

CALIFORNIA HALIBUT STOCK ASSESSMENT

Section A: Background Information

A1. Stock Assessment Team

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A2. Executive Summary

A sex-structured model with different growth, natural mortality, and selectivity for males and females developed using Stock Synthesis is used to assess California halibut (halibut) in two stocks within California separated at Point Conception. The models are fit to a Commercial Passenger Fishing Vessel (CPFV) index of relative abundance and length composition data from recreational and commercial fisheries. The central stock is also fit to indices of relative abundance from trawl logbook catch-per-unit effort (CPUE) and the San Francisco Bay young-of-the-year survey, a swept area trawl survey estimate of absolute abundance with associated age composition data, and age-conditioned-on-length data. Due to limited size composition and discard data for the central stock, all selectivity parameters, except for a few parameters for the selectivity curve of the recreational fishery and the bottom trawl fishery, for the central stock are fixed based on the southern stock assessment.

The southern population is estimated to be depleted to about 14% of its unexploited spawning biomass level. The population level is estimated to have been at a low level since the start of the modeling time period (1971). There was substantial catch prior to 1971, but changes in the management (e.g., minimum legal size) and lack of data prior to 1971 prevent adequate assessment of the abundance prior to 1971. The assessment is able to estimate the depletion level in 1971 by calculating the abundance at age that is consistent with the length composition data seen in the fisheries compared to what would be expected in the absence of fishing. Recent recruitments since 1999 are estimated to be low and are supported by data not included in the assessment. The estimated depletion level is sensitive to the value of natural mortality, the average length assumed for the oldest fish, and the method used to derive an index of relative abundance from the CPFV CPUE data.

The central population is estimated to have increased substantially since 1980 due to high recruitment. The model is very sensitive to initial parameter values and phases of estimation and has convergence issues. These are technical issues related to estimating parameters of the model that represent the biological and fishing processes and indicate that the values for these parameters determined by the model fitting procedure may not be reliable. However, the general conclusions remain consistent for different sets of parameters that are estimated.

The CPFV CPUE data indicates there are different population trends and fishery impacts within the central and southern areas. This indicates that stock assessments and management on a finer spatial scale may be appropriate.

A3. Introduction

California halibut (*Paralichthys californicus*) ranges from Magdalena Bay, Baja California (Gilbert and Scofield 1898), to the Quillayute River in Washington (Pattie and Baker 1969), and prior to the early 1970's was most common from Morro Bay south (Fitch and Lavenberg 1971). Since then it has become common from Bodega Bay south. Large adult fish inhabit deeper water (Sunada 1985), outer banks, and islands (Wallace 1990), except during the peak spawning season (winter-spring) (Clark 1931). In southern California halibut move inshore to spawn during April through May (Clark 1931). Females grow to a larger size and at a faster rate than males. This is true in both southern and central California (MacNair et al. 2001). California halibut is an important target species for both recreational and commercial fisheries. A uniform minimum legal size (MLS) of 22 inches (559 mm) total length (TL) was introduced in 1971 with an allowance for a small number of undersized fish for the commercial fishery (Reed and MacCall 1988). A history of management actions are listed in Appendix I. No stock status reference points have been developed for California halibut. Stock status reference points are quantities that when compared to measures of the current state of the stock can be used as a guide to the stock's health.

An additional comprehensive set of investigatory analyses is provided in the report from the California Halibut Stock Assessment Review Panel.

A4. Data and biological characteristics

A4.1. Catch

California halibut is an important target species for both recreational and commercial fisheries. The recreational catch is taken by all three of the main modes of fishing: shore, private/rental boats, and party/charter boats. The proportion of halibut taken by private boats has increased in recent years. The commercial fisheries have caught California halibut using trawl, hook-and-line, and set nets. Set nets, both gill and trammel nets were historically important, but their use has been reduced due to regulations banning these fishing methods in some areas.

Commercial catch data was taken from three sources: 1) California Department of Fish and Game (CDFG) annual status reports, 1916-1929; 2) Barsky, 1990, catch by port, 1930-1968; and 3) CMASTER catch by port and fishing method, 1969-2008. The catch was converted from pounds to metric tons by dividing by 2204.622. Catch in (2) and (3) was divided into the central and southern regions (separated by Point Conception) based on port. Catch in (3) was divided into fishing method based on grouping methods that were somewhat similar. Catch in (1) and (2) was grouped into fishing method based on the ratios from 1969-1978 in (3). Catch in (1) was grouped into regions based on the ratios from 1930-1939 in (2). Since the model is initiated in 1971, only data starting in 1971 was used in the stock assessment and this data is available by port and fishing method.

There is ambiguity in some of the definitions of the trawl gear and which gear is recorded on catch reports. Despite these ambiguities, the three trawl gears are kept separate to allow comparison of length composition data. There is a large amount of catch for which the fishing method is unrecorded. This catch was grouped with gill net because gill net comprised the majority of the historical catch.

The commercial catch has shown three large peaks in the 1910s, 1940s, and the 1960s (Figure A4.1.1). The second of these two peaks can be seen in both the recreational (CPFV) and the commercial catch. The earliest peak is during a period lacking recreational catch data so it is not clear if the recreational catch was also high. In general, the commercial catch has been higher than the recreational catch (based on reconstructing the recreational catch in weight from earlier years using the CPFV data). However, the recreational catch could have been higher than the commercial catch in the peak catch years.

A uniform minimum legal size (MLS) of 22 inches (559 mm) TL was introduced in 1971 with an allowance for a small number of undersized fish for the commercial fishery (Reed and MacCall 1988). The CPFV catch dropped in 1971 as expected due to the release of undersized fish. However, the expected increases in CPFV catch as the undersized fish reached the MLS several years later did not occur (Reed and MacCall 1988). The commercial catch appeared to be less impacted by the MLS.

The introduction of the MLS in 1971 undoubtedly increased the level of discarding undersized fish. Therefore, the discard rates and discard mortality may be important factors that need to be taken into consideration in the stock assessment.

Prior to 1960, the commercial catch landed north of Point Conception (San Francisco and Monterey port areas) was only a small portion of the total commercial catch. However, it increased in the late 1960s to early 1970s and in the mid 1980s the catch landed north of Point Conception was about 40% of the total commercial catch.

Recreational catch is available by fishing mode from the Marine Recreational Fisheries Statistics Survey (MRFSS) from 1980 to 2003 and the California Recreational Fisheries Survey (CRFS) since 2004 except for the period 1990-1992. Catch by the CPFV fleet is available from logbooks from 1947, but it does not cover all the vessels and is an underestimate of the total CPFV catch. Recreational data prior to 1947 is not available and data for the non-CPFV fisheries are not available prior to 1980. Therefore, the data for these years has to be reconstructed (Figure A4.1.2). Reed and MacCall (1988) report that data on recreational fishing modes indicate the contribution of the CPFV-caught fish to the total recreational halibut catch has decreased from approximately 40% in the mid-1960s (Pinkas et al. 1968) to about 10% in 1981-85 (Anon. 1984, 1985).

The MRFSS estimates of recreational catch are notoriously problematic and the latter CRFS estimates may be more reliable. For example, Berkson (1990) stated he did not believe the 1982 recreational catch estimate in numbers of fish because it was three times the size of adjacent

years and because the mean weight of fish caught, which is used in the calculation of numbers of fish caught, was much lower than in other years. He revised the 1982 estimate of recreational catch using the average of the mean weights for 1981 and 1983. The large increases in the 1982 estimate appear to be in the shore-based mode, which is usually only a small component of the total catch. There is also a large estimate for the private/rental boats in 1995. For the early period of MRFSS (1980-1989) the CPFV logbook catch is, as expected due to non-reporting of logbooks, lower than the MRFSS estimates, but for the latter period of MRFSS/CRFS (1993-2008) the logbook catch is often higher than the MRFSS/CRFS estimates.

Discarded fish from the recreational fisheries can be substantial. Discards by all recreational modes are available from MRFSS and CRFS and discards for the CPFV fishery are available from logbooks and observers. The proportion of fish discarded varies considerably over time and among the data sources. The discard mortality rate is unknown, however it has been observed to be low for other flatfish (e.g., summer flounder).

A4.2. Growth

There have been several studies looking at growth of California halibut (Table A4.2.1; Figure A4.2.1). Most of these are based on age data, but some have looked at tagging growth increment data. In general, females grow to a larger size than males (MacNair et al. 2001; Pattison and McAlister 1990; Sunada et al. 1990) and there are apparent differences in growth among areas and perhaps over time. Some differences in growth rates among studies may also be due to differences in selectivity of the gears used to sample the individuals.

Pattison and McAlister (1990) determined otoliths provided the most reliable ages for California halibut. They found an opaque band was formed in spring and summer (April to October) and a translucent band was formed during winter (November to March). They validated the formation of an annual ring using oxytetracycline (only four fish) and edge formation analysis. Pattison and McAlister (1990) suggested age may be underestimated when old (age 11 and older) fish are aged using whole otoliths and recommended using sectioned otoliths for these ages. The birth date for halibut is generally assigned to 1 January.

Pattison and McAllister (1990)

Pattison and McAllister (1990) combined data from two time periods, 1955-66 (N=903; Schott unpublished data) and 1984-88 (N=1156). Most fish were taken south of Point Conception and they did not separate fish into southern and central California. Only 157 fish were sampled from San Francisco to Morro Bay and all were from 1984-86. A variety of collection methods including trawl, gill net, beach seine, hook-and-line, and spearfishing were used to collect the data (Table A4.2.3).

MacNair et al. (2001)

MacNair et al. (2001) collected age and length data using a 400-mesh eastern trawl in southern California (Mexican border to Point Conception) from 8 July through 3 August 1993 and central California (Point Conception to Tomales Bay) from 14 Feb through 18 March 1994 (Table A4.2.5). Sampling was stratified by depth. An additional ten fish were collected in southern California from July 1994 to June 1995. They measured both TL and standard length (SL). In the

analysis of the growth data they removed outliers from the sample before refitting the von Bertalanffy model. They used the average of four readings per otolith as the age estimate. Otoliths that were hard to age were sectioned.

Sunada et al. (1990)

Sunada et al. (1990) analyzed data from the main southern California ports: Santa Barbara, Ventura, San Pedro, and San Diego (Table A4.2.4). The samples were taken randomly. The fishing gears sampled included gill nets and trawl nets. Otoliths were collected beginning in 1985 from Santa Barbara, Ventura, and San Diego, and from San Pedro beginning in 1986. Otoliths were also taken from sub-adults collected on a research trawl in 1985. Sex was determined by visually examining the gonads. They analyzed the data by inshore and offshore areas. Inshore was defined as all CDFG blocks that were adjacent to the coast. Offshore areas were generally associated with islands.

Haaker (1975)

Haaker (1975) analyzed data collected in Anaheim Bay (southern California) (Table A4.2.6). Fish were less than 3 years old, immature, and at most 510 mm TL. Most of the fish were collected using an otter trawl from January 1970 to Feb 1971. Sex was determined by microscopic examination of gonads.

Reed and MacCall (1988)

Reed and MacCall (1988) reported growth parameters and weight length parameters (Figure A4.2.2) from unpublished data (J.W. Schott). The data was also included in the analysis of Pattison and McAllister (1990).

Tupen (1990)

Tupen (1990) estimated an annual growth rate based on tagging data. All but one of the known-sex fish were female.

