SOUTHERN LINGCOD STOCK ASSESSMENT IN 1999

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Executive Summary

Southern lingcod (*Ophiodon elongatus*) life-history, landings, length-frequency, age-frequency, and survey data were summarized for the Eureka, Monterey, and Conception INPFC areas. Genetic evidence indicates that lingcod along the coast of Washington, Oregon, and California are one stock. Lingcod catch in the southern area has been declining steadily from around 1,400 mt in 1970's to 600 mt in the 1990's. Catch is dominated by the Monterey INPFC area and has shifted from primarily trawl to an even mixture of trawl, non-trawl (mostly hook-and-line and some set-net), and recreational catch.

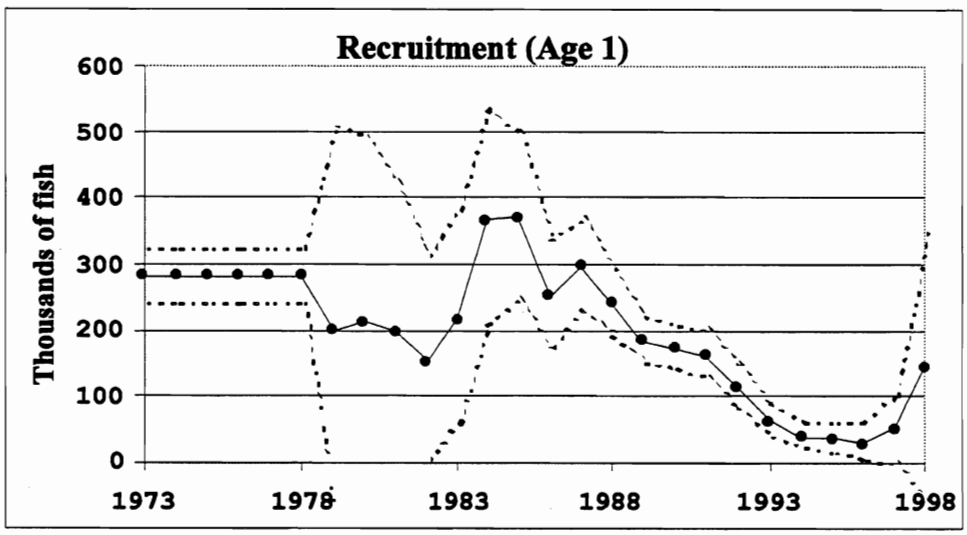
California instituted the earliest management regulations reducing recreational bag limits from 10 to 5 fish in 1980 and establishing a 22 inch size limit in 1981. In 1983, the Groundfish plan set a 2,000 mt Acceptable Biological Catch (ABC) for this area (Eureka 500 mt, Monterey 1,100 mt, and Conception 400 mt). In 1995, these ABCs were reduced to 1,100 mt (Eureka 300 mt, Monterey 700 mt, and Conception 100 mt) and a 22 inch commercial and recreational size limit was imposed. Trip limits were also imposed but allowed a 100 lb allowance of fish under the 22 inch size limit. In 1998, these ABCs were reduced to 510 mt (Eureka 139 mt, Monterey 325 mt, and Conception 46 mt). The size limit was raised to 24 inch, but the 100 lb allowance remained.

The most recent lingcod assessment off Washington and Oregon (Jagielo et al. 1997) indicated a significant population decline over the period from 1978 to 1996 to approximately 19% of the starting biomass. This assessment placed lingcod into a rebuilding mode. There was considerable concern about placing southern lingcod under a rebuilding plan due to an assessment conducted off Washington and Oregon. Because of this concern, a southern lingcod assessment was conducted even though there are only length and age data from 1992 to 1997. This short length and age data series are the principal areas of uncertainty associated with the assessment. Previous reviews of southern lingcod in 1986 and 1994 expressed concern about lingcod population condition.

The assessment uses a new conceptual model that was developed at the Tiburon Laboratory. The model is essentially a forward projecting, separable, length-based, age-structured population model. The modeling concepts were applied using the AD (Automatic Differentiation) Model Builder Software (Fournier 1996). There are three distinct fisheries in the model: 1) trawl, 2) non-trawl, and 3) recreational. Landings are available for the time period 1973 to 1998. Length and age composition data are available from 1992 to 1997. Auxiliary information include three surveys: 1) AFSC triennial trawl survey (1977-1998, every third year), 2) California trawl logbook CPUE (1978-1996), and 3) MRFSS recreational CPUE (1980-1989, 1992-1998).

The southern lingcod base model results indicated a heavily exploited stock. The current spawning potential estimate is 7.5% of the mean unfished level. There is a 94% probability that the current spawning potential is 25% or less of the unfished level (overfishing threshold). The current level of spawning potential has been reduced to 24.2% of levels corresponding to the

1973-1978 time period..



Time series for estimates of exploitation rates indicate high levels of exploitation with values exceeding the $F_{35\%}$ guideline throughout the entire time series. A sensitivity analysis to changes in natural mortality (M) over a range of values from 0.35 to 0.1 has better model fit (lower likelihood) at lower natural mortalities.

Spawning potential estimates are fairly robust to changes in natural mortality. It is appears that southern lingcod stock is highly productive with good potential for rapid population increases given appropriate decreases in fishing effort. However, it is important to note that the most aggressive harvest policy presented here is $F_{35\%}$ compared to an estimated historical $F_{10\%}$ harvest policy that fishery has been operating at.

Research recommendations were made by the STAT team and the STAR panel. Comparative lingcod age reading studies should continue to be pursued. Southern lingcod monitoring should be improved with particular emphases on the non-trawl fishery which had no samples for this assessment. A lingcod discard mortality study needs to be implemented to evaluate the size limit regulations. A source of fishery-independent data for southern lingcod needs to be developed.

1.0 Introduction

The previous assessment of lingcod (*Ophiodon elongatus*) for the US-Vancouver and Columbia International North Pacific Fishery Commission (INPFC) areas (Jagielo et al. 1997) found a substantial decline in population size to approximately 19% of starting biomass (Figure 1) in those areas. At that time, it was decided not to conduct an assessment on Eureka, Monterey, and Conception INPFC areas due to the short time series of length and age data (at that time 1992-1996), although landing and age composition data were summarized. The situation is further complicated by the introduction of a commerical size limit in 1995. While the data situation has not changed, it was decided to do a southern assessment given the likelihood of restrictive regulatory actions and the fact that there will not a significant increase in the amount of data in the near future.

The assessment area covers the Eureka, Monterey, and Conception INPFC areas, from Cape Blanco (42° 50' N) south to the US-Mexico border (Figure 2). Genetic evidence suggests that there is only one large lingcod stock off the coast of Washington, Oregon, and California (Jagielo et al. 1996), although California is only represented by a single sample off San Francisco. Landings data were gathered for the trawl fishery (1973-1998), the non-trawl (1973-1998); the hook and line and set net; fishery (1973-1998), and the recreational fishery (1973-1998). Catch-at-size and age time series were compiled for trawl fishery (1992-1997) and the recreational fishery (1992-1997). Auxiliary data sets include the NMFS triennial survey (1977-1998, every third year), a California trawl CPUE index (1978-1996), and the MRFSS recreational CPUE index (1980-1989, 1993-1998).

