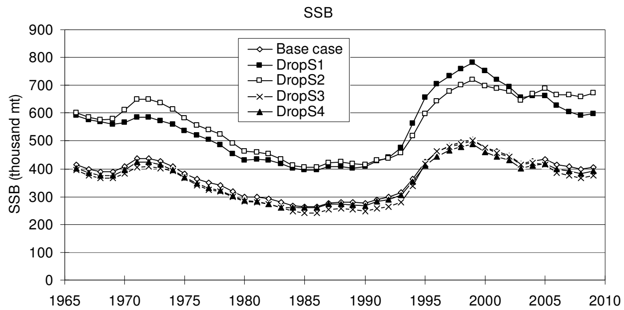
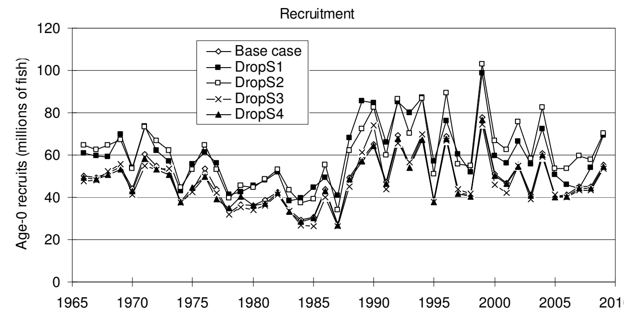



**Figure 19.** Retrospective analysis results showing estimated spawning stock biomass (SSB (1,000s t) - top panel) and recruitment (age-0 fish (1,000s) - bottom) trajectories when 1 to 4 years of data (2009 – 2006) are removed from the base-case model.

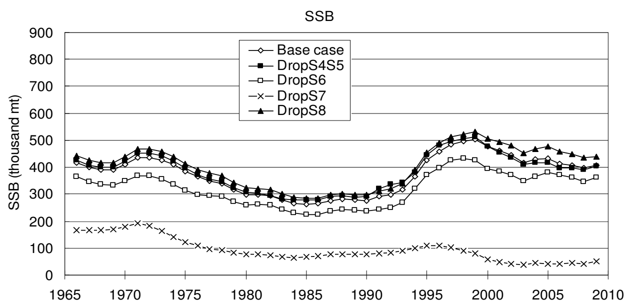
**A.**




**B.**




**C.**




**D.**

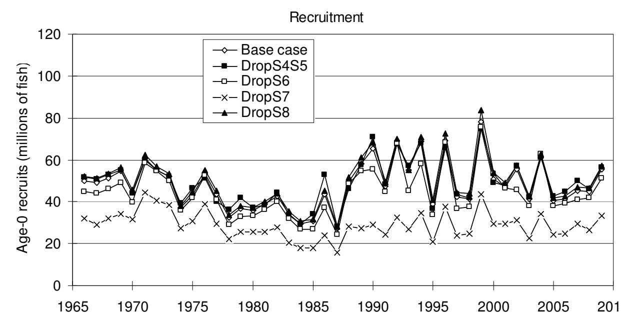



**Figure 20.** Estimates of spawning stock biomass (A,C) and recruitment (B,D) when individual CPUEs indices are dropped from the base-case model.

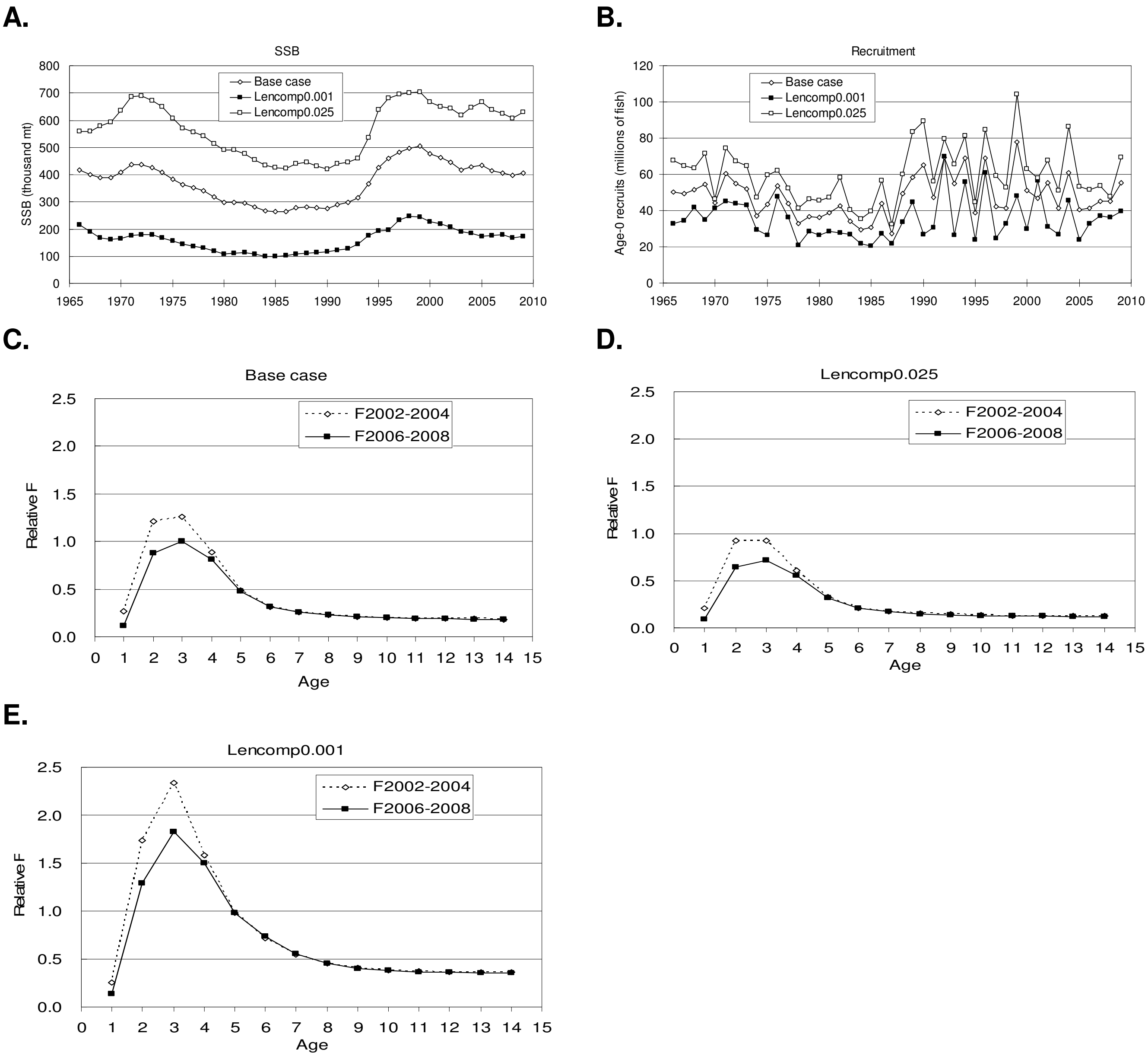



**Figure 21.** Estimates of spawning stock biomass (A), recruitment (B), and F-at-age (C,D,E) for the base-case and sensitivity runs assuming length composition lambdas = 0.025 and =0.001. F-at-age plots are scaled to the highest age-specific $F_{2006\text{-}2008}$ (= 1.0) on the base-case plot (C).

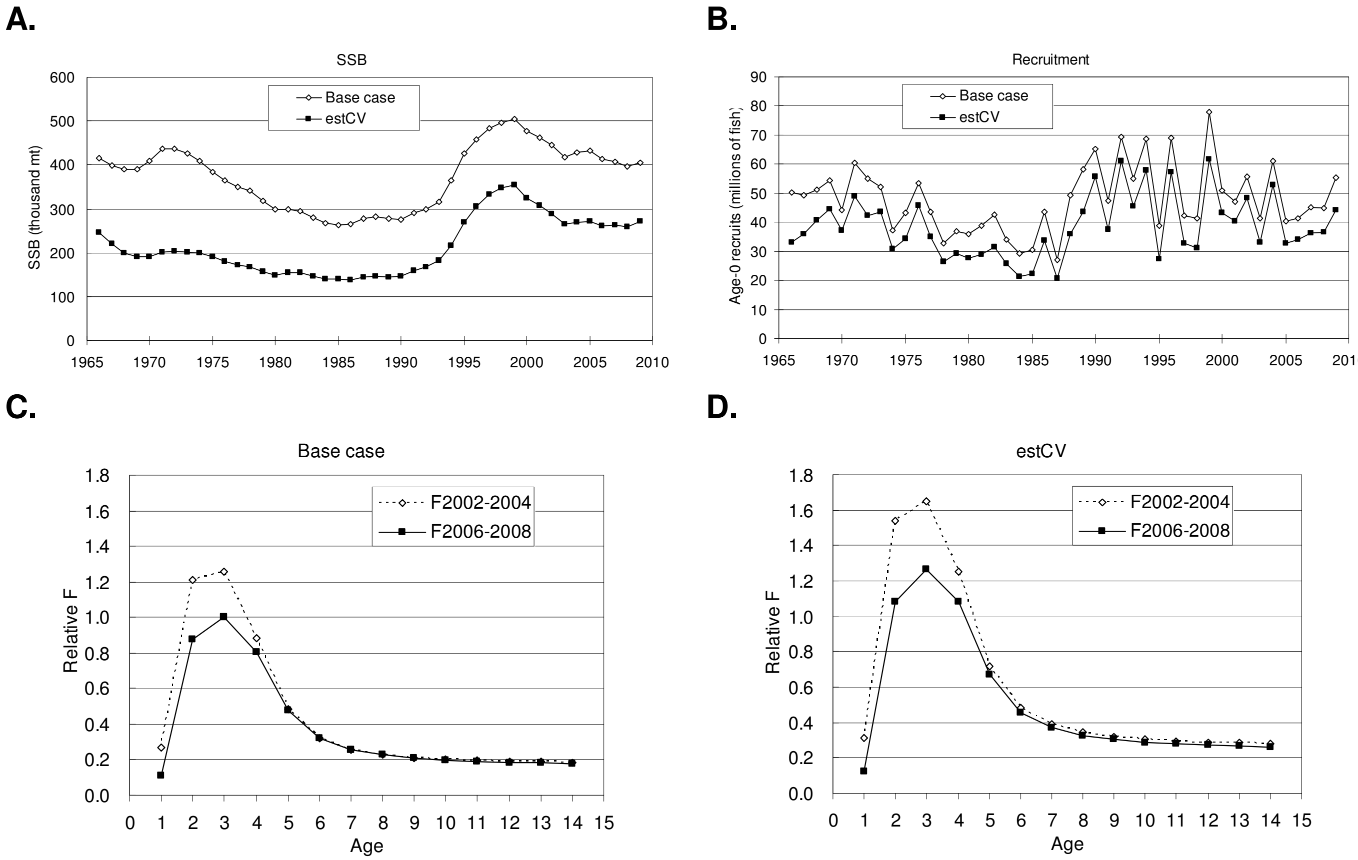



**Figure 22.** Estimates of spawning biomass (A), recruitment (B), and F-at-age (C,D) for the base case and the sensitivity run in which CV for S6 is fixed = 0.2 and all other CPUE index CVs are estimated. F-at-age plots are scaled to the highest age-specific $F_{2006\text{-}2008}$ (= 1.0) on the base-case plot (C).