Reilly and Tanaka

Thin-sectioned otoliths (Reilly and Tanaka) were used to fit von Bertalanffy growth curves (Figure A4.2.3; Table A4.2.7). The data included 134 males and 181 females from the central region and 35 males and 182 females from the southern region. The samples were collected from bottom trawl, hook-and-line, gill net, and purse seine gears during 2007-2010. Bycatch in the Pacific sardine fishery purse seine fishery provided sublegal-sized fish for ageing. The estimated growth curves were similar to those of Pattison, Sunada, and Reed, but differed substantially from MacNair et al. (2001) (Figure A4.2.4).

Growth rates

Females grow to a larger size and at a faster rate than males. This is true in both southern and central California (MacNair et al. 2001). Both female and male length at age is larger in the central area than in the southern area (MacNair et al. 2001). Most of the studies show similar growth rates. However, note some of these studies are based on the same data. The estimates of MacNair et al. (2001) are most different from the others. Differences in growth rates among studies could be due to different environmental conditions in different years or different

geographic locations of the samples (MacNair et al. 2001). The difference could also be due to the differences in gear used to sample the fish. MacNair et al. (2001) used a relatively small-meshed trawl, which tends to not catch large individuals, while the other studies used samples from a variety of gears. The maximum lengths estimated in MacNair et al. (2001) may be underestimated due to a lack of large old fish or the influence of reducing length based selectivity for larger individuals. The relationships of Reed and MacCall (1988) tend to underestimate the length of young fish indicating a more flexible growth curve is needed (e.g., a Richards curve). Pattison and McAllister (1990) probably provide the best data set to estimate growth because it contains more large individuals. Unfortunately, they do not provide information on lengths for which there is only a single fish sampled. Ageing of larger individuals and individuals from a wider range of areas is needed.

Tupen (1990) estimated an annual growth rate of 66.7 mm for fish 428-561 mm TL based on tagging data. All but one of the known-sex fish was female. This is similar to the low growth estimates of MacNair et al. (2001) for southern California. Frey (1971) estimated a growth rate of approximately 100 mm/year for females 438-648 mm (Table A4.2.2) sampled in southern California (Santa Barbara to Port Hueneme) cited in Tupen (1990).

In some flatfish stocks, growth rates increase as abundance reduces, presumably as a result of reduced competition for food (Rice et al. 2005). Such patterns have been observed for plaice, Atlantic halibut, common sole, and yellowtail flounder (Rice et al. 2005). The California halibut abundance appears to have gone through substantial fluctuations with possible large peaks in the 1940s and in the 1960s. The growth rates in these time periods may have been lower than when the abundance was low.

Weight length relationship

Both Reed and MacCall (1988) and Haaker (1975) provide weight-length relationships (Figure A4.2.2). Haaker's (1975) relationship is based on fish less than 3 years old and combines males and females, therefore, for stock assessment purposes, it is probably more appropriate to use the relationships given by Reed and MacCall (1988).

Conversion from standard length to total length

Haaker (1975) provides a conversion from SL to TL as $TL = 8.15 + 1.13 SL$. Unfortunately, this is only based on fish less than 3 years old.

A4.3. Variation of length-at-age

The variation of length-at-age is an important component of stock assessment models that fit to size composition data. Pattison and McAllister (1990) and MacNair et al. (2001) provide information on the variation in length-at-age (see above for details). Males and females show a similar relationship between the standard deviation of the variation of length-at-age and the mean length-at-age (Figure A4.3.1). The relationship is linear up until about 900 mm in the data from Pattison and McAllister (1990). The large reduction in variation in length-at-age for larger individuals could be due to small samples sizes for these sizes, the fact that the larger fish come from the earlier time period, selectivity of the sampling gear, or some other factor. We provide a linear regression on the combined male and female data for the linear part of the data from

Pattison and McAllister (1990) to predict variation of length-at-age from the mean length (Figure A4.3.2). A linear regression is also fit to the combined male and female data from MacNair et al. (2001) (Figure A4.3.3). Finally, a linear regression is fit to both data sets combined (Figure A4.3.4). Ages with less than 10 fish are left out of the regressions. This relationship can be used to determine the parameters of the Stock Synthesis model to represent variation in length-at-age.

A4.4. The environment

Halibut between 245 and 300 mm TL have been found to feed substantially on northern anchovy (Roberts et al. 1982; Plummer et al. 1983) and halibut greater than 300 mm TL feed on Pacific sardine (Wertz and Domeier 1997). Temporal changes in prey consumed may be due to changes in the relative abundances of these species (Wertz unpublished). The abundance of these prey species may change the abundance or population process (e.g., growth and survival) of halibut.

Berkson (1990) estimated recruitment to the fishery in 1985-87 was two to three times higher than in 1981-83. He suggested this may be due to the warming of water temperature caused by the 1982-83 El Nino. He supported this by the observation that increased water temperature improves growth and survival of pre-recruits in the laboratory.

A4.5. Sex ratio

Many studies that have collected information on the gender of California halibut have found one of the genders dominates. Differences in sex ratios may indicate different natural or fishing mortality rates, difference in growth rates, different vulnerability to the sampling gear, or temporary spatial separation of the sexes. These processes can have substantial consequences for assessment and management of the stock. In addition, growth rates differ between males and females. Reed and MacCall (1988) report the commercial fishery takes from 60% to 80% females and took this into consideration when assessing the population. At lengths greater than 100 mm (3.9 inches) determination of sex is easily accomplished by macroscopic inspection (Haaker 1975). Therefore, the potential for sex-specific information for fish vulnerable to the fisheries is good. There are several studies that have collected and reported sex-specific information.

Using a 400-mesh eastern trawl MacNair et al. (2001) found 69% and 53% males in southern and central California, respectively. They also found the age distributions of males and females were significantly different in both southern and central California. In southern California, a higher proportion of females were older. Females had a mode (most frequent age) in the catch-at-age composition at age six while males had a mode at age three. In central California, males had a higher proportion of older fish. However, both genders had modes at age three.

Pattison and McAllister (1990) found 75% of the sampled fish to be females in combined data from two time periods 1955-66 (N=903; Schott unpublished data) and 1984-88 (N=1156), mostly sampled in southern California and using a variety of gears.

Sunada et al. (1990) analyzed sampled data from southern California ports using gill nets and trawl nets. Females outnumbered males by 4.3:1 and the ratio was higher inshore than offshore. (This is unexpected because larger fish are found offshore and females are larger than males)

The ratio of females increased from 1985 to 1988. Both trawl nets and gill nets took more females than males. Trawling is restricted to offshore areas during the spawning season and this may be why fewer females were caught by trawls. Alternatively, females are larger and they may out swim the trawl nets.

Haaker (1975) found the sex ratio is highly skewed to males at lengths below 100 mm, and in ages zero and one, in samples taken from Anaheim Bay (southern California). However, females predominated at age two, but this may be due to males maturing and migrating.

There are obviously processes occurring in the stock dynamics or in the fishery that are influencing the sex ratio of California halibut caught. The higher number of females at older ages is expected since other flatfish, which also have slower-growing, earlier-maturing males, have the same predominance of females at older ages; this is believed to be due to higher natural mortality rates for males. However, the higher number of males found by MacNair et al. (2001), the much higher and increasing number of females found by Sunada et al. (1990), and the higher numbers of females inshore found by Sunada et al. (1990) confuse things. It is likely males have a higher natural mortality rate than females, there are spatial or depth differences in the distribution of males and females, and males and females have different vulnerabilities to the various fishing methods. These differences need to be taken into consideration in the stock assessment (e.g., males and females need to have different selectivity curves and different catchability parameters that vary by area or depth).

A4.6. Spatial distribution and stock structure

California halibut ranges from Magdalena Bay, Baja California (Gilbert and Scofield 1898), to the Quillayute River in Washington (Pattie and Baker 1969), and prior to the early 1970's was most common from Morro Bay south (Fitch and Lavenberg 1971). Since then it has become common from Bodega Bay south. Large adult fish inhabit deeper water (Sunada 1985), outer banks, and islands (Wallace 1990), except during the peak spawning season (winter-spring) (Clark 1931). In southern California halibut move inshore to spawn during April through May (Clark 1931). The spawning migration hypothesis is supported by higher recreational CPUE during the peak of the spawning season from the Santa Monica Bay Halibut Derby (Posner and Lavenberg 1999). There is little genetic work done on the stock structure of California halibut. Hedgecock and Bartley (1988) found, using allozyme variation, that samples from Mission Bay in San Diego and Santa Monica Bay near Los Angeles showed genetic variation typical of broadcast spawners with pelagic eggs. However, they did find large differences in allelic frequencies at two loci between fish sampled from Mission Bay and Santa Monica Bay. Keep in mind genetic studies are generally not useful in determining stock structure at levels important to management unless the populations are very isolated. The southern and central areas are biogeographically different in temperature, circulation patterns, bottom topography, and substrate (MacNair et al. 2001). Tagging studies have shown halibut do not move much along the coast in general, but most of the studies have been biased towards young halibut, are spatially restricted, and do not take into consideration recovery sampling rates (exploitation rates) or reporting rates.

The limited studies that have looked at spatial variability in population processes and fish distribution have generally found differences. MacNair et al. (2001) found males comprised 69% and 53% of the individuals sampled in southern and central California, respectively. They also found differences in the age structure with a higher proportion of older fish in the southern area compared to the central area. Sunada et al. (1990) found the San Diego area had more older and larger fish than San Pedro, Santa Barbara, and Ventura, while younger fish were more abundant in Santa Barbara and Ventura. MacNair et al. (2001) also found females were older than males in southern California, but the opposite in central California. Sunada et al. (1990) found inshore caught halibut were smaller than those taken offshore.

There is little solid evidence to base any stock structure decisions for stock assessment. However, splitting the stock at Point Conception may be appropriate given the differences in growth rates and exploitation histories of the two areas.

A4.7. Movement

California halibut go through several ontogenetic shifts in their spatial distribution as well as spawning migrations. Juveniles move from offshore into the bays at a very young age then move back offshore as they mature. Haaker (1975) suggests migration from inshore areas occurs at maturity, but there is no direct information. Clark (1930a, 1930b) reported that in the spring, adult halibut migrate from deeper offshore waters to shallower waters near the coast to spawn then return to deeper water. Outside these ontogenetic and spawning migrations, young individuals appear to move very little. Older individuals tend to move further, but the data on their movement is limited. Frey (1971) reported young fish do not move extensively, but the larger older fish move great distances.

There have been several tagging studies to investigate the movement of California halibut. However, most of these have focused on young, often sub-legal (< 559 mm), individuals.

Haaker (1975)

Haaker (1975) tagged halibut in Anaheim Bay (southern California) at three tagging stations. Fish were less than 3 years old, immature, and at most 510 mm TL. Only 7 out of 39 recaptures occurred at a different station than where they were released and movement was not related to size. This tagging study suggests there is relatively little movement of juveniles until emigration occurs.

Tupen (1990)

As part of CDFG's Alternative Gear Development Program, 1,052 sub-legal halibut were tagged and released off the central California coast from April 1987 to December 1988. Major tagging locations were San Simeon Bay (N=211), south Estero Bay (N=521), and San Luis Bay (N=122). All but one of the known sex recoveries (31) were female. Based on 40 usable recaptures as of 1 Jan 1989, 55% of tagged recoveries exhibited no net movement and movement was not related to time at liberty or size at tagging. The distance between release and recapture were: 1-10 km 17.5%, 11-30 km 12.5%, 31-70 km 12.5 %, >70 km 2.5%. All halibut displaying significant movement (>20 km) did so in a southward direction.

Young (1962)

Young (1962) found smaller halibut (< 559 mm) in southern California tended to move south while larger halibut (> 559 mm) tended to move north. A majority of the tagged fish moved less than 10 nautical miles (18.5 km) (cited in Tupen 1990).