2.0 Management History

California recreation lingcod bag limits were reduced from 10 fish to 5 fish in 1980. A recreational size limit of 22 inch size limit was implemented in 1981. In 1983 with the implementation of the Groundfish Plan, Acceptable Biological Catches (ABC) for the Eureka, Monterey, and Conception INPFC areas were set at 500, 1100, and 400 mt for combined total of 2,000 mt, over 600 mt higher than the maximum commercial landings. Vancouver and Columbia INPFC area ABCs were 1,000 and 4,000 mt for a combined total of 7,000 mt, twice the highest historical annual landings. In 1995, the coast-wide ABC were reduced to 2,400 mt with ABCs for the Eureka, Monterey and Conception INPFC areas of 300, 700, and 100 mt. The recreational catch is assumed to be 700 mt coast-wide. A 22 inch commercial and recreational size limit was imposed coast-wide and in Oregon and Washington a 3 fish bag recreational limit was put into effect. A monthly commercial trip limit of 20,000 lb per month and a trawl trip limit of 100 lb of lingcod under 22 inch were established. In 1996, the commercial trip limit was changed to a 40,000 lb per two months and in July 1997, that was reduced to 30,000 lb per two months. In 1998, the Eureka, Monterey, and Conception INPFC area ABCs were reduced to 139, 325, and 46 mt of a coast-wide total of 1,021 mt. The two month trip limit was reduced to 1,000 mt and the commercial and recreational size limit was increased to 24 inch. The trawl 100 lb trip

limit under 24 inch remained. California recreational bag limits were reduced from 5 fish to 3 and were further reduced to 2 fish in 1999.

3.0 Life History Characteristics

Lingcod range from Kodiak Island, Gulf of Alaska to Baja California with the center of their distribution in British Columbia and Washington. Lingcod are most abundant in waters less than 100 fm, but are found out to depths exceeding 200 fm. They have patchy distributions and are most abundant on areas of hard substrate with high rocky relief. Lingcod are high level predators, feeding primarily on fish. For a more complete description of lingcod life history, see Cass et al. (1990), or Adams and Hardwick (1992).

Lingcod have a unique nesting reproductive cycle. In late fall, male lingcod aggregate and become territorial, in areas suitable for spawning. Nesting occurs in areas with rocky crevices which allows significant current and flow. The current provides maximum oxygen levels to the egg nest and improves egg survival. Spawning has been reported from mean low water line to 126 m. Mature females are rarely seen on the spawning grounds, so it is assumed that their migration there is very brief. Females deposit eggs in successive layers followed by male fertilization. After spawning, the male remains at the egg mass until incubation. Egg mass incubation averages 7 weeks, and ranges from 5 to 11 weeks. Hatching has been observed as early as January and as late as June. Hatching in California from one large sample ranged from early March to early April (Adams et al. 1993). Hatching is synchronized, mostly occurring in 24 hours, but can range up to 7 days. Larval and juvenile lingcod are pelagic until mid-May to mid-June, when they make an inshore benthic migration to adult habitats (Adams et al. 1993).

Lingcod are considered to be sedentary. Large scale Canadian tagging studies have found that 95% of the fish recovered are recovered near their point of release. However, some long migrations have been documented. One lingcod tagged at Cordell Bank off San Francisco, CA was recaptured off Coos Bay, Oregon (Adams, unpub. data). Lingcod must make a seasonal migration in the winter to spawn in shallow water.

3.1 Growth

Growth is modeled by the von Bertalanffy growth equation. The von Bertalanffy growth parameters are fit following Xiao (1994) since the Monte Carlo use of a bivariate normal distribution of L_∞ and K parameters are an integral part of the population modeling. The von Bertalanffy model was fit to all lingcod length and age taken in both the commercial and recreational sampling from 1992 to 1997. Performance of this growth model (Estimate Length) estimated here is general similar to others (Jagielo et al. 1997, reviewed in Adams 1986), but the Jagielo et al. (1997) growth model estimates smaller fish at young ages, which would be expected since it uses the model that explicitly sets length at age 1. These model results here are remarkably similar to those estimated from previous work in California (Miller and Geibel 1973)

even though that work was done thirty years previous and used surface otolith aging. At the suggestion of the STAR panel, a second growth model (Corrected Estimate) was developed using size-at-age for the first year from Jagielo et al. (1997). This model estimates substantially smaller fish up to age 6. This model was then used in the modeling. The Corrected Estimate parameter estimates are listed in Table 1 and the fit of both the original Estimated Length and Corrected Estimate models and data points are shown in Figure 3.

3.2 Weight-Length Relationships

Weight-length relationships (Table 1) were taken from Jagielo et al. (1997). Previously published weight-length relationships are reviewed in Adams (1986) and the performance of all are similar.

3.3 Length-at-Maturity Relationships

Length-at-maturity relationships were estimated for female and male lingcod (Table 1) from California commercial sample data from the period 1993-1995. Samples were collected during all times of the year and showed strong seasonal pattern of maturity with both males and females maturing from November through February (Silberberg et al., in review). Examination of north to south trends in 50% length-at-maturity and age-at-maturity show declining trend in length-at-maturity while there is no trend in age-at-maturity.

3.4 Fecundity

Fecundity, the relationship between number of eggs and length, is taken from Hart (1967) (Table 1). Hart reported the fecundity relationship for number of eggs versus total length and this relationship was recalculated for fork length using total length to fork length conversions (Laidig et al. 1997).

3.5 Natural Mortality

Natural mortality for lingcod has been estimated over a range 0.20 to 0.80 using both tagging and age composition methods (Table 2). Natural mortality estimates from tagging covers the 0.20 to 0.80 range, but are estimates of net loss which would include other factors such as emigration, tag loss, and non-reporting. Jagielo (1995) estimated emigration rates in one study at 0.23. The only age composition natural mortality estimate for lingcod was 0.28 (Richards 1991). Lingcod natural mortality studies are summarized in detail by Adams (1986) and Jagielo (1994)

Lingcod natural mortality estimates were computed for three empirical methods (Alverson and Carney 1975, Pauley 1980, and Hoeing 1983) by Jagielo (1994). The average of the three methods for both sexes was 0.25 (Table 1).

4.0 Fishery Landings History

4.1 Commercial Landings

Commercial landings by gear type from 1973 to 1988 were compiled for the Eureka INPFC area (Table 3), the Monterey INPFC area (Table 4), and the Conception INPFC area (Table 5). The data series from 1973 to 1980 were taken from the Historical Annotated Landings and is summarized in Adams (1986). The data series from 1981 to 1998 was taken from the Pacific Fisheries Information Network (PacFIN).

Total commercial landings are erratic, but show a general declining trend (Figure 4). Total landings are high averaging 1,400 mt from a period from 1973 to 1982, then decline sharply to a low of 589 mt in 1986. This is followed by a increase to the previously high level in 1989 and a decline to a level of around 650 mt from 1992 on. The sharp drop in the final year is regulatory driven. Monterey and Eureka INPFC areas follow a similar pattern, but Conception INPFC area declines in 1982 and stays low thereafter. Monterey INPFC area accounts for about 60% of the landings, Eureka about 30%, and Conception about 10%. Over the three INPFC areas, trawls accounted for approximately 85% of the landings from 1973 to 1982 and then associated with the drop in landings around 1986, deceased to approximately 50% of the landings. The individual INPFC areas follow the same pattern except that Eureka area recovers to over 70% trawl landings and Conception area recovers to around 20% trawl landings. Hook and line landings are the dominate non-trawl component in all areas. Monterey and Conception INPFC areas also have substantial set net landings.