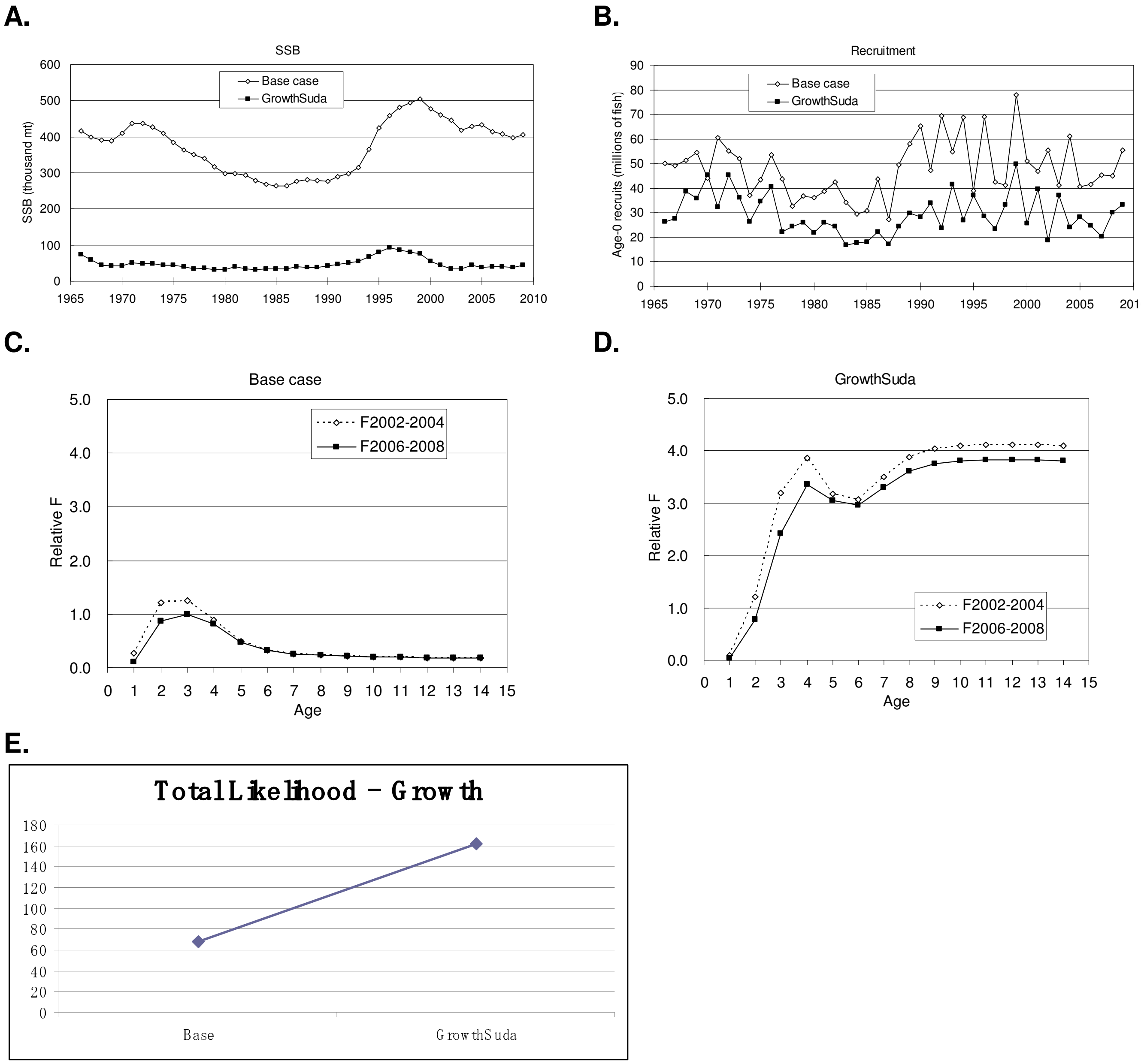



**Figure 23.** Estimates of spawning biomass (A), recruitment (B), and F-at-age (C – Base-case; D-Suda estimates) and total model likelihood (E) for the base case and sensitivity run in which growth curve parameters are fixed to Suda's (1966) estimates. F-at-age plots are scaled to the highest age-specific $F_{2006\text{-}2008}$ (= 1.0) on the base-case plot (C).

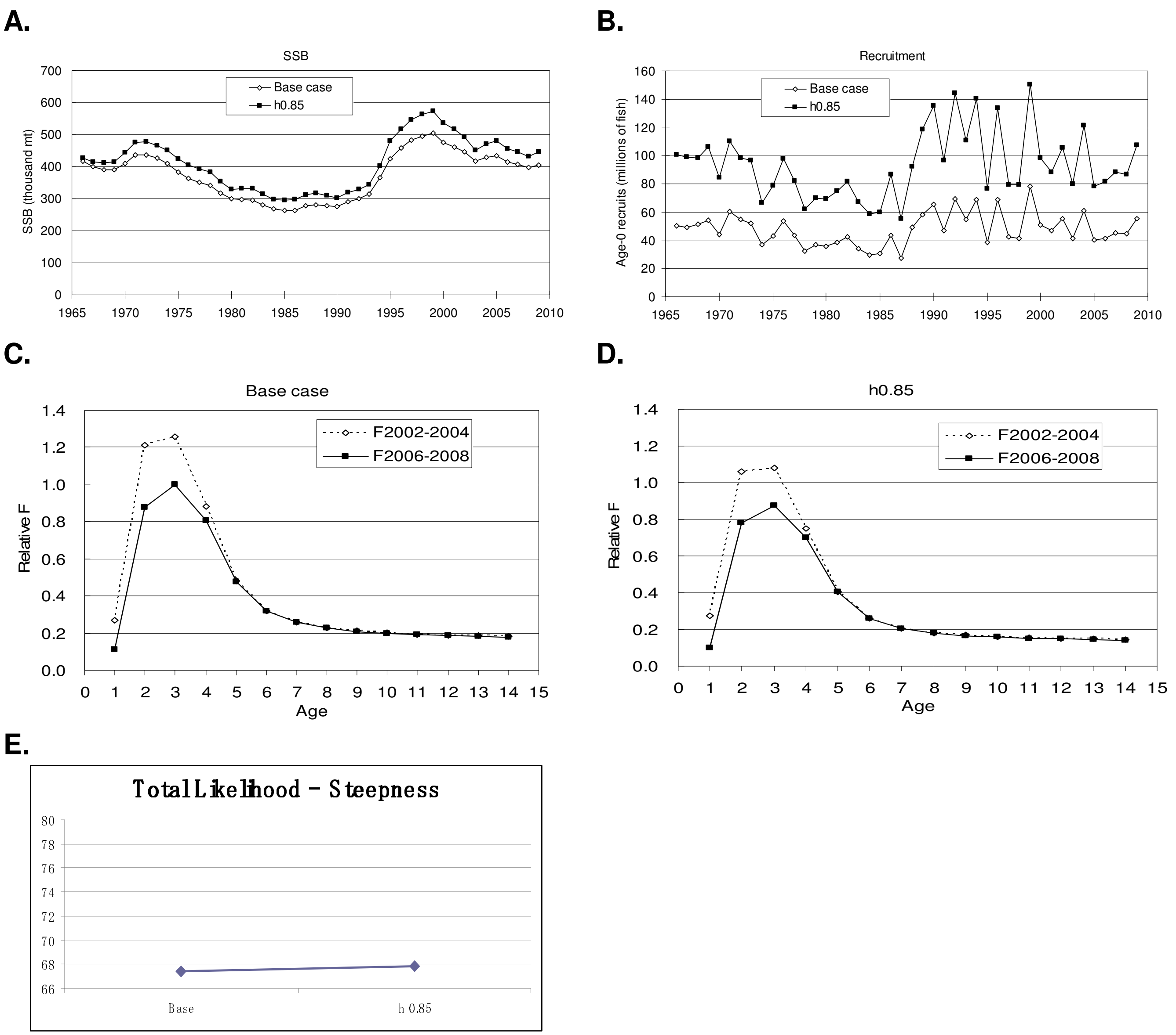



**Figure 24.** Estimates of spawning biomass (A), recruitment (B), F-at-age (C,D), and total likelihood (E) for the base-case and steepness (h) = 0.85. F-at-age plots are scaled to the highest age-specific $F_{2006\text{-}2008}$ (= 1.0) on the base-case plot (C).

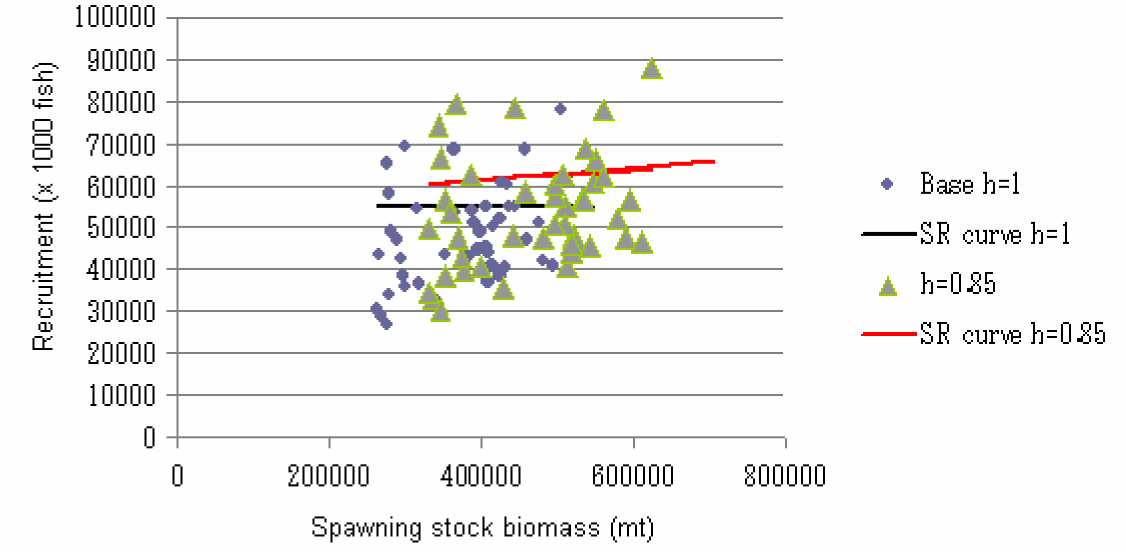



**Figure 25.** Spawning stock biomass and recruitment in the base-case model using two steepness assumptions: h = 1.0 (base-case) and h = 0.85 (sensitivity run).

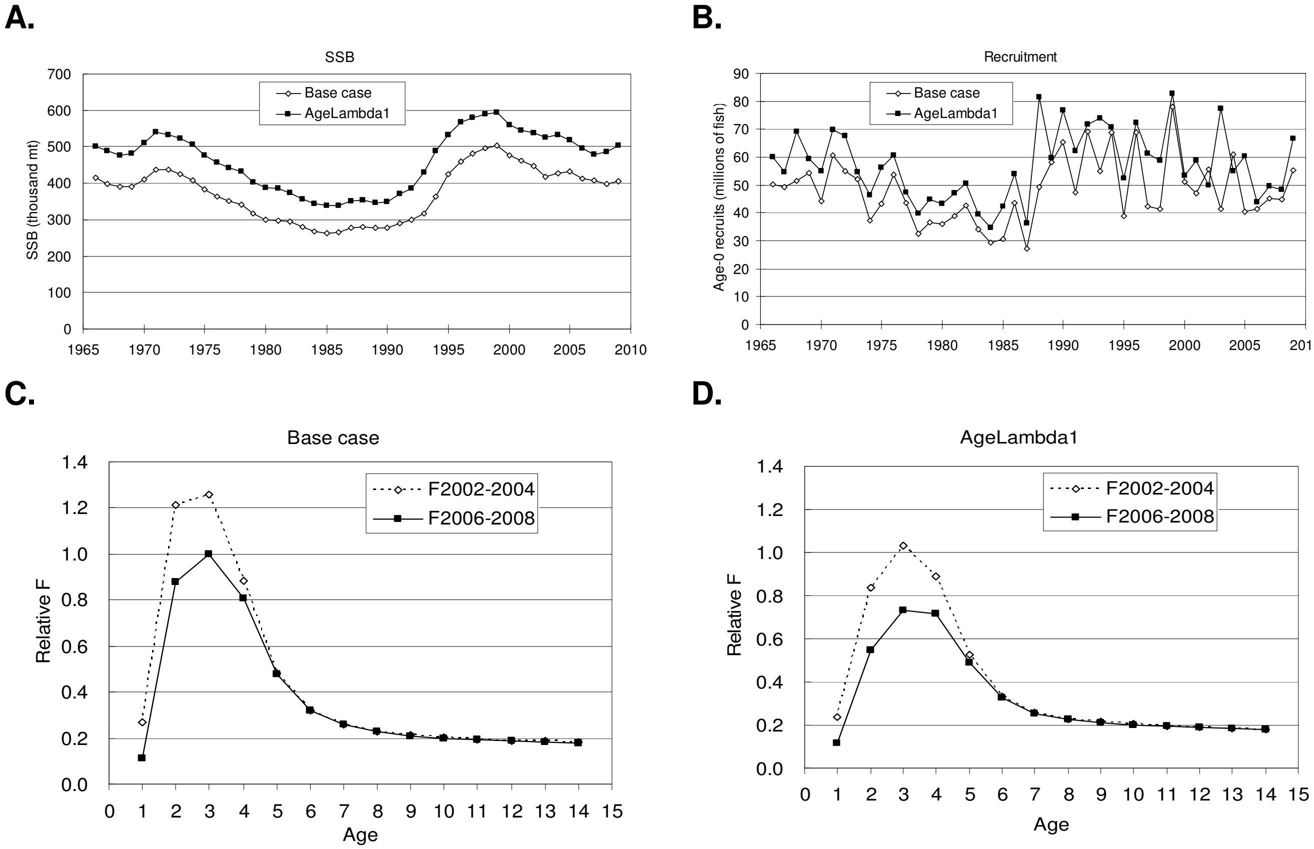



**Figure 26.** Estimates of spawning biomass (A), recruitment (B), and F-at-age (C – Base-case; D-aging lambda = 1) for the base case and sensitivity run assuming aging lambda = 1.0. F-at-age plots are scaled to the highest age-specific $F_{2006\text{-}2008}$ (= 1.0) on the base-case plot (C).