Posner and Lavenberg (1999)

Posner and Lavenberg (1999) evaluated tagging data from April 1992 to April 1997. In total, 26,827 halibut were tagged by volunteers from Morro Bay to Isla Coronado del Norte. These fish were tagged in cooperation with the Marina del Rey Halibut Derby within Santa Monica Bay. Most fish were tagged in Santa Monica Bay. Recaptures of 852 halibut were used to evaluate movement. Most releases and recaptures (95%) occurred in Santa Monica Bay. Most halibut were caught between 16 and 25 m, with a mean depth of 17.3 m. The majority of recaptured halibut moved less than 5.5 km. Many (64%) were caught in the same region as tagged (generally no further than 5.5 km) (Table A4.7.1). Distance traveled and total length were not significantly correlated. The number of fish traveling and distance traveled was not significantly different between the north and south directions. For those that traveled more than 30 km, fish traveling north moved a significantly greater distance than those traveling south. They found mean movement increased in fish larger than 550 mm, but the increase was not statistically significant and may be due to the small sample size for these large fish. The fish were all larger than 200 mm, which is the size juveniles leave the protected waters, so the results do not include this important migration event. They suggest increases in mean movement may be linked with sexual maturity. Unfortunately, most fish in this and other studies are all below the sport fishery MLS of 559 mm TL (3% > 550 in this study, 17% in Domeier and Chun 1995). The recovery effort was generally in the same depths as the release effort so the data probably does not show inshore-offshore movement. They concluded, "It is not clear whether long movements are typical of adult California halibut or whether only a small proportion of individuals move long distances."

Domeier and Chun (1995)

During a span of 40 years (1955-1960, 1965, 1989-1994) CDFG tagged 16,827 halibut with 858 returns. Tagging occurred from Bahia Sebastian Viscaïno, Baja California to Tomales Bay, California. Most were caught between Oceanside and Santa Barbara by trawl nets, but some were also captured with gill nets and hook-and-line. Fish ranged from 280 to 1,005 mm, but the majority of fish were less than 500 mm. The results indicate halibut remain in a localized area throughout their adult life. The mean distance traveled was 13.4 km (Table A4.7.2). Halibut larger than 500 mm TL travel further and faster than smaller halibut. Young (1961) summarized earlier data from this study, but the analysis was not rigorous. Several relationships between movement and characteristics of the fish were statistically significant including total length vs. migration distance, total length vs. migration rate, time at liberty vs. migration distance. Sex vs. distance or migration rate and size vs. direction were not statistically significant. Fish that moved north move further on average and faster than those that moved south and this was statistically significant. The number moving north and south was about the same. Tagged fish that moved large distances south may have ended up in Mexico and not recovered thus biasing the calculation of average distance traveled south. Six fish moved from south of Point Conception to

north of it. No fish moved from north of Point Conception to south of it. The significance of these movements for separating the stock at Point Conception is dependent on the recovery effort (e.g., exploitation rates) in each area, the reporting rates in each area, and how close the fish were tagged to Point Conception. Only a small number of fish were tagged north of Point Conception. The authors state, “We do not feel confident in labeling Point Conception as a geographic barrier to halibut migration, but we believe the issue may warrant more research.” They concluded, “Although some California halibut made distant, rapid migrations, clearly this behavior was unusual.” The authors speculate the drastic increase in average migration rates for large halibut result from an important event in the life history like reproduction or prey switching.

A4.8. Maturity

The most comprehensive study of California halibut maturity was conducted by Love and Brooks (1990) (Figure A4.8.2; Table A4.8.1). They examined samples from otter trawls in the Southern California Bight from 1984, 1988, and 1989 at depths of 6-20 m (3-11 fathoms) during March to July (the reproductive period). Gonads were initially examined macroscopically and histologically and these matched 100%, so the remaining samples were examined macroscopically. In total, 313 males (140-530 mm) and 295 females (150-620 mm) were examined. A few males matured at 190 mm, 50% at 230 mm, and all by 320 mm. Many males matured at age one and all were mature at age three. A few females matured at 360 mm, 50% were mature at 470 mm, and all were mature by 590 mm. This corresponds to an initial age of 2 years, 50% maturity at 4 years, and 100% at 7 years.

Other authors have commented on the maturity of California halibut, but it is not clear where the information came from. Higgins (1919) first looked at maturity in 1918 and 1919, finding the smallest milting males at 9 inches (229 mm) and smallest spawning females at 17 inches (432 mm). Kucas and Hassler (1986) commented that Frey (1971) stated most females are mature at 430 mm TL or at the end of their third year of life (age two) and most males mature when about 230 mm TL long or at the end of their second year of life (age one). Pattison and McAllister (1990) found the smallest maturing female was 409 mm and the smallest maturing male was 229 mm. Haaker (1975) stated males mature at about 200 mm (7.78 inches) and females at about 375 mm (14.76 inches). The variability in maturity may be due to sampling methods, or spatial or temporal differences in maturity. Age at maturity may be density dependent as has been observed in Atlantic halibut and yellowtail flounder (Rice et al. 2005). The California halibut has possibly gone through large changes in abundance and age and size at maturity may have also changed over time.

Love and Brooks (1990) noted compared to Atlantic and Caribbean species of *Paralichthys*, California halibut females mature considerably later. Males may mature at a slightly younger age. In three of the four species examined, males matured at a smaller size compared to females.

The logistic equation provided by Love and Brooks (1990) can be used to model size or age at maturity in Stock Synthesis.

$$P_x = \frac{1}{1 + \exp(\alpha x + \beta)}$$

A4.9. Natural Mortality

Natural mortality (M) is one of the most difficult quantities to estimate. Commonly used methods, based on empirical relationships, life history theory, and maximum age, are notoriously problematic. In addition, many of the methods estimate only total mortality, so natural mortality must be separated from fishing mortality. Maximum age-based methods (e.g., Hoenig's method) are some of the most commonly used approaches to estimate natural mortality. However, the maximum age of fish in a sample is dependent on the sampling design, including the effective sample size, and the sampling design is often unknown. If the sampling design is known and the data available, then catch-curve or integrated analysis may be better choices. Life history-based methods provide insight into the relationship between natural mortality and other life history parameters. However, as estimation tools, they must be validated with empirical data. There are numerous studies that have developed relationships with life-history parameters, maximum age, and other quantities to estimate natural mortality based on regressing estimates of natural mortality with these quantities. Unfortunately, the variation in the predictions from these relationships is so large they are generally not useful for stock assessment and the initial estimates of natural mortality they are based on are often of dubious quality. Catch-curve analysis is crude and relies on many assumptions that are likely to be violated. Analysis of tagging data is probably the most promising direct method to estimate natural mortality. The success of estimating natural mortality within a stock assessment model has been variable and is probably dependent on the amount and type of data that are available, other structural features of the assessment model, and the age-specific pattern of the natural mortality that is modeled. Data used in other approaches (e.g., catch-curve and tagging analyses) to estimate natural mortality can be included in stock assessment models and the stock assessment model more appropriately identifies and deals with model assumptions.

Reed and MacCall (1988) estimated M as 0.3 based on Pauly (1979) and 0.15 on a maximum age of 30 years (obtained from sampling in the mid-1960s) using Hoenig's method. An M of 0.3 is within the ranges reported by Beverton and Holt and others (see below) for a variety of flatfish species. Because Hoenig's method is an estimate of total mortality and there was substantial fishing before the mid-1960s' they assumed a value of 0.3 was too high and used the arbitrary values of 0.1 and 0.2 in their analysis to explore the sensitivity to M .

Both males and females may live as long as 30 years, though in general males do not live as long as females (Frey 1971). Pattison and McAllister (1990) found maximum ages of 30 and 23 for females and males, respectively. However, despite the maximum aged females being 30, the next oldest females were 23 and 19. The oldest fish found by MacNair et al. (2001) was 13. More recent data from Reilly and Tanaka have females aged to 19 and males to 16. The difference in maximum age between males and females suggests males have a higher rate of natural mortality. Sunada et al. (1990) suggest increased M for males might be a reason for the sex ratio difference shown for other flatfish (see Table A4.9.4).

Hewitt and Hoenig (2005) suggest, based on an empirical relationship (Hoenig 1983), natural mortality is 40-50% higher than estimated using the rule of thumb ($M = 3/a_{\max}$) and $4.22/a_{\max}$

should be used instead, where “ $a_{\max}$ ” = maximum observed age. Estimates based on life history theory and empirical relationships with life history parameters are higher (Table A4.9.1).

Natural mortality is likely to vary with age and time. Natural mortality could be higher for younger individuals because of predation or physiological constraints and higher for older individuals due to the cost of reproduction or senescence. It might be important to model the change in natural mortality for young halibut if data for these fish is included in the analysis (e.g., indices of abundance and length frequency data from the sanitation surveys or the Bay Study). Lorenzen’s (1996) relationship that natural mortality is inversely proportional to length, with the absolute levels scaled for halibut, using the assumption natural mortality stops declining (or perhaps increases) with length at the age at maturity, might be a useful way to model halibut natural mortality including the age specific nature and the difference between males and females. Estimates (Table A4.9.3) based on these assumptions using the mean length-at-age data from Sunada et al. (1990) and the natural mortality of female adults is 0.15 [close to the 30 max age value using Hewitt and Hoenig (2005) suggestion and halfway between the two values used by Reed and McCall (1988)].

Estimates of natural mortality are available from several other species related to California halibut (Table A4.9.4). These can be used as proxies for California halibut or to produce more specific empirical relationships with maximum age or life history parameters. Beverton and Holt (1959), Pauly (1980), and Gunderson (1997) provide summaries of species for which M has been estimated. FishBase (Froese and Pauly 2010) provides information on additional species for which M has been estimated. The methods used to estimate M are generally based on tagging data or catch-curve analysis. The estimates of M range from 0.1 to 0.6 with some higher limits. However, many of the estimates are uncertain (e.g., only upper bounds are given) or the methods used to estimate M are questionable. However, when estimates are available for both females and males, the male M is always higher. In general, these estimates for other species are unreliable and are not suitable for using as proxies for California halibut.

A4.10. Selectivity

A higher proportion of larger fish are taken by gill nets than by trawl nets, while inshore-caught halibut are smaller than those taken offshore (Sunada et al. 1990). Females grow larger than males and the sex ratio of the catch is skewed, usually towards females. Males and females should have different selectivity curves and the overall selectivity (catchability) should be different between males and females (e.g., maximum selectivity set to one for one sex and estimated for the other sex).

A4.11. Recruitment

Halibut spawn (based on larval abundance) predominantly between Rosario Bay, northern Baja California, to Point Conception all year round with a major peak in February and minor secondary peaks in July and October (Moser and Watson 1990). It is likely that halibut also spawn in central California, based on the presence of females with mature eggs in sampled catches and the occurrence of young-of-the-year halibut in Bay Delta Study trawl samples. Halibut spawn in water 6 to 20 m (3 to 11 fathoms) deep (Frey 1971). Halibut is a broadcast spawner, eggs are planktonic, found in the upper 30 m, and hatch after 30 days (Lavenberg et al.

1986). Larvae are planktonic, concentrated in the upper 20 m, make diel vertical migrations (Barnett et al. 1984), and settle after about 20 days on the open coast and in embayments (Kramer 1990, 1991). The timing of peak larval abundance differs among areas (Moser and Watson 1990). Larval abundance in the Southern California Bight peaks approximately one month after both the primary and secondary peaks in northern Baja California. The number of eggs released during a spawning event is dependent on the size of the fish and annual fecundity is dependent on batch fecundity and number of spawns per year (Lavenberg 1987). A typical 5-year old fish has a batch fecundity of 300,000 eggs. Juvenile halibut between 20 and 140 mm SL length emigrate into the shallow waters (4 m and less) of embayments (Kramer 1990, 1991).