4.2 Recreational Landings

The Marine Recreational Fishery Statistics Survey (MRFSS) estimates recreational landings from the period of 1980 through 1989 and from 1993 to 1998 (Table 6). Recreational landings from 1973 to 1979 are summarized by Adams (1986). Silberberg and Adams (1993) compared MRFSS and Washington Department of Fish and Wildlife (WDFW) total recreational landings and MRFSS and California Department of Fish and Game (CDF&G) partyboat landings and found good consistency after the 1980-1981 period, although MRFSS estimates were consistently higher. For the period 1990 to 1992 when there were no MRFSS data, estimates were made by multiplying the annual trend in the CDF&G Commercial Fishing Passenger Vessel (CPFV) logbook times the average MRFSS estimate over the period 1980 to 1989 and 1993 to 1998. MRFSS recreational landings ranged from 1658 mt to 260 mt in a generally downward trend after the high 1980-1981 period (Figure 5). Recreational landings average 36% of total removals, ranging from 16% to 61% with no apparent annual trend. Northern California accounts for approximately 83% of the landings and Southern California 17% and those percentages are consistent over the time series.

5.0 Length and Age Composition Data

Length and age composition data is available for two (Trawl and Recreational) of the three fisheries (Trawl, Non-Trawl, and Recreational). The time series for both data sets are 1992 to 1997.

5.1 Trawl Fishery Length and Age Composition Data

The proportions of fish by sex, length, and year were estimated for the period 1992 to 1997 from trawl fishery samples. Length samples and fin-rays were collected by CDF&G port samplers. The fin-rays were aged at NMFS Tiburon Laboratory. The individual length and age frequency were expanded by landing weight of the sampled trips. Both female and male length composition (Table 7 and Figure 6) show a shift to large sizes over the 1992 to 1997 time period. Some of this is regulatory driven by the 1995 size limit, but it begins before 1995. The female and male age composition (Table 8) show a similar trend. Examination of the average-size-at-age show no apparent trend over the 1992-1997 period (Figure 7).

5.2 Recreational Fishery Length and Age Composition Data

Recreational length and fin-ray samples were obtained from CDF&G Central California Marine Sport Fish Project from the CPFV fishery and were expanded over other fishing modes (primarily skiff fishing). Sampling was conducted from Crescent City to Avila Beach and over a time period of 1992 to 1997. Female and male length composition (Table 9 and Figure 8) and age composition (Table 10) trends are complicated by the 22 inch (559 mm) size limit that was in place during this time period. As in the commercial data, there is no apparent trend in the average-size-at-age over the 1992-1997 period (Figure 9).

6.0 Surveys

Three surveys are used as auxiliary data sets; these include the NMFS triennial survey, California trawl CPUE index, and the MRFSS recreational CPUE index.

6.1 NMFS Triennial Survey

The Alaska Fisheries Science Center (AFSC) has conducted the triennial groundfish surveys off the coast of Washington, Oregon, and California every third year since 1977 (see Wilkins 1996). Estimates of swept-area biomass of lingcod by year and INPFC area along with their standard errors (Table 11) were obtained (Mark Wilkins, pers. communication, March 1999). The data were summed over the Eureka, Monterey, and Conception INPFC areas for the assessment. The total estimate are dominated by the Monterey estimate which is often 75% of the total and is highly erratic. Length frequency data were not used in the model because they were so few in the southern area.

6.2 California trawl CPUE index

Trawl logbook CPUE indices from California logbook data were calculated following Ralston (1999). The trawl logbook CPUE index is derived over the period from 1978 to 1996 by applying a General Linear Model (GLM) to censored logbook data with individual terms for year, month, boat, and CDF&G block number. State-wide least mean squares and coefficients of variation are estimated and back-transformed to lb/hr and standard errors (Table 12). The data series shows a decline after an initial high value around 1981, recovering to approximately half that level in the late 1980's and then reducing again. Calculated SE were extremely low and were replaced in the model by estimates based on a CV at 10% of the least mean square.

6.3 MRFSS recreational CPUE index

The MRFSS also provides a recreational CPUE index in numbers of lingcod caught per 1,000 angler trips (Table 13). This index includes both the partyboat and skiff fishery The CDF&G Commercial Passenger Fishing Vessel (CPFV) CPUE index in numbers of lingcod per angler day is also shown in Table 13 (Tom Barnes, CDF&G, pers. comm.). The MRFSS recreational CPUE index shows an erratic pattern with no apparent trend beside a decline after the extremely high 1980-81 years. The CDF&G index seems to track the MRFSS index except for the high 1980-1981 and ending in 1996 (Figure 10).

7.0 Assessment Modeling

7.1 Assessment History

The first U. S. lingcod assessment was by Adams (1986) who reviewed available data, conducted yield per recruit analysis, and identified data needs. Lingcod's vulnerability to harvesting due to the increased accessibility from their reproductive activity and to the potential rapid decline due to lingcod's large individual biomass (small number can result in large decline in biomass) were identified. Jagielo (1994) conducted an assessment of lingcod from 49° 00' N (Southern Vancouver Island) south to 45° 46' N (Cape Falcon). He concluded that biomass dropped from 19,000 mt to 13,500 mt and was relatively stable. Adams (1994) reviewed two years of lingcod sampling from Oregon and California and although it is difficult to draw conclusions from only two years sampling, expressed concern at the small size and young age of the fish. Jagielo et al. (1997) conducted an assessment from 49° 00' N (Southern Vancouver Island) south to 42° 50' N (Cape Blanco). They concluded that biomass dropped from 34,601 mt to 6,714 mt and that lingcod were a heavily exploited stock.

7.2 Model Description

A new conceptual model was developed for the assessment of southern canary rockfish

(Williams et al. 1999) and this description is taken from that document. The model is essentially a forward projecting, separable, length-based, age-structured population model. That assessment report represents the first documentation of this model. The modeling concepts were applied using the AD (Automatic Differentiation) Model Builder 3.10 software obtained from Otter Research, Ltd. (Fournier 1996).

7.2.1 Introduction

Modern fishery stock assessment models can be classified into two major types of population models, length-based models and age-based models. The decision to use one of these types of models is usually determined by the quality or quantity of the collected population data. Age-based models are a preferred choice due to simplifications of annual calculations. However, age information can be difficult to obtain and inaccurate.

In some instance such as lingcod, management is explicitly length based through the use of size limits. Also length information is easy to obtain and more accurate compared to age information for most fisheries. In addition, population and fishery parameters such as maturity, mortality, and gear selectivity are frequently related to length better than age information (Quinn and Deriso 1998). For these reasons it is attractive and occasionally more informative to incorporate length information into population models (Ralston and Ianelli 1999). Most research in the past has focused on adding growth via some type of stochastic growth function or age to length transformation (Sullivan 1992; Methot 1990; Quinn and Deriso 1998).

Deriso and Parma (1988) and Parma and Deriso (1990) discussed the properties of stochastic growth functions and indicated that most length-based models inherently assume variation in growth is due to environmental forces, as opposed to inherent variation. Variation in growth due to environmental forces or genetic forces is analogous to measurement and process error properties in statistics, respectively. Genetic variation in growth is variation in the growth between individuals based on inherent differences in their growth trajectories, i.e. smaller fish at age will tend to remain smaller fish at age throughout their life. For this model, growth was cast as a genetically variable process.