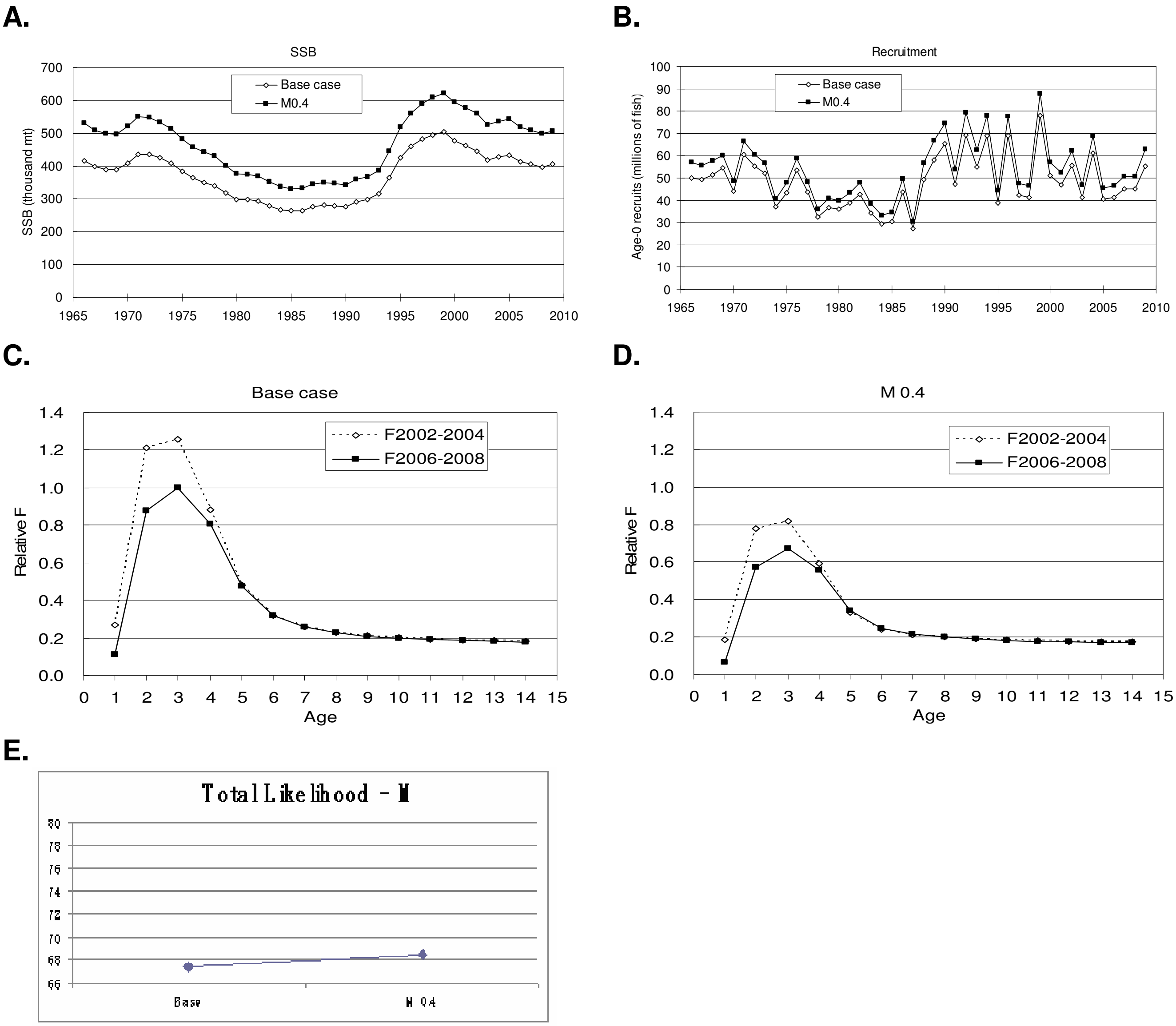
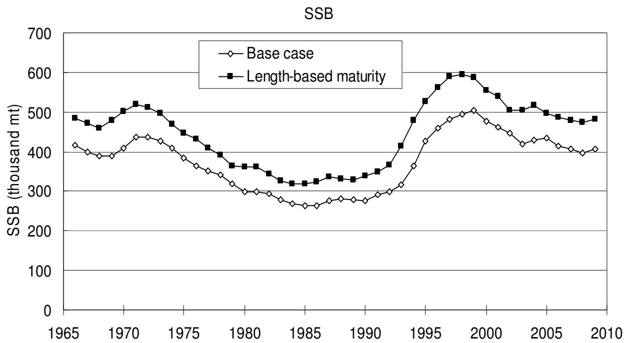



**Figure 27.** Estimates of spawning biomass (A), recruitment (B), F-at-age (C,D), and total likelihood for the base-case model and sensitivity run assuming M = 0.4 $yr^{-1}$ for all ages. F-at-age plots are scaled to the highest age-specific $F_{2006\text{-}2008}$ (= 1.0) on the base-case plot (C).

A.




B.

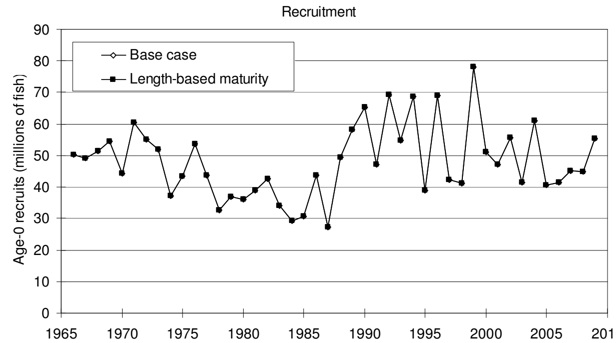



**Figure 28.** Estimates of spawning stock biomass (A) and recruitment (B) for the base-case (age-based maturity) and a sensitivity run using a length-based maturity schedule. Note that recruitment levels and trajectories are identical in the base-case and sensitivity run.

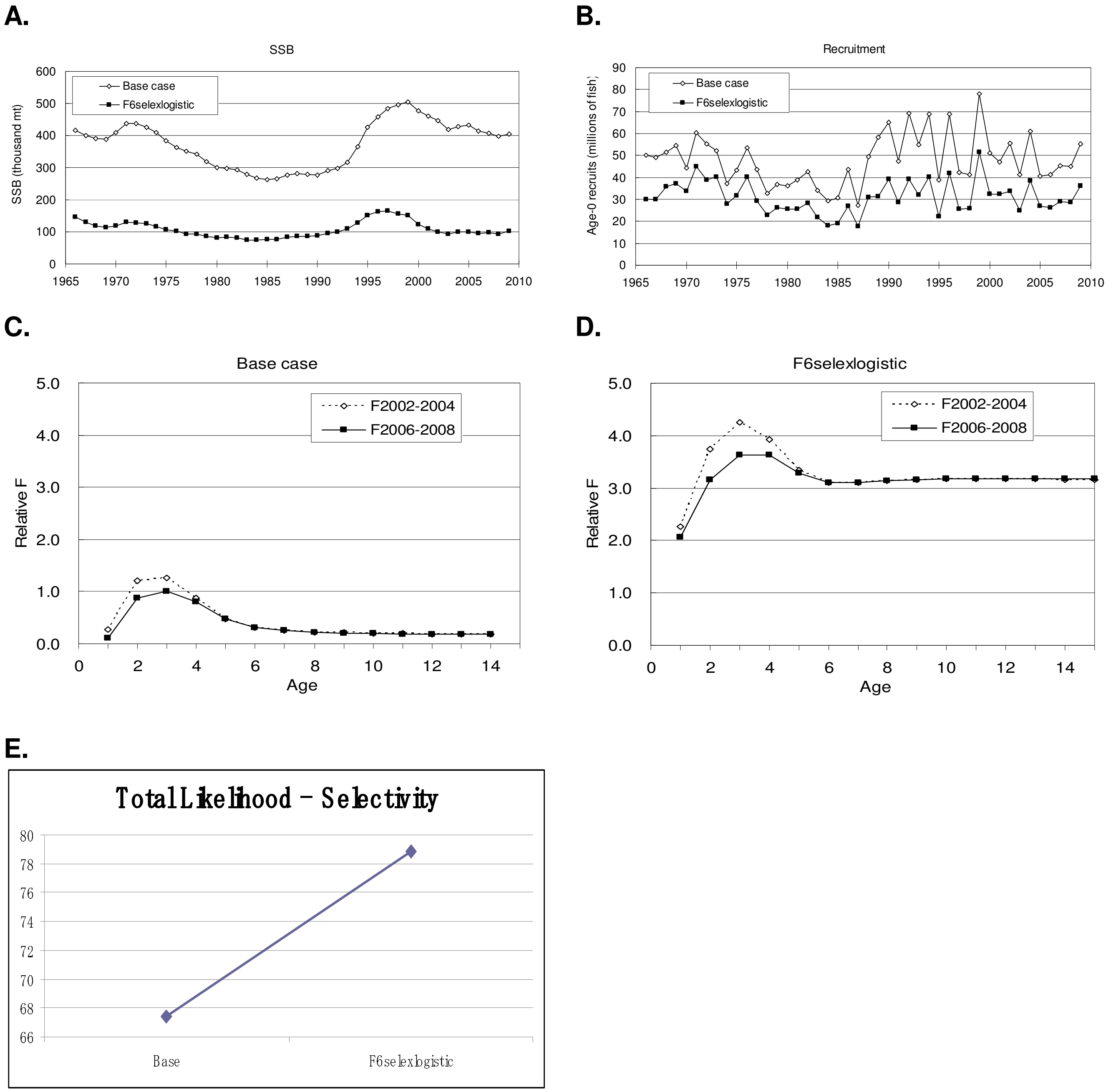



**Figure 29.** Estimates of spawning biomass (A), recruitment (B), F-at-age (C,D), and total likelihood (E) for the base-case model and a sensitivity run assuming that selectivity for fishery F6 is asymptotic rather than dome-shaped. F-at-age plots are scaled to the highest age-specific $F_{2006\text{-}2008}$ (= 1.0) on the base-case plot (C).

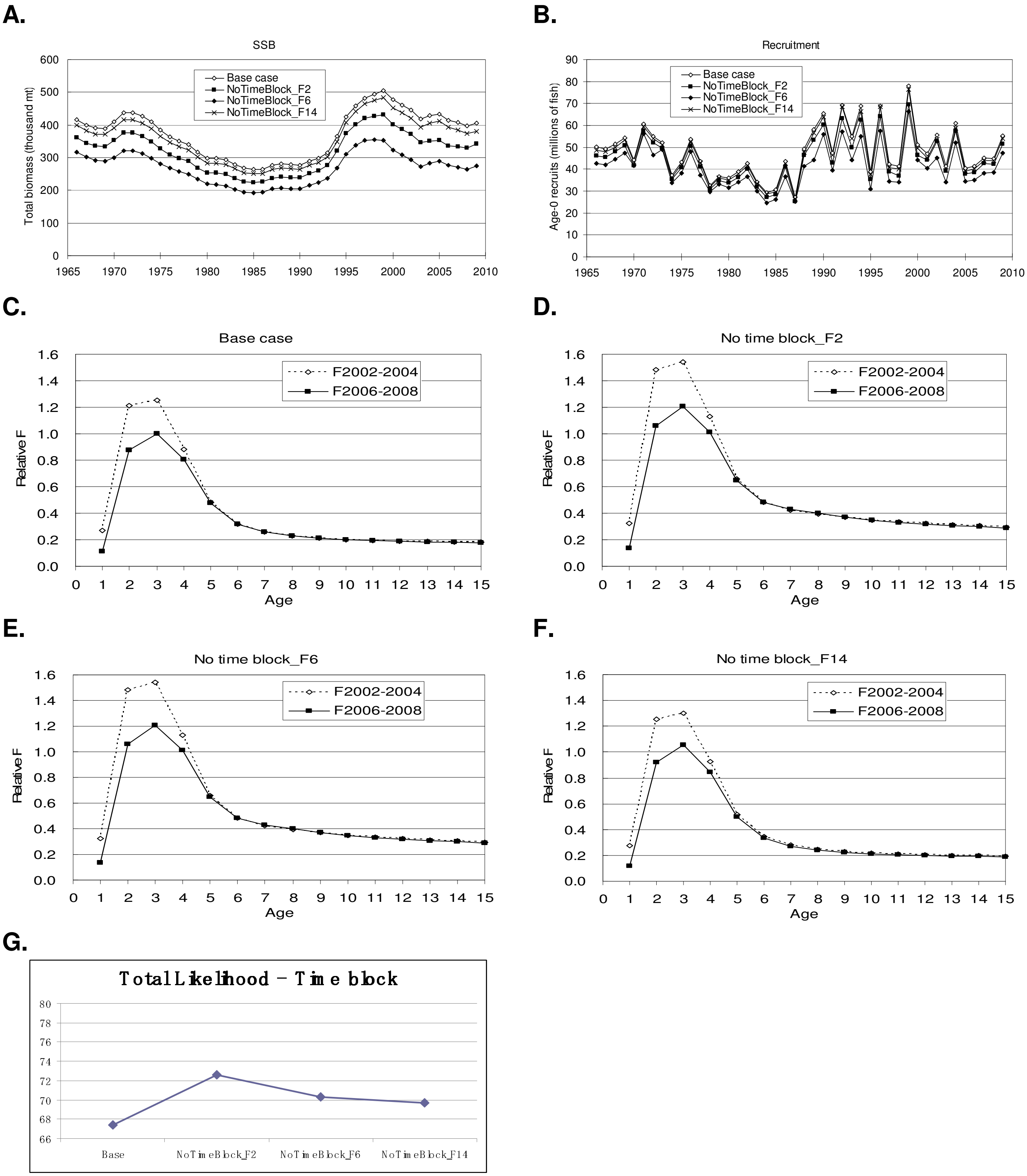



**Figure 30.** Estimates of spawning biomass (A), recruitment (B), F-at-age (C-F), and total model likelihood (G) for the base case scenario and sensitivity runs in which time blocks on selectivity for fisheries F2, F6, and F14 were removed. F-at-age plots are scaled to the highest age-specific $F_{2006\text{-}2008}$ (= 1.0) on the base-case plot (C).