It has been a common view for flatfish that relatively small spawning biomass levels can produce enough juveniles to seed the nursery grounds and this has been observed for a number of heavily exploited flatfish stocks (Rice et al. 2005). In general, flatfish are more resilient than most commercial species (Rice et al. 2005). Rice et al. (2005) evaluated recruitment from 35 flatfish stocks in the north Atlantic and northeast Pacific. Their results generally indicated a positive relationship between spawning stock and recruitment. However, the methods used are probably highly influenced by autocorrelation in recruitment and environmental regime shifts which tend to link high recruitment with high spawning biomass even in the absence of a stock recruitment relationship. Their results also showed strong compensatory survival, which dampens out the stock recruitment relationship. They concluded “for the great majority of the stocks reviewed ... it appears recruitment at low levels of spawning biomass is not very different from recruitment at higher levels of spawning biomass.” Berkson (1990) assumed recruitment was independent of stock size and suggested this assumption was supported by the fact that a 22-inch female halibut could produce 300,000 eggs per week in the laboratory.

Myers et al. (1999) estimated the steepness of the stock recruitment relationship from several species including 14 stocks from the family Pleuronectidae and 7 stocks from the family Soleidae (Table A4.11.1). The median estimate of steepness was 0.80 and 0.84 for Pleuronectidae and Soleidae, respectively. It should be noted the methods used by Myers et al. (1999) produce negatively biased estimates of steepness.

Large-scale and multi-year environmental trends can affect many biological processes (e.g., recruitment, growth, and natural mortality). Work on flatfish is at the forefront of including these trends in stock assessments and management (Rice et al. 2005). Over half the assessed flatfish stocks in the northeast Atlantic have been specifically noted to have strong environmental effects on year-class strength (Rice et al. 2005). Recently, effects of environmental conditions on stock productivity have featured prominently in assessment, advice, and management action on many flatfish stocks (Rice et al. 2005). Catch and, probably, biomass of California halibut has shown large fluctuations over time indicating recruitment for this stock may be driven by environmental forces. Berkson (1990) estimated recruitment to the fishery in 1985-87 was two to three times higher than in 1981-83. He suggested this may be due to the warming of water temperature caused by the 1982-83 El Nino. He supported this by the observation that increased water temperature improves growth and survival of prerecruits in the laboratory. Autocorrelation in recruitment may also be important to include in the stock assessment (Rice et al. 2005).

Domeier and Chun (1995) state it is not known if the local populations are self-recruiting or if larval dispersal occurs over a much larger area. If they are self-recruiting, then spatial management may be needed.

A4.12. Catch-at-age data

Several sets of catch-at-age data are available, but all except one are sampled from a range of gears and are therefore not suitable for using as age composition data since they cannot be completely associated with a fishery. The data from MacNair et al. (2001) is from a single swept area trawl survey.

Sunada et al. (1990)

Sunada et al. (1990) provides data from the main southern California ports: Santa Barbara, Ventura, San Pedro, and San Diego (Table A4.12.1; Figure A4.12.1). The samples were taken randomly. The fishing gears sampled included gill nets and trawl nets. Otoliths were collected beginning in 1985 from Santa Barbara, Ventura, and San Diego, and from San Pedro beginning in 1986. Otoliths were also taken from sub-adults collected on a research trawl in 1985. Sex was determined by visually examining the gonads.

MacNair et al. (2001)

MacNair et al. (2001) collected age and length data using a 400-mesh eastern trawl net in southern California (Mexican border to Point Conception) from 8 July through 3 August 1993 and central California (Point Conception to Tomales Bay) from 14 February through 18 March 1994 (Figure A4.6.1). Sampling was stratified by depth and the information about the stratification is not complete making the development of age composition difficult. An additional ten fish were collected in southern California from July 1994 to June 1995. They used the average of four readings per otolith as the age estimate. Otoliths that were hard to age were sectioned.

Reilly and Tanaka

Reilly and Tanaka aged California halibut from both the central and southern regions. The samples were collected from bottom trawl, hook-and-line, gill net, and purse seine gears during 2007-2010. Small, juvenile fish were caught as bycatch in the Pacific sardine purse seine fishery.

Ageing error was evaluated using multiple readings. MacNair et al. (2001) obtained within reader average percent error for whole otoliths ranging from 8.1% to 13.2% and for sectioned otoliths ranging from 4.7% to 8.9%. Pattison and McAllister (1990) obtained within reader average percent error of 9.8% and 20.8% for two readers and between reader error as a combination of three readers of 19.7%, 23.9% and 21.4%. These data could be used to develop an ageing error matrix for age composition data used in the assessment. Tanaka and Reilly continued to re-read otoliths with age differences until agreement was reached, otherwise the reading was not used in the database.

In the three studies above and in Pattison and McAllister (1990) halibut aged as 10 years and older were uncommon.

A4.13. Catch-at-length

Length composition data is available from the commercial and recreational fisheries, and from the fishery-independent surveys. The sample sizes and the years available differ among the fisheries and surveys. The length composition data is available by gender for the commercial fisheries and discard information is available for the southern California recreational fishery. See the specific assessment for details about data availability.

A4.14. Indices of abundance

Several indices of abundance are available and they differ between north and south of Point Conception. The indices include CPUE from detailed trawl logs, CPUE from CPFV logs, gill net surveys, California Cooperative Oceanic Fisheries Investigations Reports (CalCOFI) larvae survey, San Francisco Bay young-of-the-year trawl survey, sanitation district trawl surveys, electricity generating station impingement data, electricity generating station trawl surveys, and a DFG swept area trawl survey. See the specific assessment for details about data availability.

A5. History of modeling approaches

Flatfish stocks are relatively easy to assess because they are widely distributed on the bottom where they can be surveyed effectively with standard gear (Rice et al. 2005). They are also generally easy to age and therefore conducive to age-structured assessment methods (Rice et al. 2005).

Assessments of flatfish in the northeast Pacific commonly use statistical age-structured models (e.g., Stock Synthesis) that allow the assessment model to be tailored to the specific stock (Rice et al. 2005). Assessments in the northwest Atlantic vary according to the amount of data available and range from Virtual Population Analysis, which requires comprehensive catch-at-age data, to monitoring catch and survey indices. Surplus production models have become popular for the data poor species in recent years. In the northeast Atlantic all the flatfish assessments are conducted using extended survivors analysis (Shepherd 1992), which incorporates commercial catch and survey data (Rice et al. 2005).

Reed and MacCall (1988) used a VPA and concluded the stock was probably overexploited in terms of maximizing yield. They also evaluated proposed changes in minimum legal size.

Using Robson and Chapman's (1961) catch-curve analysis MacNair et al. (2001) estimated instantaneous mortality rates of 0.91 and 0.68 for males and females, respectively. Sample sizes were too small to estimate mortality rates for central California.

Berkson (1990) used a simple age aggregated model to estimate recruitment levels for two periods from recreational telephone survey catch-per-hour fished data. He found recruitment to the fishery in 1985-87 were two to three times higher than levels in 1981-83. Using simulation analysis, he found, under current catches at the time, the population would remain near current levels or continue to increase if recruitment remained at the high level, but would decrease rapidly under the lower recruitment level and catches would not be sustainable. He evaluated two levels of natural mortality (survival) based on Reed and MacCall (1988) and two levels of total

catch based on different assumptions for mean weight in the commercial fishery (catch was implemented in numbers so commercial catch was converted from weight to numbers of fish).

A6. Stock assessment

A sex-structured model with different growth, natural mortality, and selectivity for males and females developed using Stock Synthesis is used to assess California halibut in two stocks separated at Point Conception. The models are fit to a CPFV index of relative abundance and length composition data from the recreational and commercial fisheries. The central stock is also fit to indices of relative abundance from trawl logbook CPUE and the San Francisco Bay survey, a swept area trawl survey estimate of absolute abundance with associated age composition data, and age-conditioned on length data. Due to limited size composition and discard data for the central stock, all selectivity parameters, except for a few parameters for the selectivity curve of the recreational fishery and the bottom trawl fishery, for the central stock are fixed based on the southern stock assessment. The details of the stock assessments are described in sections B and C for the southern and central stocks, respectively.

A7. Reference points

No stock status reference points have been developed for California halibut. Reference points are quantities that when compared to measures of the current state of the stock can be used as a guide to the stock's health. For example, if maximizing catch from the stock is the management objective, the abundance levels and fishing mortality rates corresponding to maximum sustainable yield might be appropriate reference points. The estimated maximum sustainable yield (MSY) based reference points are inappropriate because the biology of California halibut and the assumption that recruitment is independent of stock size causes the spawning stock biomass associated with MSY to occur at a high depletion level (7-12% of the unexploited stock biomass). The 25% proxy level might be a reasonable reference point.

A8. Research needs

A systematic analysis of all data sets available for all California species is needed. This includes developing and maintaining data bases for data such as CPFV logbooks, sanitation district's trawl surveys, CalCOFI, impingement, and gill net surveys. Appropriate standardized indices of abundance should be developed from each data set for all species and length composition data generated.

A thorough investigation of the CPFV CPUE index of relative abundance needs to be carried out, including the appropriate identification of trips targeting California halibut. The current method produces a stable index of abundance that may indicate too many trips that did not catch halibut were not considered target trips when in fact they may have either been targeting California halibut or fishing in a manner that had the potential of catching California halibut. For example, the Stephens and MacCall (2004) filter could be applied. The preferred habitat of California halibut should be used in constructing the CPUE index either through the restriction of trips and blocks fished or in weighting of data.

Increase gender-specific age sampling of commercial and recreational fishery catches and discards will greatly facilitate the estimation of sex specific selectivity and retention.

The CPFV CPUE suggests there is additional spatial structure in the population and fishery impacts. A more detailed analysis of the spatial structure of California halibut and its movement is needed. Tagging programs have been spatially limited and a comprehensive tagging program that appropriately accounts for recovery effort and reporting rates is needed to evaluate the spatial structure. A tagging program may also provide estimates of age and sex specific natural mortality, which is a main uncertainty in the model.

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Alec MacCall, NMFS/SWFSC-FED (Chair)
André Punt, University of Washington
EJ Dick, NMFS/SWFSC-FED

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Tables and Figures

Table A4.2.1. Parameter estimates of the von Bertalanffy growth equation and weight length relationship [$\text{kg} = f(\text{mm})$] from several studies. L_{inf} , K and t_0 are parameters of the von Bertalanffy growth equation. The quantities a and b are the parameters of the relationship between weight and age.

	L_{inf}	K	t_0	a	b
Reed and MacCall					
Females	1417.42	0.1194	0.3801	0.000007768	3.0496
Males	1137.43	0.1218	0.1004	0.000009216	3.0165
MacNair et al.					
Southern Male	925.3	0.08	-2.2		
Southern Female	1367.7	0.08	-1.2		
Central Male	956.7	0.10	-2.1		
Central Female	1477.1	0.10	-0.2		
Haaker (SL ages 0-2)				9.39×10^{-6}	3.088
Reilly and Tanaka	See Table A4.2.6				

Table A4.2.2. Age and growth (mid-year lengths) of female halibut from California commercial landings (from Frey 1971 reported by Kucas and Hassler 1986; Biological Report 82(11.44))

Age	Mid-year length (mm TL)	Weight (kg)
1	178	0.057
2	318	0.340
3	439	0.907
4	553	1.758
5	648	2.835
7	813	5.783
9	940	9.072
12	1054	10.745

Table A4.2.3. Mean length-at-age and variation of length-at-age for male and female California halibut from Pattison and McAllister (1990).