The reason for choosing to model variability in growth as a genetic process is an attempt to capture the effect of size-specific removals, in particular the largest individuals, on the population. The degree to which this effect is important in population dynamics is dependent on the level of fishing mortality, amount of variability in growth, and the steepness of the size selection curve (Deriso and Parma 1988; Parma and Deriso 1990). In addition, the population dynamics of a particular fish species undergoing size-specific removals may be affected by the presence of sexual dimorphisms, such as those commonly seen in groundfish such as lingcod and rockfish (*Sebastes* spp.).

Models which use a stochastic growth function fail to capture the full effect of removing the largest individuals from a population. Methot (1990) indicated that size-specific removal is an

important process, but was not included in the stock synthesis modeling software. Deriso and Parma (1988) and Parma and Deriso (1990) captured both environmental and genetic variation in growth resulting in a highly complex model.

We have developed an extension of age-structured population modeling which allows for both age and length information by accounting for growth via a simple fixed growth transition array. The growth transition array is estimated from a fishery samples of age-length observations.

7.2.2 Model Formulation

In order to incorporate both age and length information into a population model some form of their relationship must be specified. For this population model growth in length for each age will be modeled by a simple set of von Bertalanffy growth models by sex. A single growth model is given by $L_t = L_\infty[1 - \exp(-K\{t - t_0\})]$ with length at time or age t given by L_t and the parameters L_∞, K, and t_0. The set of growth models, representing the variation in growth, consists of a set of different L_∞ and K parameters having a joint bivariate normal distribution (Xiao 1994). The fit of this model to lingcod age-length information is shown in Figure 3 and parameter estimates are indicated in Table 1. This set of growth models is determined by a maximum likelihood fit to a set of single observations of age and length from the population (Xiao 1994).

The growth information obtained from the bivariate normal distribution of parameters L_∞ and K may be used in a population model via a transition matrix. Transition matrices have been used extensively in the past for both age, the Leslie matrix, and size, the Lefkovitch matrix, information (Law and Edley 1990). The combined transition matrix for age and size is named the Goodman matrix (Goodman 1969). Since growth in length for fish is dependent on age, the Goodman matrix is appropriate.

Many fisheries models seem to operate best on annual scales. In order to keep model formulations operating on an annual basis we need to have the probability distribution of lengths for individuals at age t+1 given L and t. Since most fisheries models are discretized into age and length bins, the probability for a given length bin, defined by a lower bound L_L and an upper bound L_U, s given by a modified bivariate probability density function (see Williams et al. 1999, Appendix I). However, this formulation is difficult to compute and therefore a fixed Goodman transition matrix was estimated using a Monte Carlo simulation.

The Monte Carlo procedure involved a random draw of L_∞ and K from a bivariate normal distribution. A length was computed for each age bin of the model using the von Bertalanffy paired random deviates. The change in length bins with age was recorded and the whole process repeated 1 million times. The result was a transition array consisting of 3 dimensions: length, age, and probability of length at age+1. This growth transition array was then incorporated into an age-structured model in which age and length are tracked through time.

The governing equations for the model are essentially the same as other forward projecting age-structured models. Appendix I contains the model parameters and equations used in this assessment. The model used for this assessment does not use a Baranov-type catch equation. Due to the constraints of modeling growth via a transition matrix, fishery removals were simply subtracted at a fraction of the year. The fraction of the year at which the removals occur was calculated by analyzing the quarterly catch statistics compared to the catches following a Baranov equation for removals. This type of estimation is dependent on a fixed natural mortality rate, but our analysis indicated it was fairly robust to major changes in natural mortality.

Because fishery removals are being removed all at once at some point in time, fishing mortality must be modeled by an exploitation fraction. We used an annually varying fraction, ranging from 0 to 1 via a logistic model, to apply to the exploitable biomass. The exploitable biomass is that biomass which is susceptible to the fishing gear as determined by the selectivity function.

The annual fishing fraction, η'_y, is then divided amongst the competing fisheries and subsequently different sexes for the trawl fishery. Fishery selectivity was modeled using a logistic function for the trawl, non-trawl, and recreational fisheries. Selectivity curves for the trawl and recreational fishery were estimated within the model. The non-trawl fishery selectivity was fixed outside the model using the limited number of samples available. This was done because there were no sample length and age composition data from that fishery. The mortality due to discard is unknown. It was assumed that discards caused no additional mortality following previous assessment (Jagielo et al. 1997) and because the appearance of age 1 fish in the sampling.

7.3 Base Model Results (*M*=0.25)

The time series for lingcod recruitment (age 1) estimates from the base model indicate a steady decline from 1985 until 1997 (Figure 11,Table 14). The most recent recruitment estimate indicates an increase, but this value is poorly estimated as indicated by the 95% confidence interval. The time series for stock biomass (age 3+) and spawning potential indicate a marked decline in the early 1980's with continued decline until 1998 (Figure 12, Table 14). The current level of spawning potential has been reduced to 24.2% of levels corresponding to the 1973-78 time period.

Since management reference points are based on spawning levels relative to an unfished state, an estimate of the unfished spawning potential is required. For this assessment, the unfished spawning potential was estimated by using a lognormal distribution fit to the recruitment time series. The cumulative lognormal distribution of recruitment was multiplied by the spawning potential-per-recruit (SPR) to get a cumulative distribution of unfished spawning potential (Figure 13). This method assumes no stock-recruit relationship exists and that observed annual recruitments are representative of the average recruitment. The cumulative lognormal distribution of unfished spawning potential estimates are then converted to percentages relative to the 1998 spawning potential estimate (Figure 13). Based on the mean of the lognormal

distribution, the current spawning potential estimate is 7.5% of the mean unfished level (Table 15). Furthermore, there is a 94% probability that the current spawning potential is 25% or less (overfished) of the unfished level (Table 15).

Time series for estimates of exploitation rates indicate high levels of exploitation, with values exceeding the $F_{35\%}$ guideline throughout the modeling time period (Figure 14). The exploitation rates have averaged around 27% of age 3+ biomass for the 1980-97 time period (Figure 14). Most of the fishing effort appears to be divided between the trawl and recreational fisheries (Figure 14). Generally the trawl fishery dominated from 1973-1984, followed by a sharp decrease in 1985 coinciding with a marked increase in recreational effort in the fishery. The non-trawl fishery has shown a fairly steady increase throughout the time period (Figure 14). The time series of model fits to the fishery landings indicate excellent fits to these data (Figure 15). The lack of fit in the earliest years is a direct result of having a constant recruitment estimation for the 1973-77 time period (Figure 15).

Model fits to the survey and indices indicate the model is tracking general trends in these data sources. The triennial trawl survey yielded highly variable estimates of biomass, resulting in the fit shown in Figure 16. The trawl logbook CPUE and MRFSS index fits appear to be adequate and capture the overall trends in these time series (Figure 17). The survey and indices all agree that there has been a decrease in abundance and biomass in the most recent time period (Figures 16 and 17).

Original model estimates based on a growth model fit to the fisheries data alone suggested the age and length composition data were poorly estimated. In order to explore the possible causes of the poor model fit for the recreational composition data, the growth parameters were compared to other estimates for lingcod. A change in the estimate of t_0 of the von Bertalanffy growth model seemed like a possible solution to improve the model fit of the recreational composition data. Based on recommendations of the Stock Assessment Review (STAR) panel, a new growth model was fit using an estimate for age 1 fish from previous analyses (Jagielo et al., 1997) (Figure 3). These changes to the growth model appear to have improved some of the fit of the model to the age and length composition information, but still indicate further changes may be warranted. However, given the limited information on growth for lingcod, there was no justification for changing the growth function further.