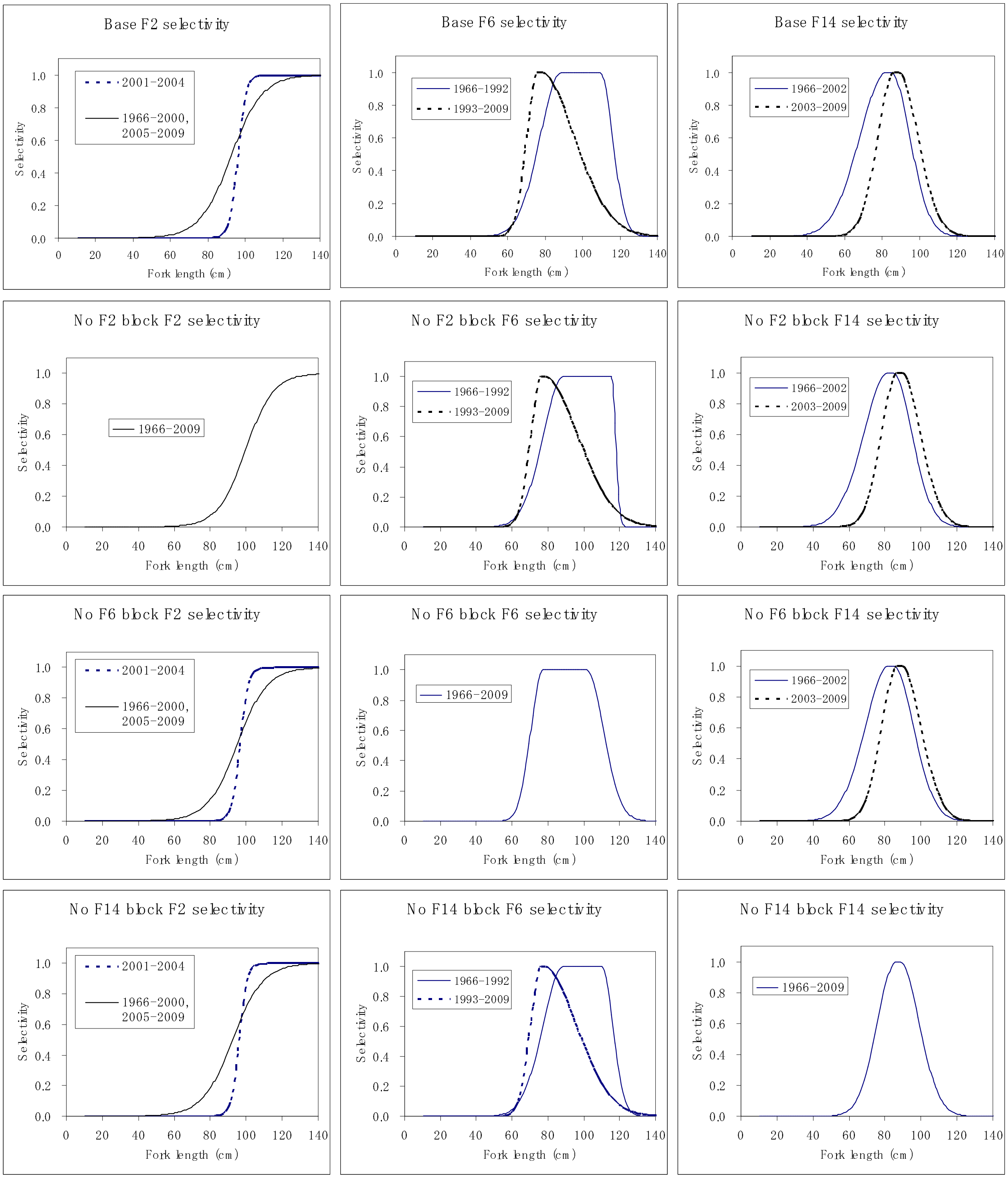



**Figure 31.** Estimated fishery selectivity patterns for the base case and sensitivity run when time blocks were sequentially removed from fisheries F2, F6, and F14.

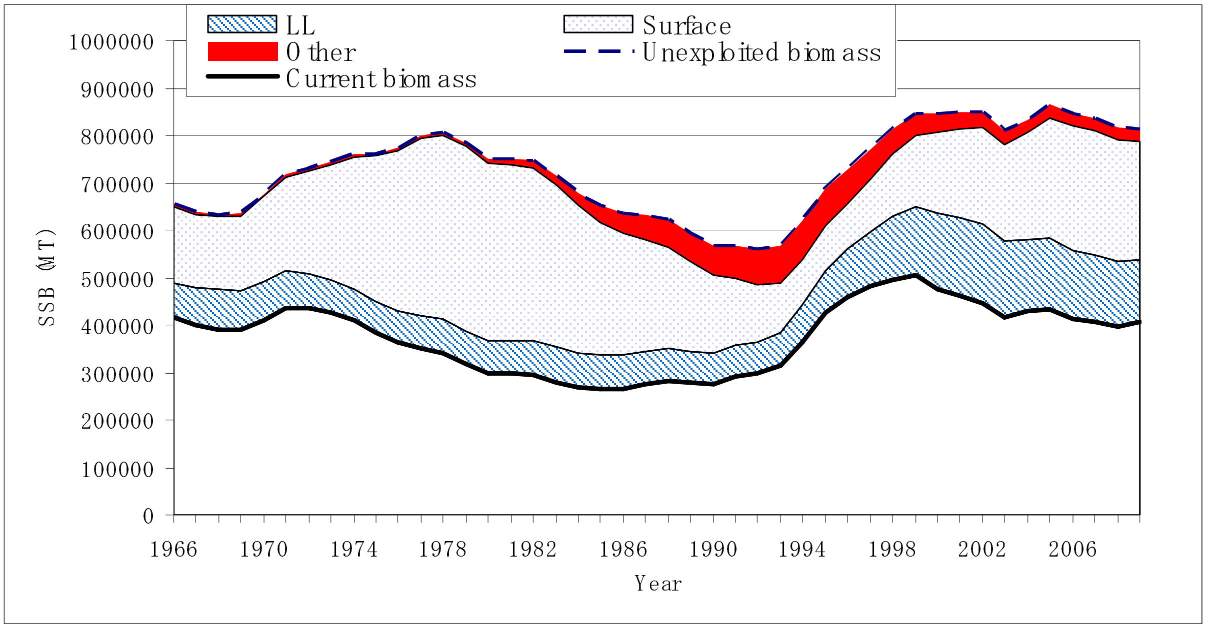



**Figure 32.** Spawning stock biomass (SSB) time series of a simulated population of north Pacific albacore that was unexploited (top dashed line) and predicted (solid line) by the base case model. The shaded areas show the portions of the impact attributed to each major fishing method. LL: longline (USA, JPN, TWN, KOR and others), surface: UCLTN and JPN PL, Other: miscellaneous fisheries not included in the longline and surface categories.

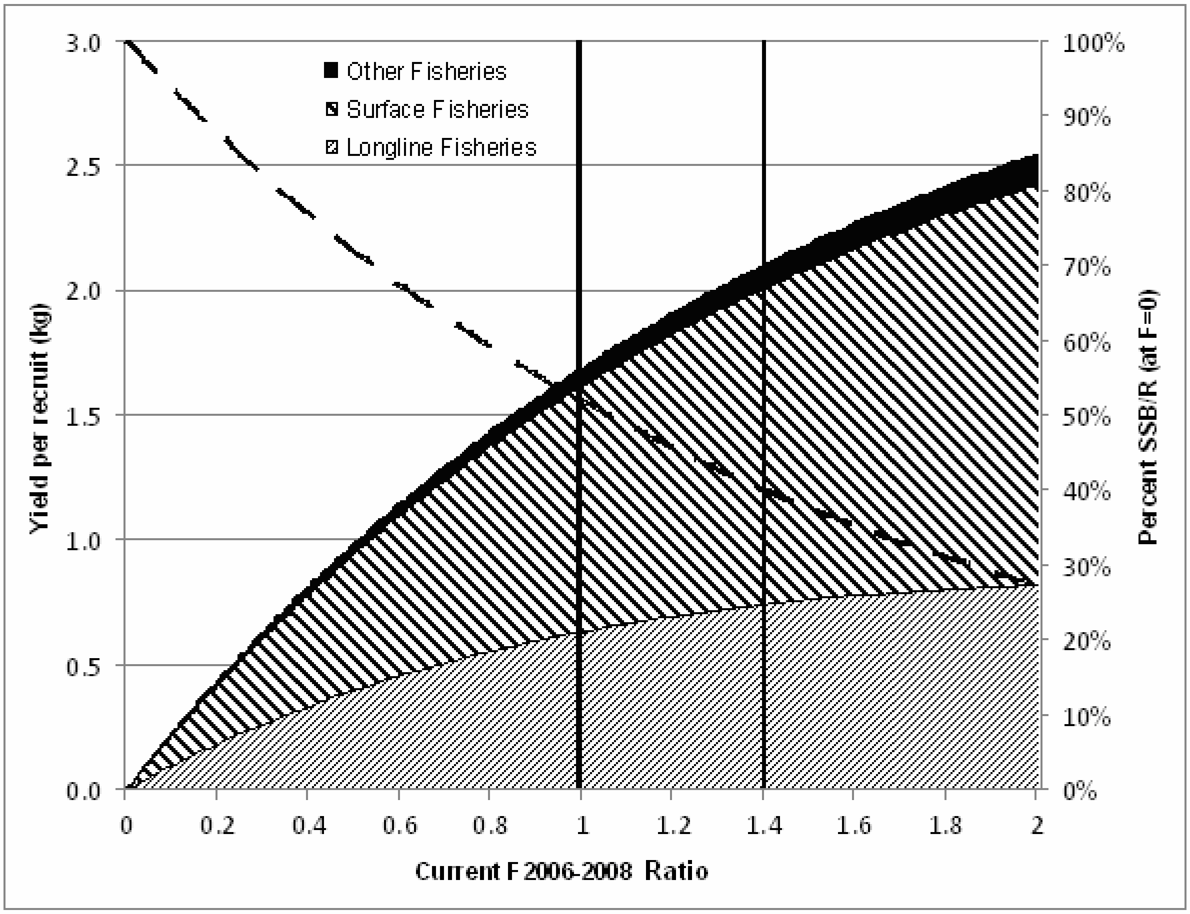



**Figure 33.** Equilibrium yield-per-recruit (shaded areas) for major fishery type and spawning potential ratio (percent of SSB/R at F relative to SSB/r at F = 0) (dashed line) as a function of fishing mortality rate (F) for north Pacific albacore associated with the base-case model. The current fishing mortality rate multiplier (F = 1.0 at F = $F_{2006\text{-}2008}$) is based on the fully-selected F observed from the geometric mean of F-at-age estimates from 2006-08. Vertical lines show $F_{2006\text{-}2008}$ (F-multiplier = 1.0) and $F_{SSB\text{-}ATHL}$ (F-multiplier = 1.41).

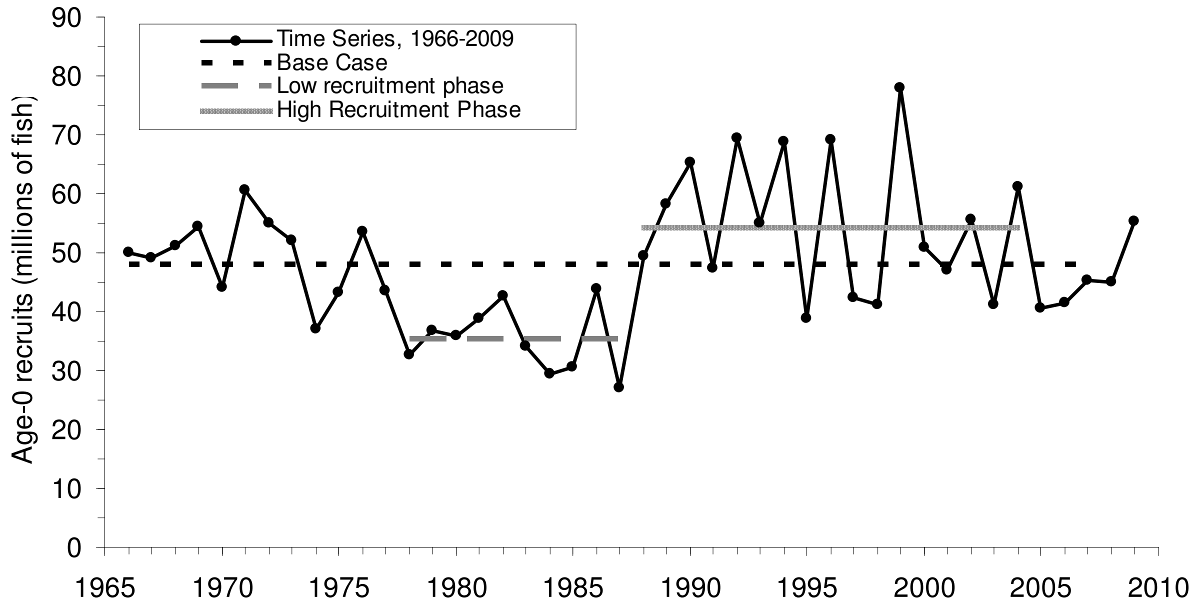



**Figure 34.** Historical trends in recruitment of north Pacific albacore (age-0) estimated by the SS3 base-case model and the assumed periods of low and high recruitments used for future projection scenarios.