Age	Males N	TL (mm) Mean	SD	Females N	TL (mm) Mean	SD
1	47	226	30.7	55	220	26.8
2	35	328	55.5	30	317	54.2
3	55	378	37.7	59	436	54.6
4	65	465	59.9	101	524	65.8
5	79	542	55.6	316	617	69.9
6	102	597	52.6	487	654	81.0
7	81	622	65.7	355	703	102.8
8	34	633	74.2	126	781	123.7
9	22	770	112.8	48	858	147.9
10	13	764	129.2	29	947	105.7
11	2	905	125.2	18	941	87.2
12	7	909	170.6	14	1023	52.3
13	3	863	123.9	12	1042	77.8
14	1 *			2	1128	9.9
15				4	1081	132.5
16						
17	2	977	24.7	2	1138	187.4
18				1 *		
19	2	1003	18.4	1 *		
20	2	1008	15.6			
21	1 *					
22						
23	1	910		1 *		
24						
25						
26						
27						
28						
29						
30				1	1180	

*Mean length not provided for ages with only one-fish sample except for the maximum age fish for each gender.

Table A4.2.4. Mean total length-at-age (mm) for male and female California halibut from Sunada et al. (1990).

Female				Male		
Age	N	Mean L	Calc	N	Mean L	Calc
			Mean L			Mean L
1	2	274	240	2	244	162
2	4	319	324	6	308	273
3	8	418	404	13	366	368
4	21	556	469	12	455	449
5	175	591	550	19	547	517
6	325	617	618	66	592	576
7	235	648	681	61	602	625
8	80	711	741	25	610	688
9	30	795	798	13	728	704
10	11	950	851	3	821	734
11	16	939	902	0		760
12	11	1017	950	3	963	762
13	8	1043	995	0		801
14	1	1121	1038	0		817
15	1	1103	1078	0		831

Table A4.2.5. Mean total length-at-age and variation of length-at-age for male and female California halibut from MacNair et al. (2001).

Southern CA						
Male				Female		
Age	N	Mean TL (mm)	SD	N	Mean TL (mm)	SD
1	4	259.3	25.0	1	252.0	
2	103	289.4	28.4	21	291.9	38.4
3	178	319.3	39.3	42	364.4	63.9
4	110	377.3	42.2	54	462.6	86.7
5	106	417.2	55.0	58	520.5	64.3
6	92	481.7	61.9	70	591.2	67.7
7	97	505.6	65.1	41	616.1	60.5
8	40	538.3	62.6	26	666.0	101.4
9	23	551.5	68.0	11	736.2	131.9
10	6	578.2	34.5	9	828.3	67.4
11	1	577.0		2	836.0	213.5
12	1	586.0				
13				1	964.0	

Central CA						
Male				Female		
Age	N	Mean TL (mm)	SD	N	Mean TL (mm)	SD
1						
2	15	325.9	29.8	12	312.9	28.7
3	46	384.8	38.1	46	373.4	70.0
4	26	447.8	60.5	35	493.5	102.3
5	9	492.8	59.0	17	606.2	101.4
6	20	538.6	49.4	4	672.0	87.0
7	13	595.6	72.7	2	725.5	43.1
8	13	582.5	74.4	5	810.4	99.3
9	3	648.7	29.5	5	842.0	112.2
10	1	781.0		1	970.0	
11	1	737.0				
12				2	1026.5	17.7

Table A4.2.6. Mean standard length-at-age (mm) from Haaker (1975).

Age	Male		Female	
	N	L	N	L
0	74	70.9	20	70.5
1	192	118.6	26	146.7
2	14	250.3	30	301.3

Table A4.2.7. von Bertalanffy growth curve parameters from the fit to the data of Reilly and Tanaka for the two genders by region.

	K	L _{inf} (cm)	t ₀ (cm)	L1 (cm)	L20 (cm)
North Males	0.157	89.2	-1.45	28.5	86.1
North Females	0.091	129.7	-2.63	36.5	113.2
South Males	0.112	119.9	-0.22	15.3	107.3
South Females	0.095	132.6	-0.92	22.1	114.5

Table A4.7.1. Mean and standard deviation (km) of distance traveled by tagged fish.

Posner and Lavenberg (1999)				Domeier and Chun (1995)			
Total length (mm)	N	Mean	SD	Total length (mm)	N	Mean	SD
201-350	94	5.5	32.0	201-350	80	8.1	26.1
351-400	174	5.3	15.7	351-400	125	8.0	36.6
401-150	215	5.3	21.8	401-150	205	8.0	26.5
451-500	203	4.6	17.7	451-500	184	7.3	21.2
501-550	135	5.6	13.7	501-550	104	19.1	50.4
>550	25	29.5	72.3	551-600	55	25.0	62.4
				601-1200	86	37.8	62.3

Table A4.7.2. Distance traveled (km) per day for different length groups Domeier and Chun (1995).

Total length (mm)	N	Mean	SD
201-350	80	0.15	0.84
351-400	125	0.12	0.49
401-150	205	0.14	0.36
451-500	184	0.12	0.80
501-550	104	0.22	0.48
551-600	55	0.59	2.36
601-1200	86	0.48	0.85

Table A4.8.1. Parameters of the logistic model for proportion mature at length and age for male and female California halibut from Love and Brooks (1990). The quantities a and b are the parameters of the logistic model, L50 is the length at 50% maturity, and r^2 is the coefficient of determination a measure of how well the logistic model describes the data.

Length				
	a	B	L50	r^2
Males	-0.34	7.77	22.7	0.83
Females	-0.15	7.02	47.1	0.85
Age				
	A	B	A50	r^2
Males	-3.10	4.00	1.3	0.94
Females	-1.52	6.56	4.3	0.91

Table A4.9.1. Estimates of natural mortality for California halibut from several different methods based on max age and life history parameters. (a_{mat} is 4.3 and 1.3 for females and males, respectively; Love and Brooks 1990; max age (a_{max}) is 30 and 23 for males and females, respectively; K is based on Reilly and Tanaka data).

Reference	Equation	Female	Male
Rule of thumb	$3/a_{max}$	0.10	0.13
Hoenig (1983)	$\exp(1.46 - 1.01 \ln[t_{max}])$	0.14	0.18
Jensen (1996) K	1.60K (south)	0.15	0.18
	(north)	0.15	0.25
Jensen (1996) a_{mat}	$1.65/a_{mat}$	0.38	1.27
Gunderson (1997)	1.79GSI	NA	

Table A4.9.2. Estimates of natural mortality for summer flounder from several different methods based on max age and life history parameters. Mean annual bottom temperature (17.5°C) from North Carolina coastal waters is used for Pauly's (1980) equation. (from Maunder and Wong in press)

Reference	Equation	Female	Male
Rule of thumb	$3/a_{max}$	0.21	0.25
Hoenig (1983)	$\exp(1.46 - 1.01 \ln[t_{max}])$	0.30	0.35
Jensen (1996) K	1.60K	0.32	0.34
Jensen (1996) a_{mat}	$1.65/a_{mat}$	1.18	1.50
Gunderson (1997)	1.79GSI	0.36	

Table A4.9.3. Age specific estimates of natural mortality based on scaling Lorenzen's (1996) relationship and assuming constant natural mortality at age for mature fish. (no estimates are available for age zero)

Age	Female	Male
1	0.31	0.28
2	0.26	0.28
3	0.20	0.28
4+	0.15	0.28

Table A4.9.4. Estimates of natural mortality (M) from species similar to California halibut

Species	Common name	locality	reference	Gender	Estimate
From Beverton and Holt					
<i>Citharichthys sordidus</i>	Sand dab	California	Arora (1951)		<0.3
<i>H. stenolepis</i>	Halibut	N. Pacific	Thompson & Herrington (1930), Thompson & Bell (1934)		<0.3
<i>Isopsetta isolepis</i>	Butter sole	Canada west coast	Hart (1948)	Female	< 1.02
				Male	< 1.41
<i>Pleuronectes platessa</i>	Plaice	North Sea	Beverton (unpub.)	Female	0.12
				Male	0.22
<i>Pseudopleuronectes americanus</i>	Winter flounder	Canada east coast	Dickie & McCracken (1955)		0.3 ¹
<i>Solea vulgaris</i>	Sole	North Sea	Beverton & Holt (1957), Margetts (unpub.)		≈0.25
From Pauly (1980)					
<i>Eopsetta jordani</i> female		Canada, W coast, M	Ketschen and Forrester (1966)	Female	0.2
				Male	0.25
<i>Hippoglossoides platessoides</i> female		Hamilton Inlet Bank, M	Pitt (1973)	Female	0.22
				Male	0.3
<i>Hippoglossoides platessoides</i> female		ICNAF 3L, M	Pitt (1973)	Female	0.23
				Male	0.25
<i>Hippoglossoides platessoides</i> female		St. Mary Bay, M	Pitt (1973)	Female	0.18
				Male	0.27
<i>Hippoglossoides platessoides</i> female		ICNAF 3L, M	Pitt (1973)	Female	0.18
				Male	0.26
<i>Limanda ferruginea</i>		S New England, M	Lux (1969)		0.15
<i>Platichthys flesus</i>		Kiel Bay, Baltic, B	Saeger (1974)		0.18
From Gunderson					
		English sole	Forrester and Ketchen (1963)		0.26
		American plaice	Pit (1975)		0.23
		Pacific halibut	IPHC Staff (1960)		0.19
		North Sea plaice	Beverton and Holt (1957)		0.10
		North Sea sole	De Veen (1976)		0.10
From fishbase					
<i>Hippoglossus stenolepis</i>			IPHC (1960)	unsexed	0.19
<i>Hippoglossus hippoglossus</i>			Mathisen and Olsen (1968)	male	0.2
<i>Hippoglossoides platessoides</i>			Pitt (1975)	unsexed	0.23
<i>Hippoglossoides platessoides</i>			Mackinnon (1973)	unsexed	0.40
<i>Arnoglossus laterna</i>			Djabali et al. (1993)	unsexed	0.60

¹ incorrectly recorded in Pauly (1980) as 0.4.

Table A4.11.1. Estimates of the stock recruitment steepness for stocks of Pleuronectiformes (from Myers et al. 1999). hmed is the median steepness value and h20% and h80% are the 20th and 80th percentiles.

Group	N	hmed	h20%	h80%
Pleuronectidae	14	0.80	0.71	0.87
Flounder (<i>Platichthys flesus</i>)	1	0.57		
Greenland halibut (<i>Reinhardtius hippoglossoides</i>)	3	0.79	0.59	0.91
Plaice (<i>Pleuronectes platessa</i>)	8	0.86	0.83	0.88
Yellowtail flounder (<i>Pleuronectes ferrugineus</i>)	2	0.75	0.69	0.81
Soleidae	7	0.84	0.72	0.91
Sole (<i>Solea vulgaris</i>)	7	0.84	0.72	0.91

Table A4.12.1. Catch-at-age data as percentages from Sunada et al. (1990) randomly sampled from the commercial fishery in southern California. Combined both gill nets and trawl, but majority is probably gill net.