Model fits to the trawl and recreational length and age composition data were analyzed through inspection of the residuals (observed minus estimated values). The trawl age composition data indicated adequate fits by the model for some of the data sources, while others indicate some biases in the fit (Figures 18-21). The female trawl age composition data appears to have the best fit of all the composition data, with the exception of the 1995 data year which clearly does not follow the pattern of the other composition data (Figure 18). The male trawl age composition fit is more variable than the female data fit (Figure 18). Both the female and male trawl length composition model estimates appear adequate, with the slightest hint of a bias toward overestimation of the 600-800 mm sizes (Figures 19).

The recreational composition model estimates do not appear to capture the observed values effectively (Figures 20 and 21). The general pattern of the residuals indicates the model is underestimating smaller sizes and overestimating larger sizes for the recreational length composition data, while overestimation is occurring for younger ages and underestimation is occurring for older ages in the recreational age composition data (Figures 20 and 21). This indicates the recreational length and age data are in slight disagreement with the existing age-length relationship in the model.

The slight difference in the age-length relationship in the recreational fishery composition data is not easily reconcilable through analysis of the age-length data. An analysis of the mean length at age does not indicate any difference between the trawl and recreational fisheries data (Figure 22). Based on the notion that either the age or length recreational fishery composition data is incorrect, the model was run with each of the age or length recreational data removed. Results did not show any significant improvement of the fits to either the age or length composition data sets, strengthening the concept of an incorrect growth model specification for the recreational fishery. The conundrum is that the observed fishery data does not support any difference in growth models between the fisheries.

Another possible solution to the troublesome recreational composition data was to explore differing selectivity functions. The base model selectivity functions are very similar for all three fisheries (Figure 23). We explored the use of dome-shaped selectivity functions for the recreational fishery, but the model avoided a large descending portion at larger sizes. In an extreme case we allowed the model to estimate the selectivity at every length size for both sexes in both the recreational and trawl fisheries. The results indicated that generally an asymptotic selection function was preferred for both sexes in both fisheries (Figure 24). There was a slight indication that the selection for largest females in the recreational fishery could be less than one, but the strongest bias in the base model occurred with the males, not the females (Figure 24).

7.4 Uncertainty and Sensitivity Analyses

Uncertainty in the model has been addressed through standard deviation estimates produced via the Delta method as described in the model specifications section. Parameter estimates from the model with their respective error estimates are shown in Table 16. The least certain estimates were the 1998 recruitment, 1984 exploitation rate, and the triennial trawl survey catchability. In general, the least variable estimates are for the selectivity parameters, followed by the recruitment values, with most of the uncertainty being in the exploitation rate estimates (Table 16).

A sensitivity analysis to changes in natural mortality (M) was performed over a range of values from 0.35 to 0.1. The overall likelihood indicates a lower natural mortality results in the best fit, as measured by the lowest likelihood value (Table 17). However, an analysis of the individual components indicates some disagreement as to which value of natural mortality is best. In Table 17, the lowest likelihood (best fit) for each component is shaded. The trawl length composition

and logbook data indicate a higher natural mortality results in a better fit, while the other data sources indicate the opposite (Table 17). Both stock and spawning biomass are positively correlated with natural mortality. It appears that the spawning potential estimates are fairly robust to changes in natural mortality (Table 17).

A sensitivity analysis of model estimates to "jacknife" deletions of data sets was performed. The results indicate the stock and spawning biomass estimates are robust to these changes (Table 17). There is some indication that removal of one of the age composition data sets resulted in improved fits to the length composition data, suggesting some discrepancy in the age-length relationship in the growth function and the composition data. It appears the deletion of one of the triennial trawl survey, trawl logbook CPUE, or MRFSS index had virtually no effect on the model estimates (Table 17).

8.0 Harvest Projections and Management Recommendation

Southern lingcod spawning potential fall well below the 25% rebuilding threshold. Spawning potential and yield per recruit were analyzed to determine the $F_{35\%}$, $F_{45\%}$, $F_{55\%}$, and $F_{65\%}$ constant exploitation rate policies. Figure 25 shows the SPR and YPR estimates with various reference points. The 1998 fishery exploitation rate is also shown in this figure for comparison (Figure 25). The $F_{35\%}$, $F_{45\%}$, $F_{55\%}$, and $F_{65\%}$ reference points are shown in the spawner-recruit relationship in Figure 25. Projections of spawning potential, yield, and stock biomass with 95% confidence intervals were produced using a parametric bootstrap sampling (n=500) from the lognormal distribution fit to the model recruitment estimates, fishery effort proportions from 1998, and the exploitation rates corresponding to $F_{35\%}$, $F_{40\%}$, $F_{45\%}$, and $F_{100\%}$ (Table 18, Figures 26-27). The southern lingcod stock appears to be highly productive with good potential for rapid population increases given appropriate decreases in fishing effort. The most aggressive harvest policy presented here is the F35% rate. It is important to note that the fishery has historically been well above this amount. Estimates indicate the fishery has been operating at about the F10% harvest policy rate.

9.0 Research Needs

1. A comparison of lingcod age reading is currently being conducted between NMFS, Tiburon, WDF&W, and DFO, Nanaimo. Inclusion of improved methods of age assignments will be important in future assessments.

2. Lingcod landing monitoring needs to be improved. There were no length or age composition data for the non-trawl fishery which in later years makes up almost one-third of the landings. Other recreational fisheries besides partyboat need to be monitored.

3. A lingcod discard mortality study needs to be implemented. The assumption that the fish under 24 inch that are caught and released suffer no additional mortality needs to be critically

examined.

4. Fishery-independent information is a critical need for lingcod. The nearshore rockfish initiative of CDF&G may provide an opportunity for fishery independent data for future assessments.

10.0 Acknowledgments

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Table 1. Summary of lingcod biological parameters used in the stock assessment. Source of data used can be found in the text section with same title.

Growth - von Bertalanffy Corrected Estimate	Female	Male
L_∞	1266	853
K	0.11	0.19
t_o	-0.79	-0.95
Weight-Length	**Female**	**Male**
α_W	7.042 E^{-7}	2.41 E^{-6}
β_W	3.3978	3.2149
Length-at-Maturity	**Female**	**Male**
α_ρ	0.021	0.016
β_ρ	557.3	461.1
r^2	0.994	0.984
Fecundity	**Female**	
α_φ	0.0003026	
β_φ	3.000	
Natural Mortality	Estimated (see Table 2)	*M*
	Tagging (net loss)	0.20-0.80
	Age Comp.	0.28
	Empirical Methods	
	Average	0.25

Table 2. Lingcod mortality estimates from tagging and age-composition methods by location and time period.

Source	Location	Time Period	M
Tagging			
Chatwin (1958)	SW Vancouver Island	1941-44	0.20
Reeves (1966)	SW Vancouver Island	1960-61	0.72
Forrester (1973)	SW Vancouver Island	1969-75	0.30-0.80
Smith et al. (1990)	Straights of Georgia	1982-87	0.34(f)-0.54(m)
Richards (1991)	Straights of Georgia	1982-86	0.78
Jagielo (1995)	Cape Flattery, Washington	1986-92	0.56
Age Composition			
Richards (1991)	Straights of Georgia	1982-1986	0.28

Table 3. Commercial lingcod landings for Eureka INPFC area for 1973 to 1998. Data from 1973 to 1980 from Adams (1986) and data from 1981 to 1998 from PacFIN.