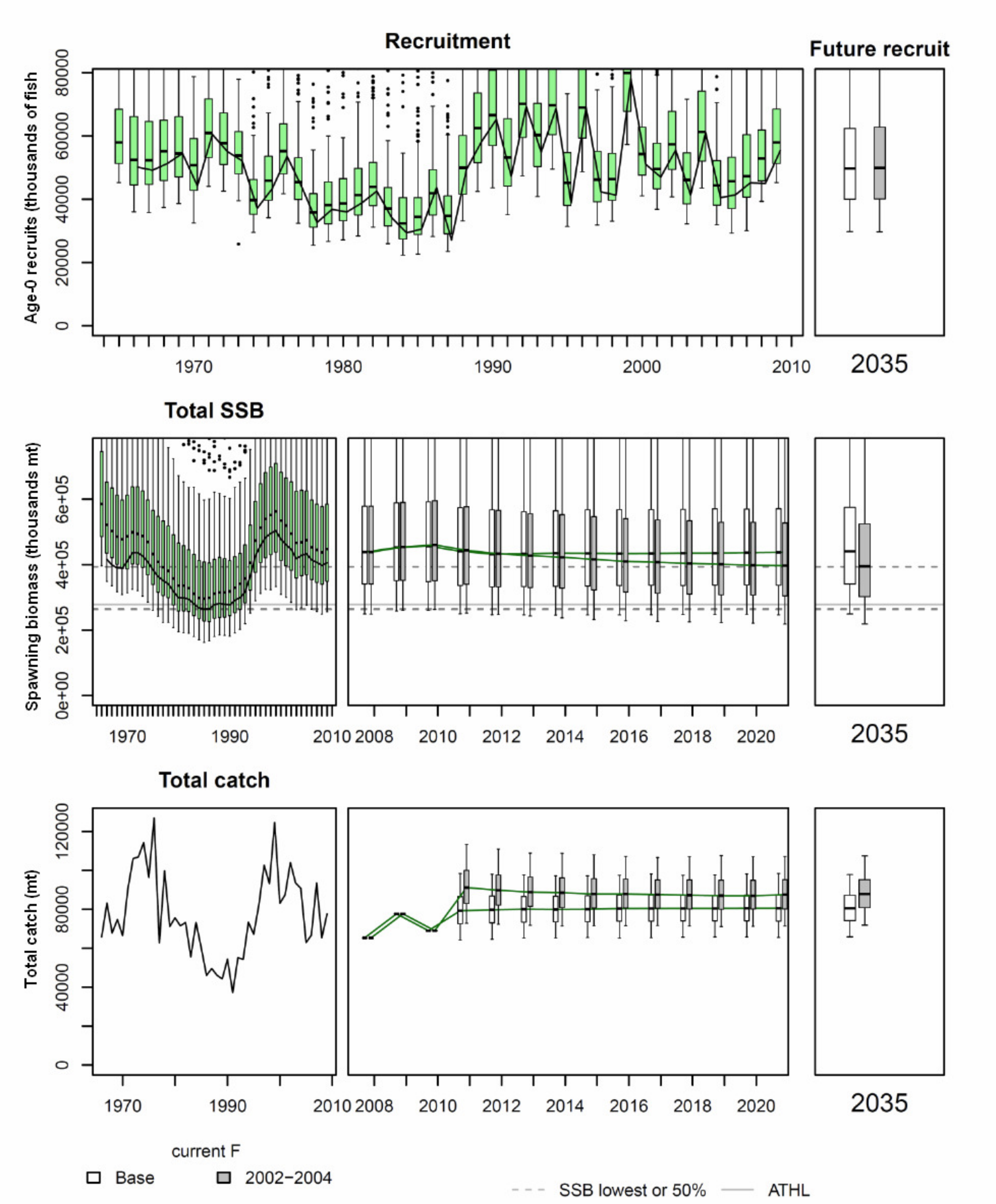



**Figure 35.** Past and future trajectories on recruitment (top), SSB (middle) and total catch (bottom), estimated with two harvesting scenarios of base-case $F_{2006\text{-}2008}$ and $F_{2002\text{-}2004}$. The lines from the boxes represent 90% confidence intervals, and lower and upper end of boxes represent 25th and 75th percentiles. Open circles are extreme values.

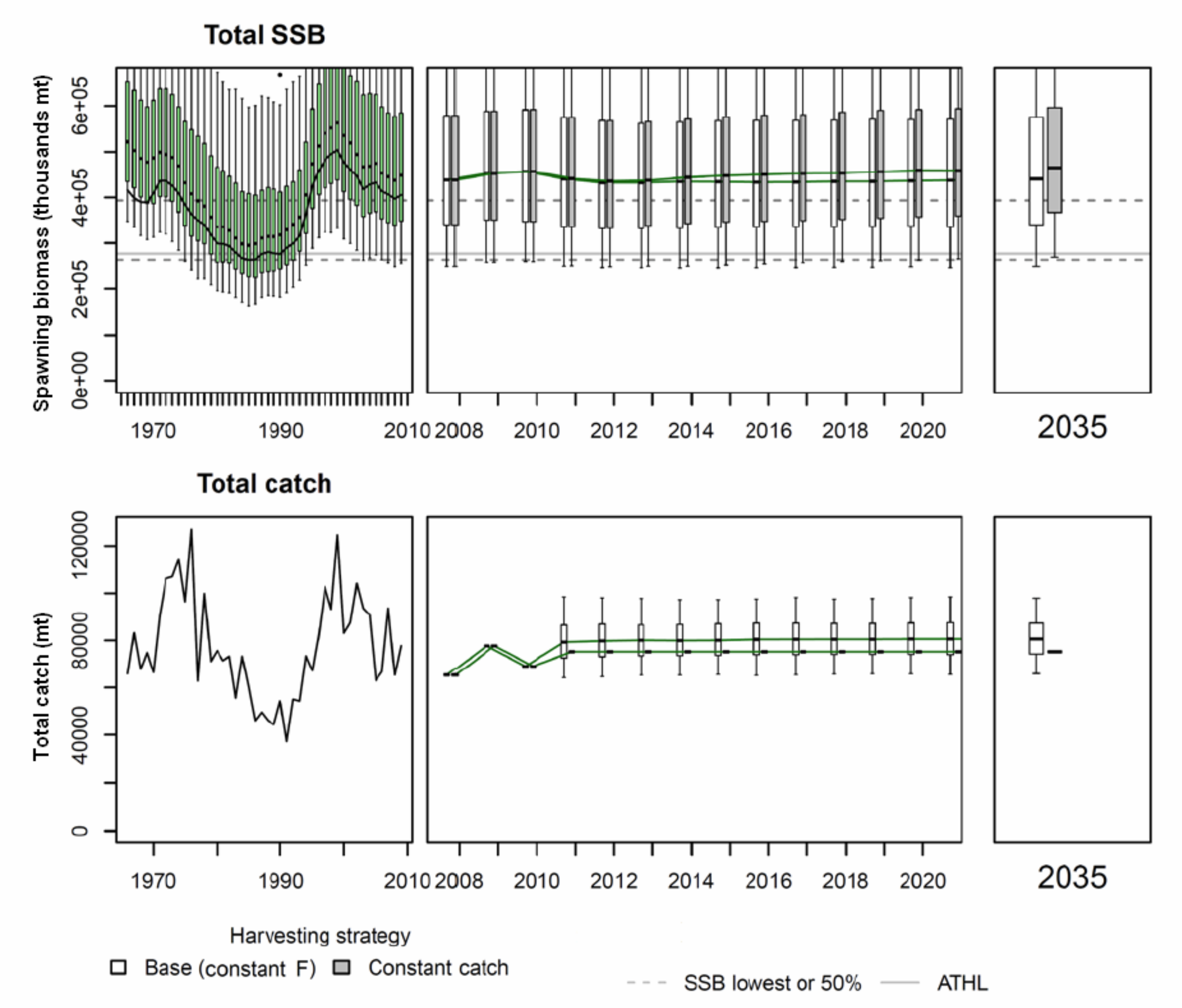



**Figure 36.** Past and future trajectories on SSB estimated with two harvesting scenarios (constant $F_{2006\text{-}2008}$) and constant catch (average catch from 2005 to 2007).

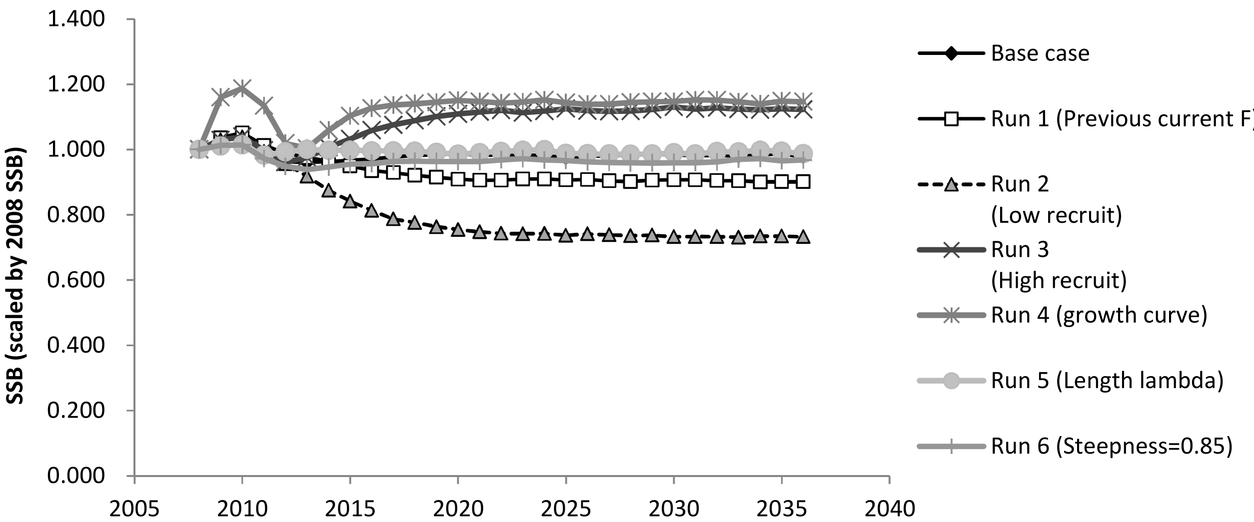



**Figure 37.** Comparison of SSB trajectories of among seven future projection runs testing harvesting and recruitment scenarios and assessing structural sensitivities. Results are scaled to $SSB_{2008}$, which is approximately the long-term median SSB during the modeled period, 1966-2009.