Age	1985	1986	1987	1988
4	8.4	4.4	0.3	0.3
5	28.4	19.2	11.5	19.4
6	28.4	32.0	33.8	35.5
7	22.1	25.0	32.4	32.7
8	4.2	9.6	12.5	8.5
9	1.1	4.4	4.4	2.4
10	2.1	0.6	1.8	0.9
11		2.3	1.2	
12	4.2	0.9	1.2	0.3
13		1.1	0.7	
14		0.3		
15+		0.3		

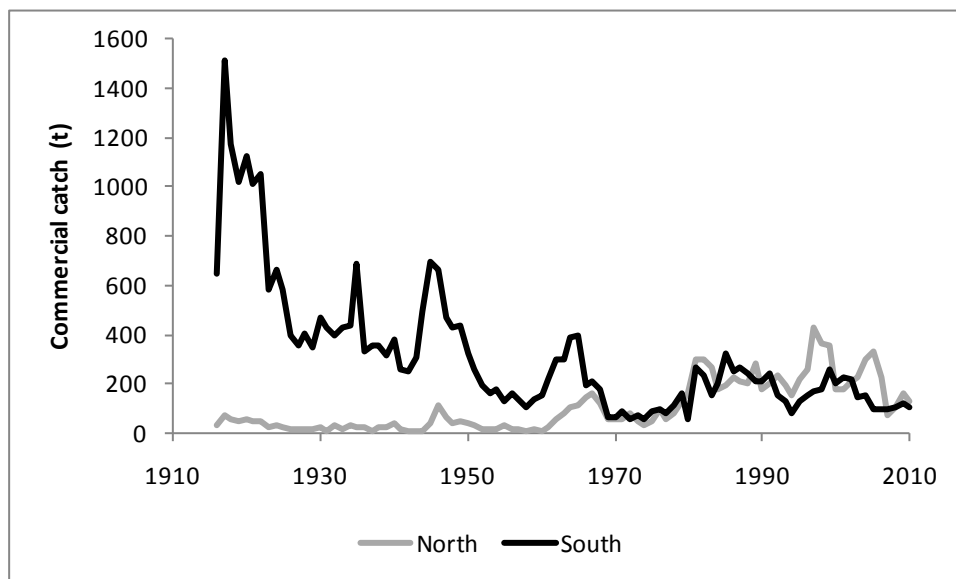


Figure A4.1.1. Commercial catch north and south of Point Conception

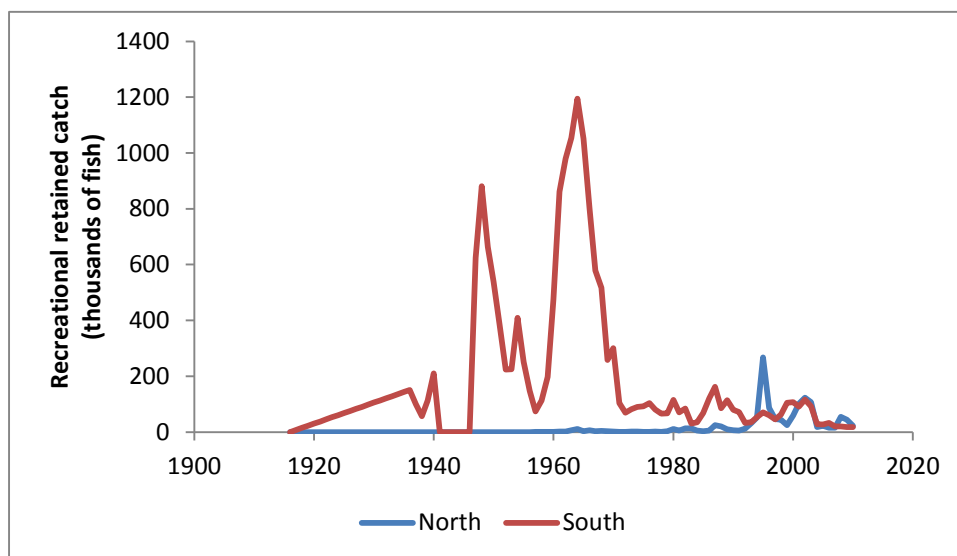


Figure A4.1.2. Recreational retained catch north and south of Point Conception

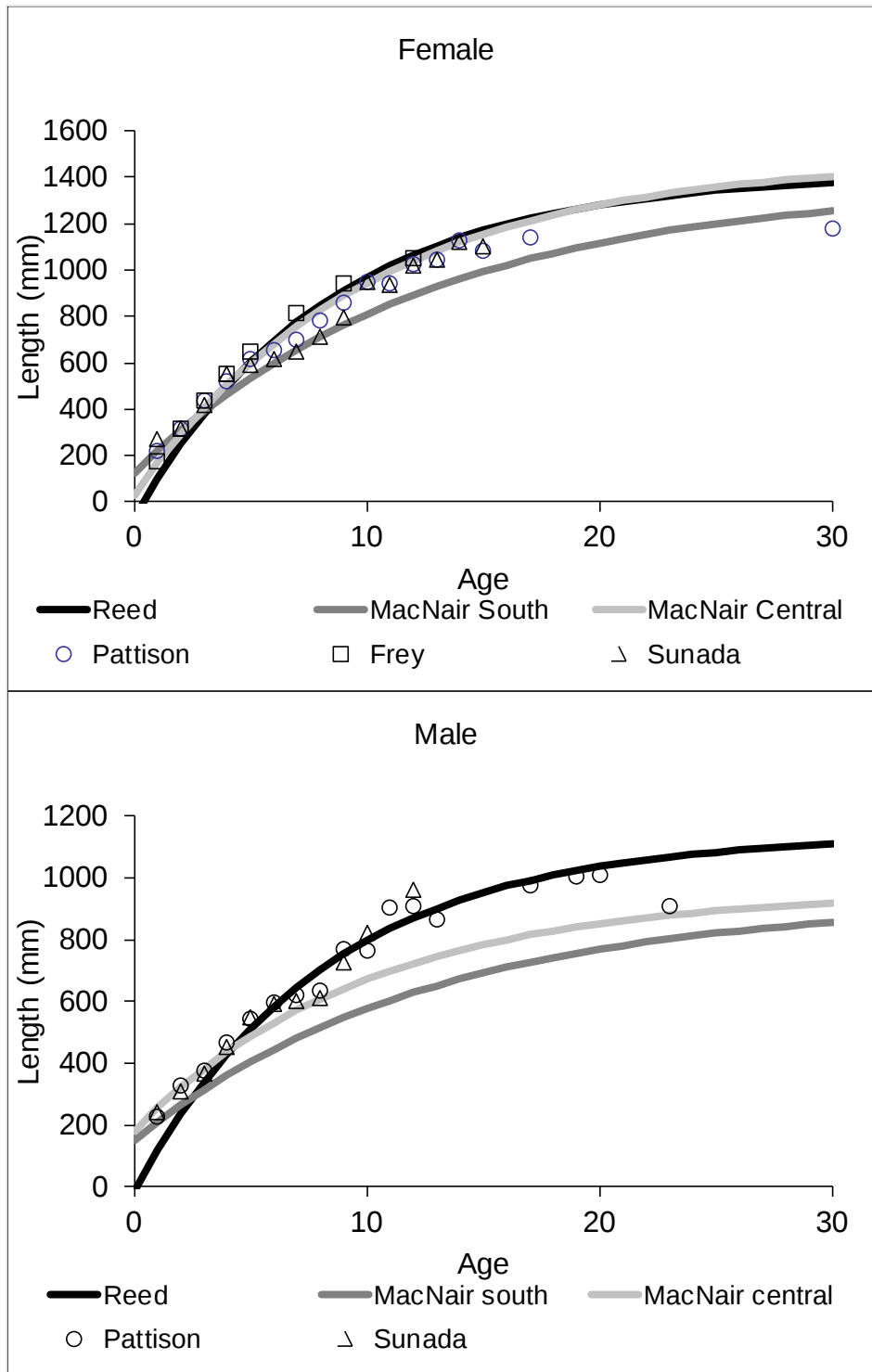


Figure A4.2.1. Comparison of several growth curves and mean length-at-age for females (top) and males (bottom).

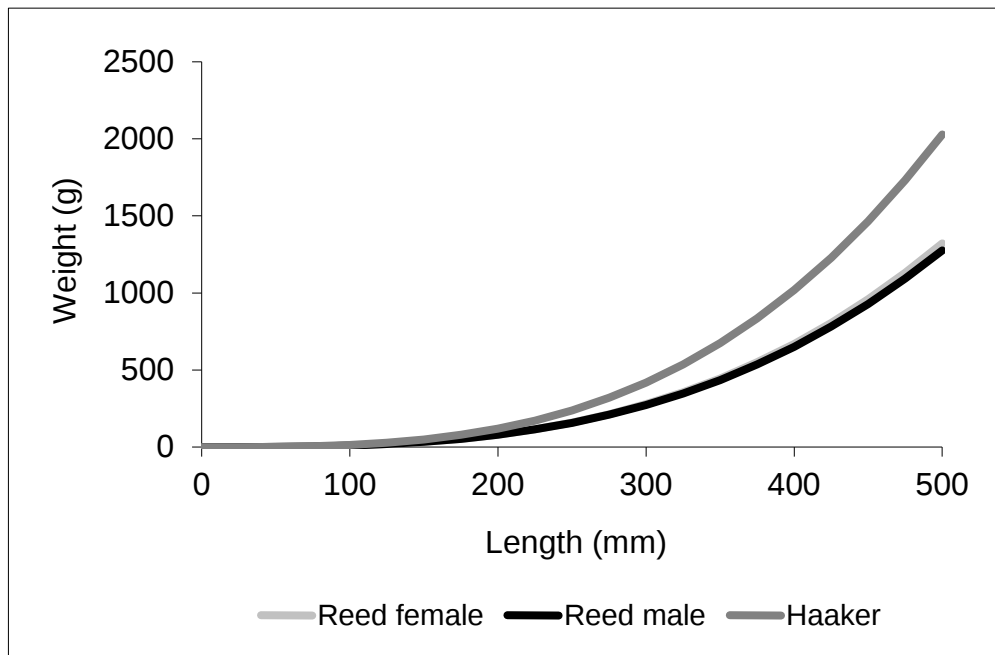


Figure A4.2.2. Weight length relationships from Reed and MacCall (1988) and Haaker (1975).

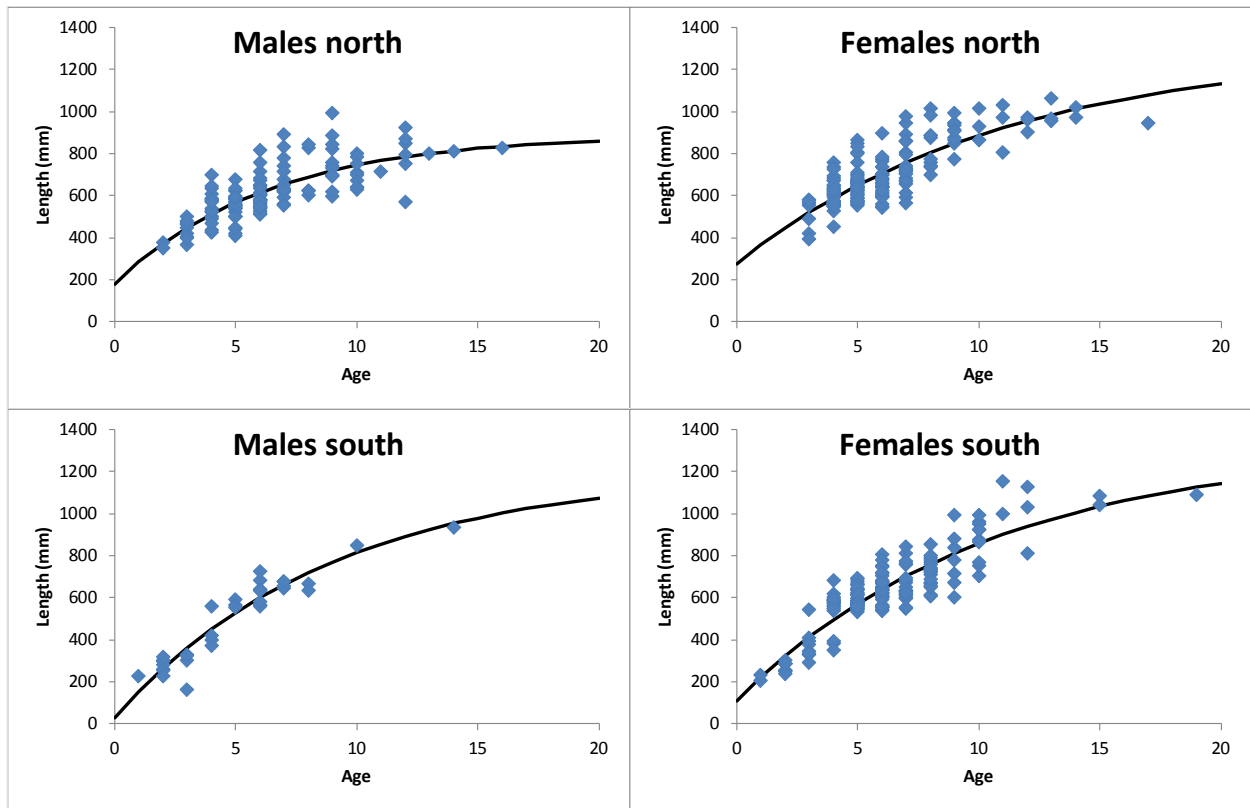


Figure A4.2.3. Fit of von Bertalanffy growth curves to the data of Reilly and Tanaka for the two genders by region.