Year	Hook& Line	Nets	Pots	Troll	Trawls	Shrimp Trawls	Other	Total
1973	45.7				488.0	4.3		538.0
1974	63.1				413.0	5.9		482.0
1975	111.6				290.0	10.5		412.0
1976	21.9				352.0	2.0		376.0
1977	64.0				202.0	6.0		272.0
1978	84.1				446.0	7.9		538.0
1979	112.5				413.0	10.6		536.0
1980	23.8				291.0	2.2		317.0
1981	13.6			8.3	349.2	8.8	0.5	380.4
1982	15.2		0.4	12.9	510.9	12.8	2.4	554.6
1983	26.1		1.3	2.4	363.8	0.2	16	409.8
1984	5.2		0.2	3.4	262.8	1.0	15.4	288.0
1985	41.8	0.1	0.9	1.2	183.4	1.6	9	238.0
1986	81.6		1.8	8.5	95.1	3.5	16.7	207.2
1987	104.0		0.3	0.5	203.9	1.1	11.7	321.5
1988	106.8		0.3	0.3	179.7	3.1	22.1	312.3
1989	175.4		1.5	1.1	188.6	3.7	18.9	389.2
1990	173.6		0.3	4.1	231.6	3.4	8.8	421.8
1991	65.5				139.9	5.9	1.3	212.6
1992	59.3		0.1		105.0	3.7	1.8	169.9
1993	40.6	0.2	0.1	0.3	153.3	1.8	1	197.3
1994	53.8	0.3	0.2	0.2	160.3	12.5	0.7	228.0
1995	90.8	0.7	0.2	0.2	132.9	5.8	1.5	232.1
1996	73.8		0.2	2.8	118.0	8.5	0.1	203.4
1997	109.1	0.1	0.2	0.1	148.8	4.1	0.1	262.5
1998	40.3		0.2	0.6	57.9	1.0	0.2	100.2

Table 4. Commercial lingcod landings for Monterey INPFC area for 1973 to 1998. Data from 1973 to 1980 from Adams (1986) and data from 1981 to 1998 from PacFIN.

Year	Hook& Line	Nets	Pots	Troll	Trawls	Shrimp Trawls	Other	Total
1973	110.0				711.0			821.0
1974	87.0				896.0			983.0
1975	91.0				738.0			829.0
1976	54.0				746.0			800.0
1977	85.0				414.0			499.0
1978	112.0				538.0			650.0
1979	105.0				800.0			905.0
1980	69.0				835.0			904.0
1981	38.2	8.6	2.7	21.2	759.5	0.3	5.5	836.0
1982	22.2	49.5	1.3	14.9	736.6	0.0	16.1	840.6
1983	10.0	71.3	0.5	1.7	477.3	0.2	85.6	646.6
1984	3.4	25.6		1.0	546.3		160.0	736.3
1985	15.3	89.6	1.6	3.7	219.6		158.8	488.6
1986	52.5	90.4	2.1	0.7	122.1		91.7	359.5
1987	66.3	152.0	0.9	1.1	288.3	0.1	73.0	581.7
1988	99.2	169.7	2.8	1.4	290.0		63.5	626.6
1989	197.9	208.8	2.2	0.4	413.6		70.9	893.8
1990	154.7	174.3	1.2	8.9	318.7		48.8	706.6
1991	131.5	105.8	0.9	0.7	299.7		23.4	562.0
1992	128.4	85.5	0.7	1.0	190.6		35.2	441.4
1993	107.0	105.6	0.3	2.6	270.6	0.1	3.1	489.3
1994	83.3	72.0	0.3	12.4	224.1	0.5	3.2	395.8
1995	73.8	48.9	0.9	8.9	184.2	0.4	1.2	318.3
1996	93.0	7.3	1.2	4.8	205.6	0.9	0.8	313.6
1997	87.7	21.0	2.0	1.9	219.0	0.3	0.1	332.0
1998	27.2	3.1	2.6	0.4	31.9		0.1	65.3

Table 5. Commercial lingcod landings for Conception INPFC area for 1973 to 1998. Data from 1973 to 1980 from Adams (1986) and data from 1981 to 1998 from PacFIN.

Year	Hook& Line	Nets	Pots	Troll	Trawls	Shrimp Trawls	Other	Total
1973	67.0				289.0			356.0
1974	109.0				205.0			314.0
1975	56.0				172.0			228.0
1976	90.0				181.0			271.0
1977	81.0				62.0			143.0
1978	107.0				38.0			145.0
1979	85.0				175.0			260.0
1980	23.0				123.0			146.0
1981	5.3	10.4	0.5	1.4	149.2	1.7	0.1	168.6
1982	4.4	27.5	0.1	0.2	133.5	8.4	0.1	174.2
1983	0.9	4.7		0.1	41.9	0.3	0.5	48.4
1984	0.6	3.3			13.1	3.4	0.9	21.3
1985	1.1	9.6			10.3	0.3	3.2	24.5
1986	2.8	9	0.2	0.3	8.2		2.3	22.8
1987	6.2	13.2	0.2	0.7	6.6		3.3	30.2
1988	4.8	23.8			4.6		3.7	36.9
1989	4.3	34.1	0.5		12.9		4.3	56.1
1990	5.5	25.3	0.2		23.7		3.2	57.9
1991	11.0	43.8	0.1		14.7		2.9	72.5
1992	19.8	25.3	0.2		15.8		3.2	64.3
1993	21.8	44.1	0.1		9.9		2.6	78.5
1994	18.4	21.2	1.5	0.2	21.3	2.6	1.0	66.2
1995	26.9	7.9	3.1	0.2	17.0	2.2	0.6	57.9
1996	23.0	4.8	6.7	0.2	5.1	0.6	0.7	41.1
1997	17.5	2.3	5.2	0.1	5.1	0.4	0.1	30.7
1998	9.9	1.2	2.9		3.2	0.7		17.9

Table 6. Recreational landings (mt) of lingcod from the Eureka, Monterey, and Conception INPFC areas from 1973 to 1998. The data from 1973 to 1979 comes from Adams (1986) and the data from 1980 to 1989 and 1996 to 1998 comes from the MRFSS. The 1990 to 1992 landings are estimated from the trend in California CPFV CPUE index (Table 13) times average landings from the MRFSS 1980-1989 and 1993-1998 landings. Additional MRFSS 1993-1995 landings were supplied from Dave Thomas (CDF&G).

Year	Northern California	Southern California	State -wide Recreational
1973			394.0
1974			390.0
1975			420.0
1976			413.0
1977			275.0
1978			327.0
1979			325.0
1980	1133.9	524.5	1658.4
1981	1018.8	132.1	1150.9
1982	488.7	81.2	569.9
1983	524.4	50.0	574.4
1984	423.2	78.2	501.4
1985	813.7	151.3	965.0
1986	746.1	171.9	918.0
1987	732.0	212.5	944.5
1988	790.9	244.2	1035.1
1989	824.8	130.6	955.4
1990	631.0	134.2	765.2
1991	655.2	139.3	794.5
1992	636.8	135.4	772.2
1993	568.0	21.0	589.0
1994	358.0	18.1	376.1
1995	423.0	18.1	441.1
1996	338.5	27.1	365.6
1997	249.6	10.9	260.5
1998	271.0	13.2	284.2

Table 7. Lingcod trawl length composition by sex, length class and year. Actual refers to actual sample size and Effective refers to effective sample size estimated in the base model.