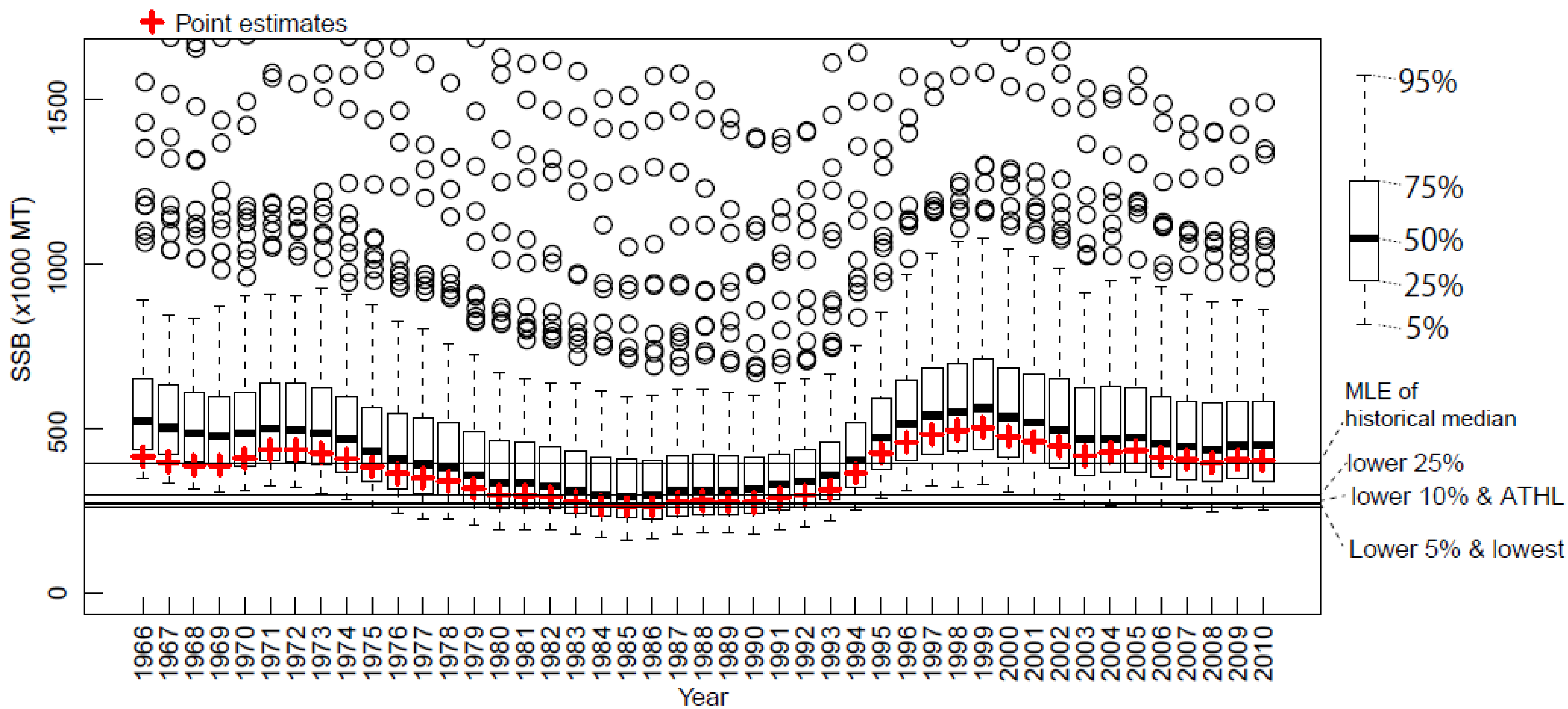
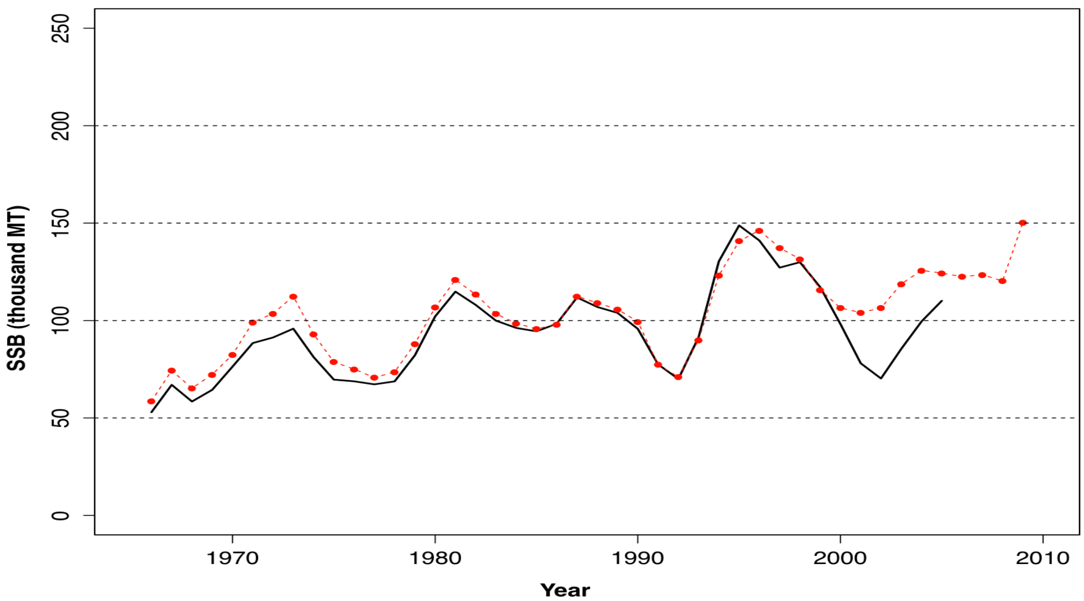



**Figure 38.** Historical SSB time series and confidence intervals estimated from 200 bootstrap results. The lines from the boxes represent 90% confidence intervals, and lower and upper end of boxes represent 25$^{th}$ and 75$^{th}$ percentiles. Open circles are extreme values. The figure also shows horizontal lines representing the maximum likelihood estimate of the historical median spawning biomass, the lower 5$^{th}$, 10$^{th}$ and 25$^{th}$ percentiles, and the ATHL. The red crosses are the point estimates of spawning biomass from the base-case assessment model.

A.




B.

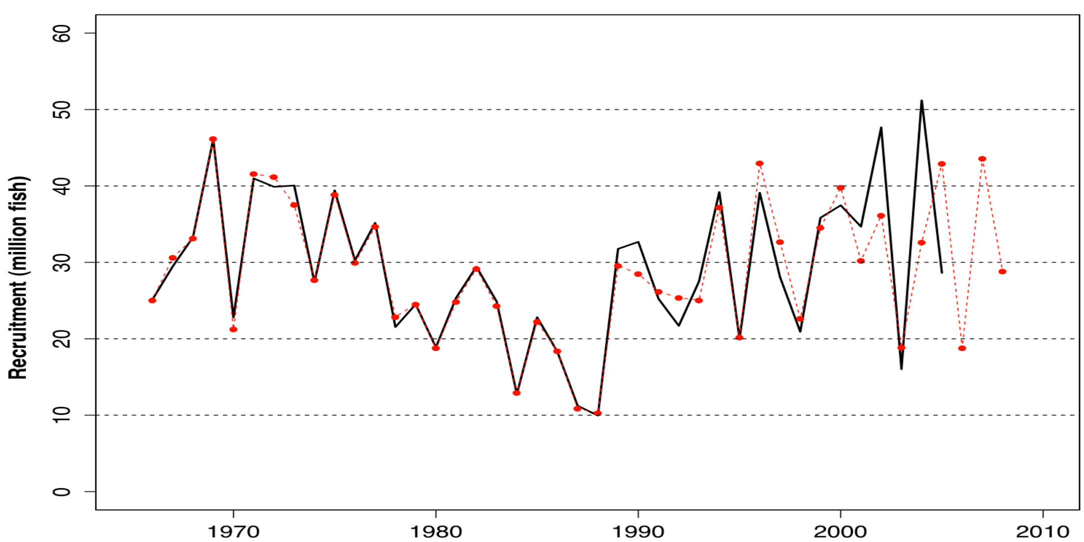



**Figure 39.** Estimated spawning stock biomass (A) and recruitment at age-1 (B) time series in the VPA reference run (red) and from the 2006 stock assessment (black).

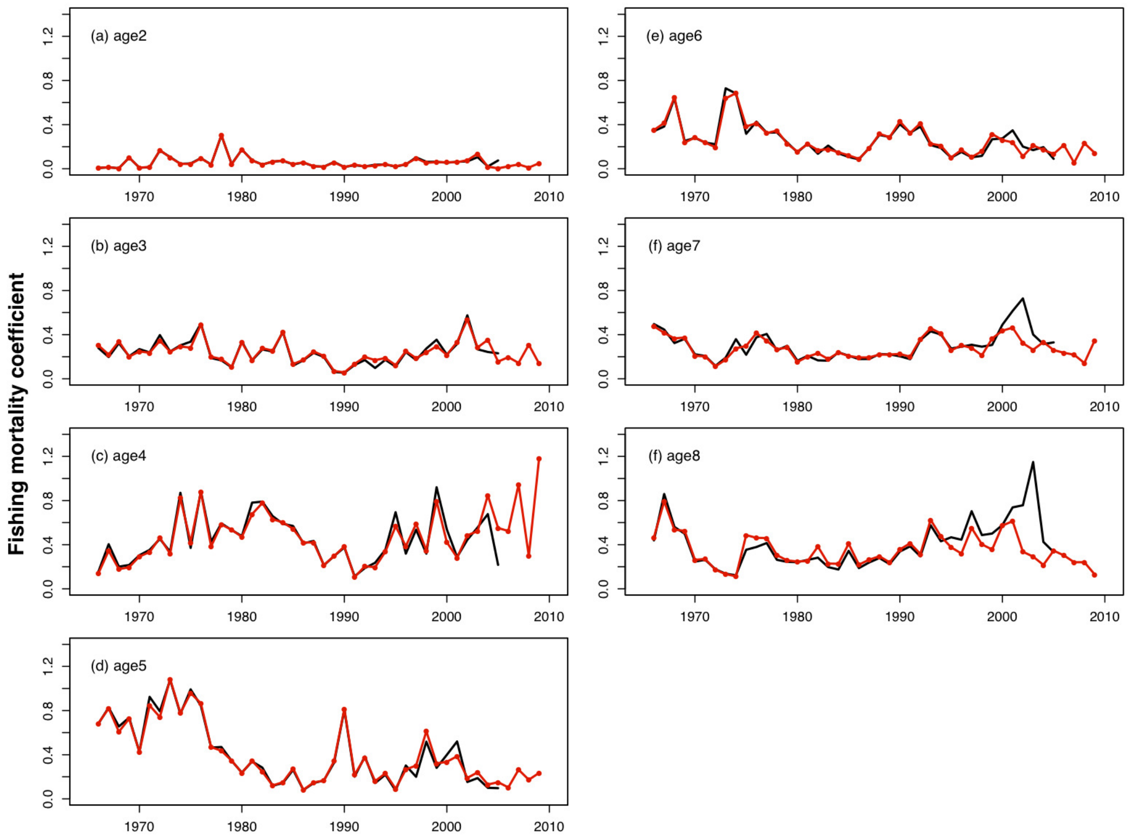



**Figure 40.** Fishing mortality coefficients for each age estimated in the VPA reference run (red) and the 2006 stock assessment (black).

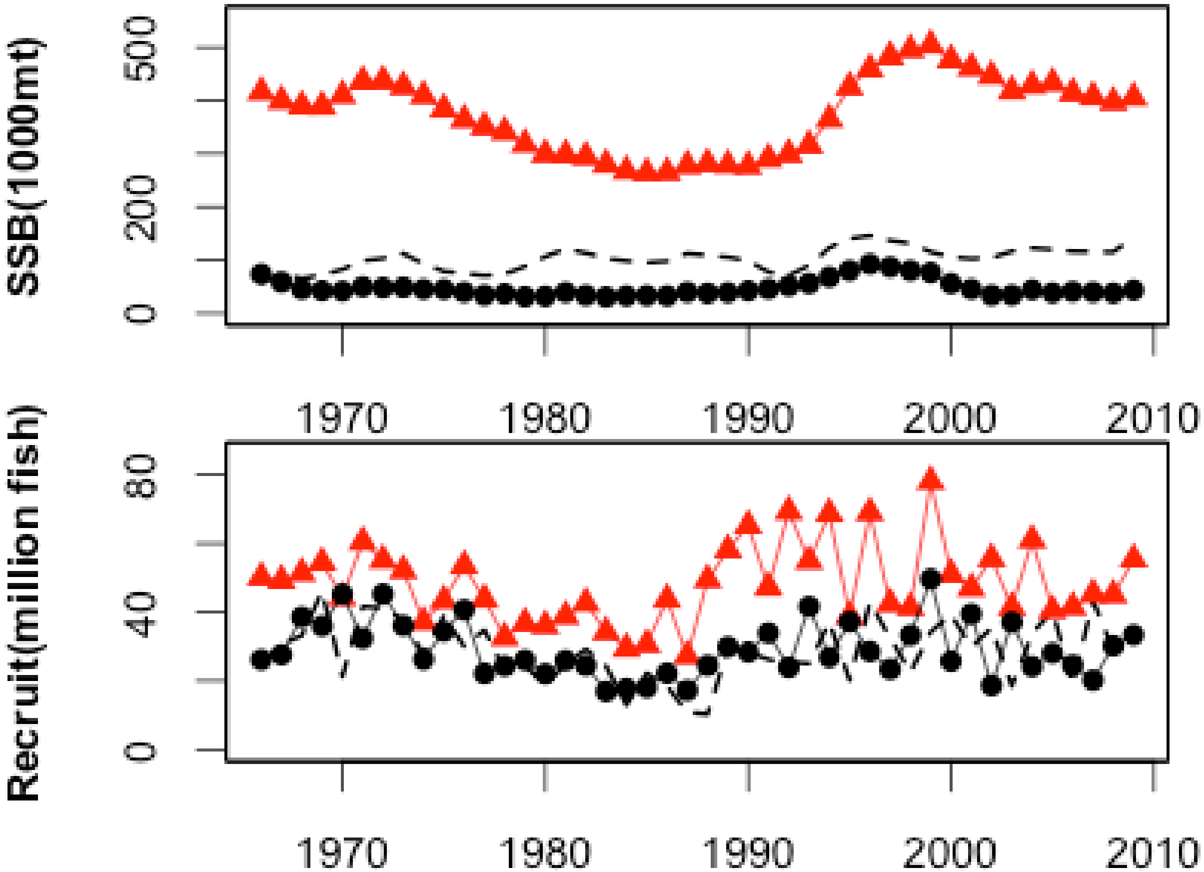



**Figure 41.** Spawning stock biomass (SSB - top) and recruitment (bottom) of north Pacific albacore estimated in the VPA reference run (black dashed line) and SS3 base-case model (red triangles). Black circles are estimates of SSB and recruitment when growth curve parameters were fixed to Suda (1966) estimates as a sensitivity run of the SS3 base-case model. Recruitment is estimated at age-1 in the VPA reference run and at age-0 in SS3 base-case model resulting in an offset of one year.