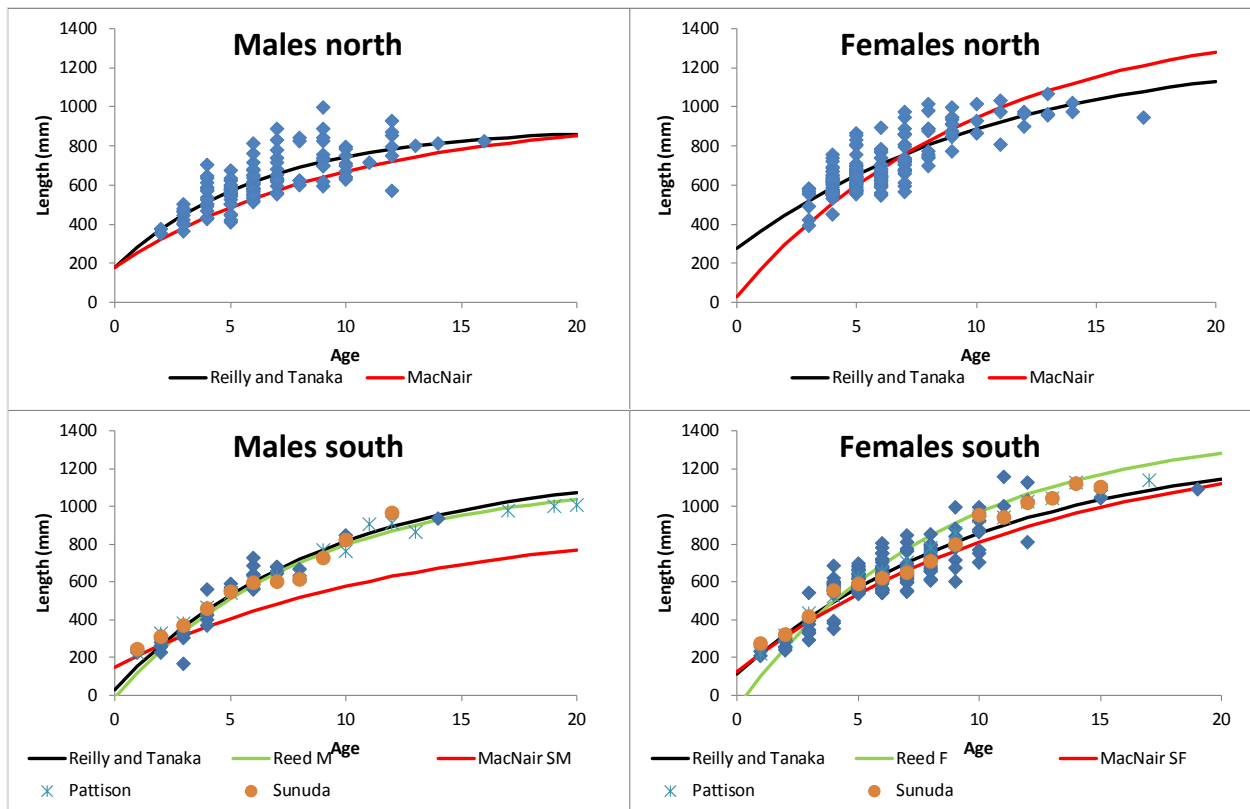


Figure A4.2.4. Comparison of the von Bertalanffy growth curves fit to the data of Reilly and Tanaka to previously estimated growth curves for the two genders by region.

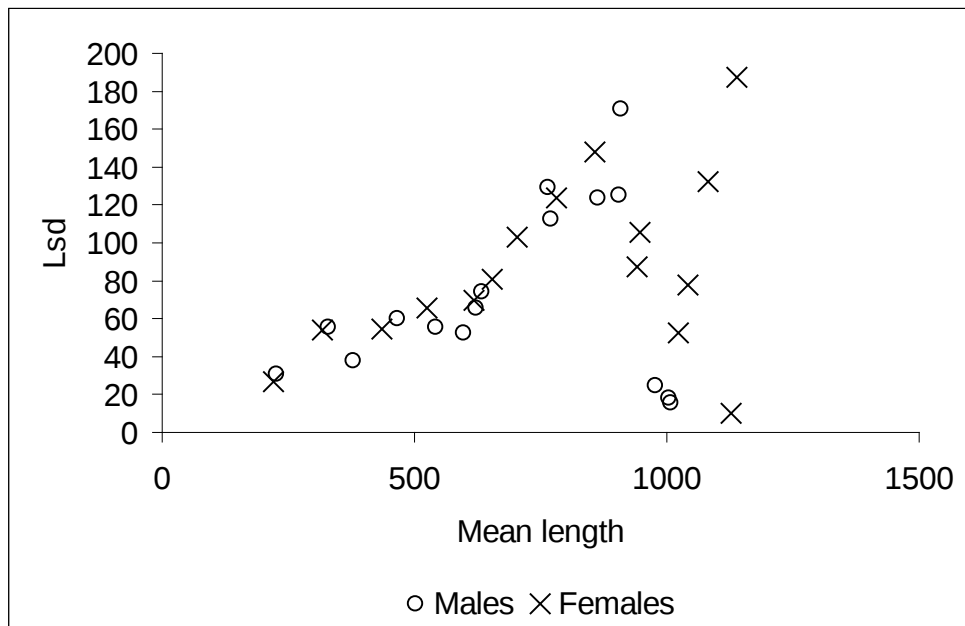


Figure A4.3.1. The standard deviation of the variation of length-at-age (Lsd) plotted against mean total length (mm) (from Pattison and McAllister 1990).

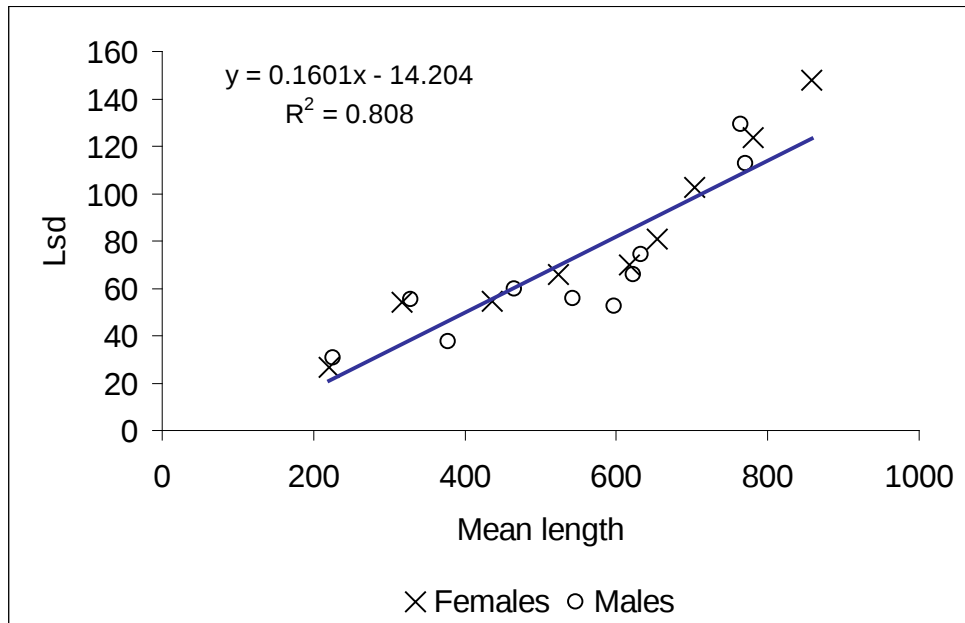


Figure A4.3.2. The standard deviation of the variation of length-at-age (Lsd) plotted against mean total length (mm) (from Pattison and McAllister 1990) with a linear regression applied to the combined male and female data. The data is restricted to the ages with more than ten samples and eliminating the older ages that show a reduced variation in length.

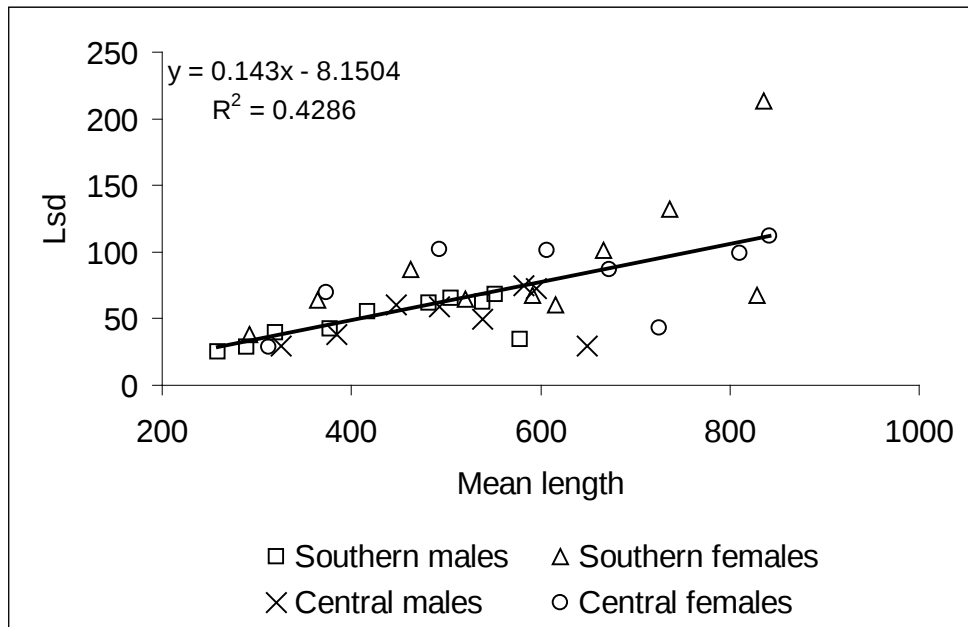


Figure A4.3.3. The standard deviation of the variation of length-at-age (Lsd) plotted against mean total length (mm) (from MacNair et al. 2001) with a linear regression applied to the combined data.