Female

Length	1992	1993	1994	1995	1996	1997
200	0.019842	0.00589	0.00767	0	0.00056	0
400	0.040728	0.049497	0.003269	0.00103	0	0.003857
440	0.097655	0.131466	0.01787	0.004148	0.011222	0.004098
480	0.154372	0.169724	0.081376	0.002088	0.020634	0.013575
520	0.092267	0.151716	0.119557	0.007099	0.082813	0.047721
560	0.071271	0.160597	0.124977	0.048579	0.128373	0.060027
600	0.085805	0.127493	0.162617	0.117947	0.166738	0.073341
640	0.134104	0.045854	0.100043	0.140426	0.141596	0.067874
680	0.109091	0.042304	0.062337	0.093119	0.118681	0.047544
720	0.057374	0.053495	0.05415	0.14973	0.17058	0.12116
760	0.02436	0.022136	0.065034	0.04987	0.06107	0.165906
800	0.05098	0.010886	0.041783	0.167374	0.052438	0.092596
840	0.034161	0.005256	0.063167	0.041595	0.010896	0.095306
880	0.019344	0.006536	0.039552	0.050092	0.003948	0.085032
920	0.003763	0.006304	0.014181	0.068802	0.019965	0.067283
960	0	0.010845	0.022167	0.025882	0.010484	0.042413
1000	0.004122	0	0.012784	0.00405	0	0.010887
1040	0	0	0	0.028169	0	0
1080	0	0	0.007466	0	0	0.00138
1200	0	0	0	0	0	0
Actual	222	707	391	268	259	905
Effective	34.4	12.2	30.5	46.9	26.1	55.2

Male

Length	1992	1993	1994	1995	1996	1997
200	0.004329	0.020197	0	0	0	0.000945
400	0.041917	0.081261	0.008673	0.00141	0	0.0048
440	0.165146	0.202273	0.024548	0.003022	0.007826	0.005977
480	0.130307	0.147928	0.115438	0.000986	0.067417	0.101218
520	0.092464	0.112474	0.323609	0.074262	0.11915	0.227455
560	0.184594	0.192159	0.199283	0.229403	0.23822	0.278735
600	0.164517	0.1242	0.13569	0.152048	0.130782	0.174756
640	0.097302	0.046326	0.095244	0.338584	0.239835	0.105722
680	0.064469	0.061287	0.069199	0.140807	0.095216	0.048256
720	0.022588	0.00916	0.028316	0.059478	0.055647	0.011909
760	0.01525	0.002735	0	0	0.045906	0.036606
800	0.008195	0	0	0	0	0
840	0.008923	0	0	0	0	0.003622
880	0	0	0	0	0	0
920	0	0	0	0	0	0
960	0	0	0	0	0	0
1000	0	0	0	0	0	0
1040	0	0	0	0	0	0
1080	0	0	0	0	0	0
1200	0	0	0	0	0	0
Actual	83	225	237	122	145	315
Effective	28.7	15.1	15.4	21.8	32.4	10.0

Table 8. Lingcod trawl age composition by sex, age class and year. Actual refers to actual sample size and Effective refers to effective sample size estimated in the base model.

Female

Age	1992	1993	1994	1995	1996	1997
1	0	0.000113	0.00015	0	0	0
2	0.038736	0.043374	0.007652	0	0.001533	0.004261
3	0.198686	0.180921	0.070951	0.002427	0.020643	0.04908
4	0.193571	0.222473	0.181673	0.014827	0.131	0.084654
5	0.165127	0.172848	0.153598	0.116138	0.20143	0.123027
6	0.175856	0.144726	0.174283	0.116752	0.211405	0.182767
7	0.079232	0.096227	0.115311	0.145993	0.206162	0.146747
8	0.080368	0.054427	0.091689	0.223359	0.096638	0.092885
9	0.059692	0.034622	0.090619	0.161568	0.074174	0.10252
10	0.003796	0.032927	0.058747	0.078983	0.022733	0.047721
11	0	0.005119	0.037694	0.05801	0.007091	0.110248
12	0	0.007087	0.008366	0.018025	0.027191	0.028247
13	0.004935	0.005136	0.009267	0.03063	0	0.002002
14	0	0	0	0.033287	0	0.02584
Actual	209	615	344	206	235	799
Effective	67.4	91.7	60.0	12.2	48.3	56.7

Male

Age	1992	1993	1994	1995	1996	1997
1	0	0.00045	0	0	0	0
2	0.025372	0.030167	0.003552	0	0	0.010061
3	0.204687	0.163284	0.061237	0.001606	0.026813	0.159378
4	0.214512	0.201056	0.214926	0.001071	0.110157	0.206595
5	0.162063	0.123778	0.196477	0.091304	0.16295	0.257626
6	0.263157	0.132261	0.206479	0.106205	0.16507	0.099352
7	0.035437	0.149171	0.158128	0.174493	0.20797	0.097716
8	0.071513	0.056434	0.036617	0.155482	0.108101	0.02822
9	0.02326	0.096027	0.090452	0.230503	0.136314	0.057815
10	0	0.026822	0.023165	0.075191	0.065014	0.013394
11	0	0.015394	0.005928	0.068833	0	0.00859
12	0	0	0.003038	0.078303	0.017612	0.035799
13	0	0.005156	0	0.017009	0	0.006702
14	0	0	0	0	0	0.018752
Actual	78	196	222	64	117	288
Effective	14.6	34.0	20.1	9.0	35.8	22.7

Table 9. Lingcod recreational length composition by sex, length class, and year. Actual refers to actual sample size and Effective refers to effective sample size estimated in the base model.

Female

Length	1992	1993	1994	1995	1996	1997
200	0	0	0	0	0.00241	0
400	0	0	0	0	0	0
440	0.003984	0.007937	0	0	0.00241	0
480	0	0.015873	0.0125	0	0.014458	0
520	0.091633	0.103175	0.10625	0.028061	0.086747	0.054983
560	0.155378	0.162698	0.1125	0.178571	0.146988	0.151203
600	0.155378	0.146825	0.1375	0.232143	0.103614	0.161512
640	0.143426	0.123016	0.14375	0.191327	0.127711	0.154639
680	0.179283	0.123016	0.16875	0.09949	0.159036	0.120275
720	0.115538	0.142857	0.10625	0.117347	0.151807	0.178694
760	0.063745	0.079365	0.0625	0.068878	0.084337	0.082474
800	0.031873	0.027778	0.05	0.033163	0.053012	0.041237
840	0.035857	0.015873	0.05	0.022959	0.043373	0.030928
880	0.003984	0.039683	0.04375	0.010204	0.016867	0.020619
920	0.007968	0.007937	0	0.017857	0.00241	0.003436
960	0.003984	0.003968	0.00625	0	0.00241	0
1000	0.007968	0	0	0	0.00241	0
1040	0	0	0	0	0	0
1080	0	0	0	0	0	0
1200	0	0	0	0	0	0
Actual	251	504	160	392	415	291
Effective	131.5	82.4	103.0	23.6	54.2	40.7