# APPENDIX 1

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# APPENDIX 2

### SS3 starter file used in the North Pacific albacore assessment for the base case.

```
#Starter file for North Pacific albacore assessment in 2011.
NPalb2011_data.dat # Data file
NPalb2011.ctl # Control file
0 # 0=use init values in control file; 1=use ss3.par
1 # run display detail (0,1,2)
1 # detailed age-structured reports in REPORT.SSO (0,1)
0 # write detailed checkup.sso file (0,1)
0 # write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all; 3=every_iter,all_parms;
4=every,active)
1 # write to cumreport.sso (0=no,1=like&timeseries; 2=add survey fits)
0 # Include prior_like for non-estimated parameters (0,1)
1 # Use Soft Boundaries to aid convergence (0,1) (recommended)
1 # Number of bootstrap datafiles to produce
10 # Turn off estimation for parameters entering after this phase
10 # MCeval burn interval
2 # MCeval thin interval
0 # jitter initial parm value by this fraction
-1 # min yr for sdreport outputs (-1 for styr)
-1 # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs
0 # N individual STD years
#vector of year values

0.0001 # final convergence criteria (e.g. 1.0e-04)
0 # retrospective year relative to end year (e.g. -4)
1 # min age for calc of summary biomass
1 # Depletion basis:  denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy; 3=rel X*B_styr
1 # Fraction (X) for Depletion denominator (e.g. 0.4)
4 # SPR_report_basis:  0=skip; 1=(1-SPR)/(1-SPR_tgt); 2=(1-SPR)/(1-SPR_MSY); 3=(1-SPR)/(1-
SPR_Btarget); 4=rawSPR
1 # F_report_units: 0=skip; 1=exploitation(Bio); 2=exploitation(Num); 3=sum(Frates)
0 # F_report_basis: 0=raw; 1=F/Fspr; 2=F/Fmsy ; 3=F/Fbtgt
999 # check value for end of file
```

# APPENDIX 2

## SS3 forecast file used in the North Pacific albacore assessment for the base case.

```
#Forecast file for North Pacific albacore assessment in 2011.
4 # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt); 4=F(endyr); 5=Ave F (enter yrs); 6=read Fmult
# -4  # first year for recent ave F for option 5 (not yet implemented)
# -1  # last year for recent ave F for option 5 (not yet implemented)
# 0.74  # F multiplier for option 6 (not yet implemented
-3 # first year to use for averaging selex to use in forecast (e.g. 2004; or use -x to be rel endyr)
0 # last year to use for averaging selex to use in forecast
1 # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2 # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=set to F(endyr)
0.4 # SPR target (e.g. 0.40)
0.4 # Biomass target (e.g. 0.40)
1 # N forecast years
0 # read 10 advanced options
#0 # Do West Coast gfish rebuilder output (0/1)
#2008 # Rebuilder:  first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
#2010 # Rebuilder:  year for current age structure (Yinit) (-1 to set to endyear+1)
#1 # Control rule method (1=west coast adjust catch; 2=adjust F)
#0.4 # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40)
#0.1 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
#1 # Control rule fraction of Flimit (e.g. 0.75)
#0 # basis for max forecast catch by seas and area (0=none; 1=deadbio; 2=retainbio; 3=deadnum; 4=retainnum)
#0 # 0= no implementation error; 1=use implementation error in forecast (not coded yet)
#0.1 # stddev of log(realized F/target F) in forecast (not coded yet)
# end of advanced options
# placeholder for max forecast catch by season and area
1 # fleet allocation (in terms of F) (1=use endyr pattern, no read; 2=read below)
0 # Number of forecast catch levels to input (rest calc catch from forecast F
# 1 # basis for input forecatch:  1=retained catch; 2=total dead catch; 3=input Hrate(F)
#Year Seas Fleet Catch


999 # verify end of input
```

# APPENDIX 2

## SS3 control file used in the North Pacific albacore assessment for the base case.

```
# Control file for North Pacific albacore assessment in 2011.
#_data_and_control_files: NPalb2011_data.dat // NPalb2011.ctl
#_SS-V3.11b-opt;_09/23/2010;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB
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
 1 2 1
#
#_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 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1 dest=2, age1=4,
age2=10
#
3 #_Nblock_Patterns
 1 1 1 #_blocks_per_pattern
# begin and end years of blocks
 2001 2004
 1993 2009
 2003 2009
#
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=not implemented; 4=not
implemented
1 #_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 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A)
3 #_maturity_option:  1=length logistic; 2=age logistic; 3=read age-maturity matrix by growth_pattern;
4=read age-fecundity; 5=read fec and wt from wtatage.ss
#_Age_Maturity by growth pattern
 0 0 0 0 0 0.5 1 1 1 1 1 1 1 1 1 1
5 #_First_Mature_Age
1 #_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b
0 #_hermaphroditism option:  0=none; 1=age-specific fxn
1 #_parameter_offset_approach (1=none, 2= M, G, 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
 0.1 0.8 0.3 0.3 -1 99 -1 0 0 0 0 0 0 0 # NatM_p_1_Fem_GP_1
 10 60 44.4038 40.2 -1 99 5 0 0 0 0 0 0 0 # L_at_Amin_Fem_GP_1
```

```
 100 160 118.029 146.46 -1 99 5 0 0 0 0 0 0 0 0 # L_at_Amax_Fem_GP_1
 0.01 0.4 0.249518 0.149 -1 99 5 0 0 0 0 0 0 0 0 # VonBert_K_Fem_GP_1
 0.01 0.3 0.0599166 0.1 -1 99 5 0 0 0 0 0 0 0 0 # CV_young_Fem_GP_1
 0.01 0.3 0.033914 0.08 -1 99 5 0 0 0 0 0 0 0 0 # CV_old_Fem_GP_1
 -2 2 8.7e-005 8.7e-005 -1 99 -3 0 0 0 0 0 0 0 0 # Wtlen_1_Fem
 -2 4 2.67 2.67 -1 99 -3 0 0 0 0 0 0 0 0 # Wtlen_2_Fem
 1 10 5 5 -1 99 -3 0 0 0 0 0 0 0 0 # Mat50%_Fem
 -5 5 -3.746 -3.746 -1 99 -3 0 0 0 0 0 0 0 0 # Mat_slope_Fem
 0 3 1 1 -1 99 -3 0 0 0 0 0 0 0 0 # Eggs/kg_inter_Fem
 0 3 0 0 -1 99 -3 0 0 0 0 0 0 0 0 # Eggs/kg_slope_wt_Fem
 -4 4 0 1 -1 99 -3 0 0 0 0 0 0 0 0 # RecrDist_GP_1
 -4 4 0 1 -1 99 -3 0 0 0 0 0 0 0 0 # RecrDist_Area_1
 -4 4 -4 1 -1 99 -3 0 0 0 0 0 0 0 0 # RecrDist_Seas_1
 -4 4 0 1 -1 99 -3 0 0 0 0 0 0 0 0 # RecrDist_Seas_2
 -4 4 -4 1 -1 99 -3 0 0 0 0 0 0 0 0 # RecrDist_Seas_3
 -4 4 -4 1 -1 99 -3 0 0 0 0 0 0 0 0 # RecrDist_Seas_4
 -4 4 1 1 -1 99 -3 0 0 0 0 0 0 0 0 # CohortGrowDev
#
#_seasonal_effects_on_biology_parms
 19 23 0 0 0 0 0 0 0 0 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
 -2 2 0 0 -1 99 -2 # F-WL1_seas_1
 -2 2 -0.80235 -0.80235 -1 99 -2 # F-WL1_seas_2
 -2 2 -1.42139 -1.42139 -1 99 -2 # F-WL1_seas_3
 -2 2 -1.1337 -1.1337 -1 99 -2 # F-WL1_seas_4
 -2 2 0 0 -1 99 -2 # F-WL2_seas_1
 -2 2 0.061726 0.061726 -1 99 -2 # F-WL2_seas_2
 -2 2 0.113195 0.113195 -1 99 -2 # F-WL2_seas_3
 -2 2 0.089505 0.09505 -1 99 -2 # F-WL2_seas_4
#
#_Cond -4 #_MGparm_Dev_Phase
#
#_Spawner-Recruitment
3 #_SR_function
#_LO HI INIT PRIOR PR_type SD PHASE
 5 15 10.922 11.4 -1 99 1 # SR_R0
 0.2 1 1 0.75 -1 99 -4 # SR_steep
 0 2 0.6 0.6 -1 99 -1 # SR_sigmaR
 -5 5 0 0 -1 99 -1 # SR_envlink
 -10 10 0 0 -1 99 -1 # SR_R1_offset
 0 0 0 0 -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
2007 # last year of main recr_devs; forecast devs start in following year
2 #_recdev phase
1 # (0/1) to read 13 advanced options
 1954 #_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 fore_recr_like occurring before endyr+1
 1954 #_last_early_yr_nobias_adj_in_MPD
 1969 #_first_yr_fullbias_adj_in_MPD
 2007 #_last_yr_fullbias_adj_in_MPD
 2009 #_first_recent_yr_nobias_adj_in_MPD
 1 #_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
#
#Fishing Mortality info
0.1 # F ballpark for tuning early phases
-2008 # F ballpark year (neg value to disable)
3 # 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 3 0.268363 0.5 -1 99 1 # InitF_1F1_UC_LTN
 0 1 0 0 -1 99 -2 # InitF_2F2_USA_LL
 0 1 0 0 -1 99 -2 # InitF_3F3_EPO_M
 0 3 0.322517 0.2 -1 99 1 # InitF_4F4_JPN_PL_LF
 0 1 0 0 -1 99 -2 # InitF_5F5_JPN_PL_SF
 0 1 0 0 -1 99 -2 # InitF_6F6s1_JPN_OLLF1
 0 1 0 0 -1 99 -2 # InitF_7F6s2_JPN_OLLF1
 0 3 0.0918992 0.2 -1 99 1 # InitF_8F7s1_JPN_CLLF1
 0 1 0 0 -1 99 -2 # InitF_9F7s2_JPN_CLLF1
 0 1 0 0 -1 99 -2 # InitF_10F8_JPN_OLLF2
 0 1 0 0 -1 99 -2 # InitF_11F9_JPN_CLLF2
 0 1 0 0 -1 99 -2 # InitF_12F10_JPN_GN
 0 1 0 0 -1 99 -2 # InitF_13F11_JPN_M
 0 1 0 0 -1 99 -2 # InitF_14F12_TWN_LL
 0 1 0 0 -1 99 -2 # InitF_15F13_KO_LL
 0 1 0 0 -1 99 -2 # InitF_16F14_TK_GN
#
#_Q_setup
 # A=do power, B=env-var, C=extra SD, D=devtype(<0=mirror, 0/1=none, 2=cons, 3=rand, 4=randwalk);
E:0=num/1=bio/2=F, F:-1=norm/0=lognorm/>0=T
 #_A  B  C  D  E  F
 0 0 0 0 0 0 # 1 F1_UC_LTN
 0 0 0 0 0 0 # 2 F2_USA_LL
 0 0 0 0 0 0 # 3 F3_EPO_M
 0 0 0 0 0 0 # 4 F4_JPN_PL_LF
 0 0 0 0 0 0 # 5 F5_JPN_PL_SF
 0 0 0 0 0 0 # 6 F6s1_JPN_OLLF1
 0 0 0 0 0 0 # 7 F6s2_JPN_OLLF1
 0 0 0 0 0 0 # 8 F7s1_JPN_CLLF1
 0 0 0 0 0 0 # 9 F7s2_JPN_CLLF1
 0 0 0 0 0 0 # 10 F8_JPN_OLLF2
 0 0 0 0 0 0 # 11 F9_JPN_CLLF2
 0 0 0 0 0 0 # 12 F10_JPN_GN
 0 0 0 0 0 0 # 13 F11_JPN_M
```