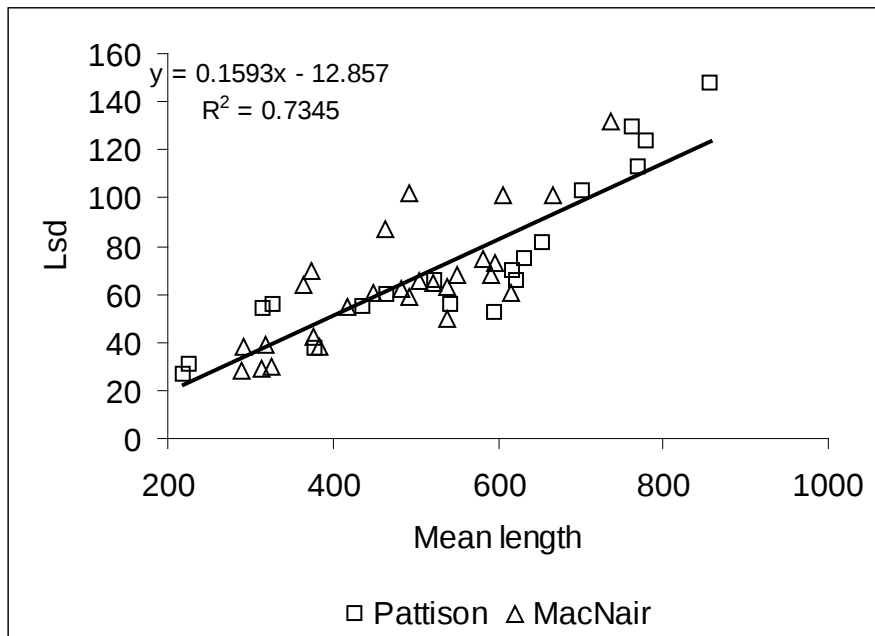


Figure A4.3.4. The standard deviation of the variation of length-at-age (Lsd) plotted against mean total length (from Pattison and McAllister 1990 and MacNair et al. 2001) with a linear regression applied to the combined male and female data. The data is restricted to the ages with more than ten samples (both data sets) and eliminating the older ages that show a reduced variation in length (Pattison and McAllister 1990 data only).

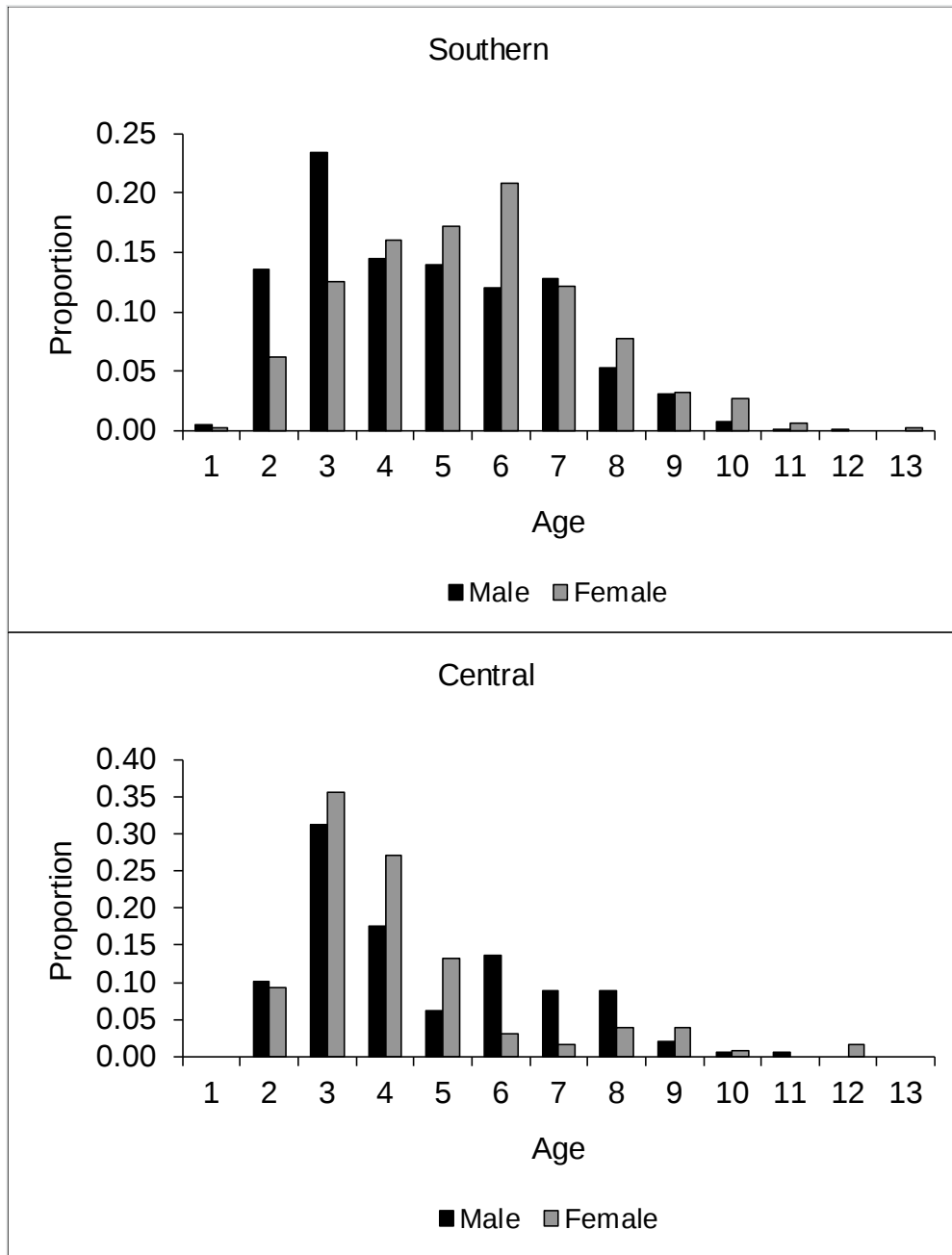


Figure A4.6.1. Proportion at age (in years) by sex for the southern (top) and central (bottom) areas from MacNair et al. (1990).

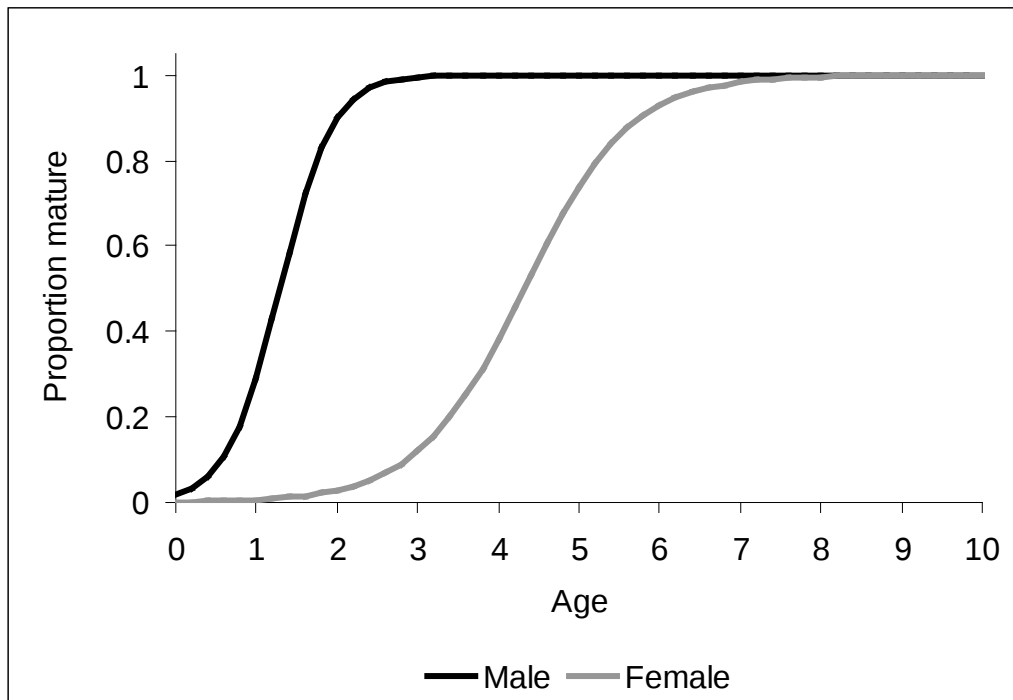


Figure A4.8.2. Proportion mature at age for male and female California halibut from Love and Brooks (1990).

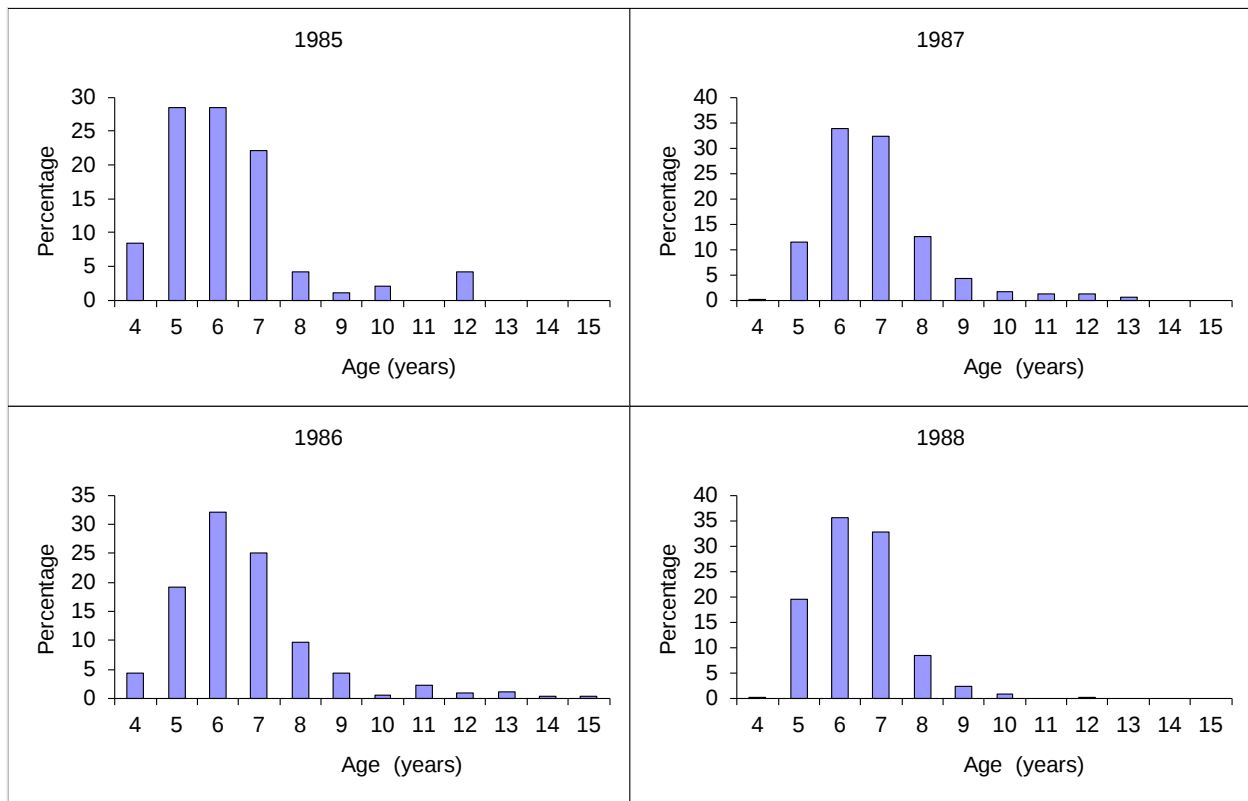


Figure A4.12.1. Catch-at-age data from Sunada et al. (1990) randomly sampled from the commercial fishery in southern California. They combined samples from both gill nets and trawl, but majority of samples are probably from gill nets.