0 0 0 0 0 0 # 14 F12_TWN_LL
0 0 0 0 0 0 # 15 F13_KO_LL
0 0 0 0 0 0 # 16 F14_TK_GN
0 0 0 0 0 0 # 17 S1_UC_LTN
0 0 0 0 0 0 # 18 S2_USA_LL
0 0 0 0 1 0 # 19 S3_JPN_PL_LF
0 0 0 0 1 0 # 20 S4_JPN_PL_SF_early
0 0 0 0 1 0 # 21 S5_JPN_PL_SF_late
0 0 0 0 0 0 # 22 S6_JPN_LLF1
0 0 0 0 0 0 # 23 S7_JPN_LLF2
0 0 0 0 0 0 # 24 S8_TWN_LL
#
#_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)
#
#_size_selex_types
#_Pattern Discard Male Special
24 0 0 0 # 1 F1_UC_LTN
1 0 0 0 # 2 F2_USA_LL
5 0 0 1 # 3 F3_EPO_M
24 0 0 0 # 4 F4_JPN_PL_LF
24 0 0 0 # 5 F5_JPN_PL_SF
24 0 0 0 # 6 F6s1_JPN_OLLF1
24 0 0 0 # 7 F6s2_JPN_OLLF1
5 0 0 6 # 8 F7s1_JPN_CLLF1
5 0 0 7 # 9 F7s2_JPN_CLLF1
1 0 0 0 # 10 F8_JPN_OLLF2
5 0 0 10 # 11 F9_JPN_CLLF2
5 0 0 5 # 12 F10_JPN_GN
5 0 0 5 # 13 F11_JPN_M
24 0 0 0 # 14 F12_TWN_LL
5 0 0 6 # 15 F13_KO_LL
5 0 0 5 # 16 F14_TK_GN
5 0 0 1 # 17 S1_UC_LTN
5 0 0 2 # 18 S2_USA_LL
5 0 0 4 # 19 S3_JPN_PL_LF
5 0 0 5 # 20 S4_JPN_PL_SF_early
5 0 0 5 # 21 S5_JPN_PL_SF_late
5 0 0 6 # 22 S6_JPN_LLF1
5 0 0 10 # 23 S7_JPN_LLF2
5 0 0 14 # 24 S8_TWN_LL
#
#_age_selex_types
#_Pattern ___ Male Special
10 0 0 0 # 1 F1_UC_LTN
10 0 0 0 # 2 F2_USA_LL
10 0 0 0 # 3 F3_EPO_M
10 0 0 0 # 4 F4_JPN_PL_LF
10 0 0 0 # 5 F5_JPN_PL_SF
10 0 0 0 # 6 F6s1_JPN_OLLF1
10 0 0 0 # 7 F6s2_JPN_OLLF1
10 0 0 0 # 8 F7s1_JPN_CLLF1
10 0 0 0 # 9 F7s2_JPN_CLLF1
10 0 0 0 # 10 F8_JPN_OLLF2
10 0 0 0 # 11 F9_JPN_CLLF2

```
 10 0 0 0 # 12 F10_JPN_GN
 10 0 0 0 # 13 F11_JPN_M
 10 0 0 0 # 14 F12_TWN_LL
 10 0 0 0 # 15 F13_KO_LL
 10 0 0 0 # 16 F14_TK_GN
 10 0 0 0 # 17 S1_UC_LTN
 10 0 0 0 # 18 S2_USA_LL
 10 0 0 0 # 19 S3_JPN_PL_LF
 10 0 0 0 # 20 S4_JPN_PL_SF_early
 10 0 0 0 # 21 S5_JPN_PL_SF_late
 10 0 0 0 # 22 S6_JPN_LLF1
 10 0 0 0 # 23 S7_JPN_LLF2
 10 0 0 0 # 24 S8_TWN_LL
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block
Block_Fxn
 27.5 100 62.9045 66 -1 99 2 0 0 0 0 0 0 0 # SizeSel_1P_1_F1_UC_LTN
 -9 4 -8.22825 -3 -1 99 4 0 0 0 0 0 0 0 # SizeSel_1P_2_F1_UC_LTN
 -1 9 3.5143 4 -1 99 3 0 0 0 0 0 0 0 # SizeSel_1P_3_F1_UC_LTN
 -1 9 5.69924 5 -1 99 4 0 0 0 0 0 0 0 # SizeSel_1P_4_F1_UC_LTN
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_1P_5_F1_UC_LTN
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_1P_6_F1_UC_LTN
 45 130 92.3678 100 -1 99 2 0 0 0 0 0 1 2 # SizeSel_2P_1_F2_USA_LL
 0.1 30 24.5657 10 -1 99 3 0 0 0 0 0 1 2 # SizeSel_2P_2_F2_USA_LL
 1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_3P_1_F3_EPO_M
 -80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_3P_2_F3_EPO_M
 27.5 130 83.3866 90 -1 99 2 0 0 0 0 0 0 0 # SizeSel_4P_1_F4_JPN_PL_LF
 -9 4 -4 -3 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_4P_2_F4_JPN_PL_LF
 -1 9 5.36443 4.6 -1 99 3 0 0 0 0 0 0 0 # SizeSel_4P_3_F4_JPN_PL_LF
 -1 9 3.97328 3 -1 99 4 0 0 0 0 0 0 0 # SizeSel_4P_4_F4_JPN_PL_LF
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_4P_5_F4_JPN_PL_LF
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_4P_6_F4_JPN_PL_LF
 27.5 100 54.7341 75 -1 99 2 0 0 0 0 0 0 0 # SizeSel_5P_1_F5_JPN_PL_SF
 -9 4 -0.931761 -3 -1 99 4 0 0 0 0 0 0 0 # SizeSel_5P_2_F5_JPN_PL_SF
 -1 9 3.21189 6 -1 99 3 0 0 0 0 0 0 0 # SizeSel_5P_3_F5_JPN_PL_SF
 -1 9 3.88478 3 -1 99 4 0 0 0 0 0 0 0 # SizeSel_5P_4_F5_JPN_PL_SF
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_5P_5_F5_JPN_PL_SF
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_5P_6_F5_JPN_PL_SF
 27.5 130 88.8463 89 -1 99 2 0 0 0 0 0 2 2 # SizeSel_6P_1_F6s1_JPN_OLLF1
 -9 4 -0.424186 -3 -1 99 4 0 0 0 0 0 2 2 # SizeSel_6P_2_F6s1_JPN_OLLF1
 -4 9 5.58817 6 -1 99 3 0 0 0 0 0 2 2 # SizeSel_6P_3_F6s1_JPN_OLLF1
 -4 9 4.49669 3 -1 99 2 0 0 0 0 0 2 2 # SizeSel_6P_4_F6s1_JPN_OLLF1
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 2 2 # SizeSel_6P_5_F6s1_JPN_OLLF1
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 2 2 # SizeSel_6P_6_F6s1_JPN_OLLF1
 27.5 130 77.6329 89 -1 99 2 0 0 0 0 0 0 0 # SizeSel_7P_1_F6s2_JPN_OLLF1
 -9 4 -8.38732 -3 -1 99 4 0 0 0 0 0 0 0 # SizeSel_7P_2_F6s2_JPN_OLLF1
 -4 9 4.06471 6 -1 99 3 0 0 0 0 0 0 0 # SizeSel_7P_3_F6s2_JPN_OLLF1
 -4 9 4.7943 3 -1 99 2 0 0 0 0 0 0 0 # SizeSel_7P_4_F6s2_JPN_OLLF1
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_7P_5_F6s2_JPN_OLLF1
 -999 -999 -999 -5 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_7P_6_F6s2_JPN_OLLF1
 1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_8P_1_F7s1_JPN_CLLF1
 -80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_8P_2_F7s1_JPN_CLLF1
 1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_9P_1_F7s2_JPN_CLLF1
 -80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_9P_2_F7s2_JPN_CLLF1
 45 130 91.5601 110 -1 99 2 0 0 0 0 0 0 0 # SizeSel_10P_1_F8_JPN_OLLF2
 0.1 30 13.9318 10 -1 99 3 0 0 0 0 0 0 0 # SizeSel_10P_2_F8_JPN_OLLF2
 1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_11P_1_F9_JPN_CLLF2
```

-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_11P_2_F9_JPN_CLLF2
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_12P_1_F10_JPN_GN
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_12P_2_F10_JPN_GN
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_13P_1_F11_JPN_M
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_13P_2_F11_JPN_M
27.5 130 82.5253 89 -1 99 2 0 0 0 0 0 3 2 # SizeSel_14P_1_F12_TWN_LL
-9 4 -4 -3 -1 99 -4 0 0 0 0 0 3 2 # SizeSel_14P_2_F12_TWN_LL
-1 9 6.03996 6 -1 99 3 0 0 0 0 0 3 2 # SizeSel_14P_3_F12_TWN_LL
-4 9 5.34978 3 -1 99 4 0 0 0 0 0 3 2 # SizeSel_14P_4_F12_TWN_LL
-999 -999 -999 -5 -1 99 -5 0 0 0 0 0 3 2 # SizeSel_14P_5_F12_TWN_LL
-999 -999 -999 -5 -1 99 -4 0 0 0 0 0 3 2 # SizeSel_14P_6_F12_TWN_LL
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_15P_1_F13_KO_LL
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_15P_2_F13_KO_LL
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_16P_1_F14_TK_GN
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_16P_2_F14_TK_GN
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_17P_1_S1_UC_LTN
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_17P_2_S1_UC_LTN
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_18P_1_S2_USA_LL
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_18P_2_S2_USA_LL
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_19P_1_S3_JPN_PL_LF
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_19P_2_S3_JPN_PL_LF
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_20P_1_S4_JPN_PL_SF_early
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_20P_2_S4_JPN_PL_SF_early
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_21P_1_S5_JPN_PL_SF_late
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_21P_2_S5_JPN_PL_SF_late
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_22P_1_S6_JPN_LLF1
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_22P_2_S6_JPN_LLF1
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_23P_1_S7_JPN_LLF2
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_23P_2_S7_JPN_LLF2
1 80 1 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_24P_1_S8_TWN_LL
-80 -80 -80 -80 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_24P_2_S8_TWN_LL
#_Cond 0 #_custom_sel-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
1 #_custom_sel-blk_setup (0/1)
45 130 96.1257 100 -1 99 2 # SizeSel_2P_1_F2_USA_LL_BLK1repl_2001
0.1 30 6.44513 10 -1 99 3 # SizeSel_2P_2_F2_USA_LL_BLK1repl_2001
27.5 130 76.0267 89 -1 99 2 # SizeSel_6P_1_F6s1_JPN_OLLF1_BLK2repl_1993
-9 4 -8.07952 -3 -1 99 4 # SizeSel_6P_2_F6s1_JPN_OLLF1_BLK2repl_1993
-4 9 4.22699 6 -1 99 3 # SizeSel_6P_3_F6s1_JPN_OLLF1_BLK2repl_1993
-4 9 6.5436 3 -1 99 2 # SizeSel_6P_4_F6s1_JPN_OLLF1_BLK2repl_1993
-999 -999 -999 -5 -1 99 -2 # SizeSel_6P_5_F6s1_JPN_OLLF1_BLK2repl_1993
-999 -999 -999 -5 -1 99 -2 # SizeSel_6P_6_F6s1_JPN_OLLF1_BLK2repl_1993
27.5 130 86.4651 89 -1 99 2 # SizeSel_14P_1_F12_TWN_LL_BLK3repl_2003
-9 4 -4 -3 -1 99 -4 # SizeSel_14P_2_F12_TWN_LL_BLK3repl_2003
-1 9 5.04604 6 -1 99 3 # SizeSel_14P_3_F12_TWN_LL_BLK3repl_2003
-4 9 5.43062 3 -1 99 4 # SizeSel_14P_4_F12_TWN_LL_BLK3repl_2003
-999 -999 -999 -5 -1 99 -5 # SizeSel_14P_5_F12_TWN_LL_BLK3repl_2003
-999 -999 -999 -5 -1 99 -4 # SizeSel_14P_6_F12_TWN_LL_BLK3repl_2003
#_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 -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters

```
#
1 #_Variance_adjustments_to_input_values
#_fleet: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_survey_CV
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_discard_stddev
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_bodywt_CV
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_lencomp_N
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_agecomp_N
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_size-at-age_N
0 #_discard_like:  >0 for DF of T-dist(read CV in data file); 0 for normal with CV; -1 for normal with se; -2 for lognormal
0 #_DF_for_meanbodywt_like
#
4 #_maxlambdaphase
1 #_sd_offset
#
26 # 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
#like_comp fleet/survey  phase  value  sizefreq_method
 1 17 1 1 1
 1 18 1 1 1
 1 19 1 1 1
 1 20 1 1 1
 1 21 1 1 1
 1 22 1 1 1
 1 23 1 1 1
 1 24 1 1 1
 4 1 1 0.01 1
 4 2 1 0.01 1
 4 4 1 0.01 1
 4 5 1 0.01 1
 4 6 1 0.01 1
 4 7 1 0.01 1
 4 10 1 0.01 1
 4 14 1 0.01 1
 5 1 1 0.1 1
 5 2 1 0.1 1
 5 6 1 0.1 1
 5 10 1 0.1 1
 9 1 1 1 1
 9 4 1 1 1
 9 8 1 1 1
 11 1 1 0 1
 12 1 1 0 1
 13 1 1 100 1
#
0 # (0/1) read specs for more stddev reporting
 # 0 1 -1 5 1 5 1 -1 5 # 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
```