Male

Length	1992	1993	1994	1995	1996	1997
200	0	0	0	0.002525	0	0
400	0.010563	0	0	0	0	0
440	0.03169	0.014286	0.020408	0	0.003226	0
480	0.03169	0.1	0.091837	0.012626	0.019355	0.014035
520	0.246479	0.2	0.295918	0.260101	0.145161	0.214035
560	0.330986	0.242857	0.22449	0.376263	0.3	0.315789
600	0.204225	0.264286	0.163265	0.166667	0.254839	0.235088
640	0.073944	0.121429	0.132653	0.090909	0.183871	0.150877
680	0.045775	0.035714	0.071429	0.060606	0.06129	0.045614
720	0.017606	0.014286	0	0.020202	0.032258	0.021053
760	0.003521	0	0	0.007576	0	0.003509
800	0.003521	0	0	0.002525	0	0
840	0	0	0	0	0	0
880	0	0	0	0	0	0
920	0	0.007143	0	0	0	0
960	0	0	0	0	0	0
1000	0	0	0	0	0	0
1040	0	0	0	0	0	0
1080	0	0	0	0	0	0
1200	0	0	0	0	0	0
Actual	284	280	98	396	310	285
Effective	20.4	31.6	16.4	8.2	16.2	9.3

Table 10. Lingcod recreational age composition by sex, age class and year. Actual refers to actual sample size and Effective refers to effective sample size estimated in the base model.

Female

Age	1992	1993	1994	1995	1996	1997
1	0	0	0	0	0	0
2	0	0	0	0	0.002433	0
3	0	0.004566	0	0	0.007299	0.016129
4	0	0.127854	0.056738	0.05305	0.121655	0.060484
5	0.2	0.173516	0.191489	0.278515	0.201946	0.157258
6	0.133333	0.173516	0.177305	0.289125	0.294404	0.245968
7	0.2	0.228311	0.191489	0.164456	0.172749	0.274194
8	0.333333	0.136986	0.191489	0.108753	0.099757	0.149194
9	0.133333	0.082192	0.078014	0.061008	0.051095	0.056452
10	0	0.045662	0.056738	0.03183	0.026764	0.032258
11	0	0.013699	0.035461	0.01061	0.017032	0.004032
12	0	0.004566	0.007092	0.002653	0.002433	0
13	0	0	0.014184	0	0.002433	0
14	0	0.009132	0	0	0	0.004032
Actual	45	438	141	371	411	248
Effective	4.5	12.5	11.7	11.8	24.7	17.3

Male

Age	1992	1993	1994	1995	1996	1997
1	0	0	0	0	0	0
2	0	0	0	0.002584	0	0
3	0.104167	0.02439	0	0	0.003247	0.003968
4	0.041667	0.113821	0.031579	0.049096	0.097403	0.075397
5	0.229167	0.243902	0.2	0.271318	0.266234	0.210317
6	0.166667	0.260163	0.221053	0.315245	0.324675	0.305556
7	0.125	0.178862	0.273684	0.155039	0.181818	0.277778
8	0.208333	0.081301	0.147368	0.085271	0.081169	0.099206
9	0.083333	0.04878	0.084211	0.036176	0.019481	0.02381
10	0.020833	0.04065	0.031579	0.033592	0.022727	0.003968
11	0	0	0.010526	0.028424	0.003247	0
12	0	0.00813	0	0.015504	0	0
13	0.020833	0	0	0.005168	0	0
14	0	0	0	0.002584	0	
Actual	48	248	95	387	308	252
Effective	13.0	11.8	8.5	10.7	12.6	12.4

Table 11. NMFS triennial survey swept area biomass estimates (mt) and variances for the Eureka, Monterey, and Conception INPFC areas during 1977 to 1998.

	Eureka		Monterey		Conception	
Year	Biomass (mt)	Var	Biomass (mt)	Var	Biomass (mt)	Var
1977	274	1.10E+04	1800	4.35E+05	69	3.48E+02
1980	431	5.56E+04	671	4.54E+04		
1983	494	3.55E+04	1467	3.88E+05		
1986	316	7.54E+03	611	3.21E+04		
1989	473	2.14E+04	2107	2.58E+05	54	4.85E+02
1992	148	2.39E+08	484	2.09E+04	27	1.28E+02
1995	179	7.28E+08	703	5.90E+04	42	1.73E+02
1998	219	6.67E+03	651	4.97E+04	34	1.68E+08

Table 12. California Trawl Logbook CPUE index state-wide over the period 1978 to 1996 with calculated SE, and 10% Coefficients of Variation SE.

Year	Trawl CPUE	Trawl SE	10%CV SE
1978	46.02	0.903322	4.602
1979	50.15	0.780532	5.015
1980	46.29	0.792774	4.629
1981	50.15	0.769948	5.015
1982	48.31	0.835294	4.831
1983	31.31	0.642455	3.131
1984	26.5	0.50837	2.65
1985	15.87	0.309447	1.587
1986	18.5	0.447729	1.85
1987	27.56	0.595972	2.756
1988	26.4	0.556468	2.64
1989	29.83	0.592482	2.983
1990	30.46	0.692171	3.046
1991	22.96	0.478676	2.296
1992	18.89	0.410415	1.889
1993	20.97	0.483905	2.097
1994	21.73	0.540509	2.173
1995	21.61	0.552615	2.161
1996	17.06	0.422863	1.706

Table 13. MRFSS CPUE index (lingcod caught per 1,000 angler trips) and CDF&G Commercial Passenger Fishing Vessel (CPFV) CPUE index (lingcod/angler day) over years. The CDF&G index is for Northern and Central California CPFV and was supplied by Tom Barnes (CDF&G).

Year		MRFSS	CDF&G
1980		94.4	0.3777
1981		83.9	0.2767
1982		63.5	0.2078
1983		45	0.1844
1984		39.4	0.1447
1985		60	0.1932
1986		66.4	0.2971
1987		79.4	0.3739
1988		71.9	0.4372
1989		82.3	0.3016
1990			0.2815
1991			0.2923
1992			0.2841
1993		72.3	0.2462
1994		48.5	0.2346
1995		53.9	0.2846
1996		67.7	0.3235
1997		87.4	
1998		61.1	

Table 14: Lingcod estimates from the base model run ($M = 0.25$), standard deviations are in parentheses.

Year	Recruitment (age 1) (thousands)	Stock Biomass (age 3+) (mt)	Spawning Potential
1973	2810 (216)	11100 (2060)	56.6 (17.5)
1974	2810 (216)	11100 (2060)	56.6 (17.5)
1975	2810 (216)	11100 (2060)	56.6 (17.5)
1976	2810 (216)	11100 (2060)	56.6 (17.5)
1977	2810 (216)	11100 (2060)	56.5 (17.5)
1978	2810 (216)	11100 (2060)	56.5 (17.5)
1979	2010 (1570)	11100 (2060)	56.5 (17.5)
1980	2130 (1420)	10700 (2060)	53.6 (17.1)
1981	1980 (1140)	9000 (1720)	42.6 (16.1)
1982	1540 (793)	7770 (1430)	34.5 (14.4)
1983	2190 (825)	6590 (1200)	26.6 (11.8)
1984	3680 (834)	5930 (1050)	23.5 (9.9)
1985	3710 (648)	5700 (890)	21.1 (8.2)
1986	2540 (419)	6110 (693)	17.8 (6.7)
1987	2980 (349)	7010 (517)	17.7 (5.5)
1988	2410 (254)	7100 (408)	18.2 (4.2)
1989	1850 (186)	7180 (332)	18.9 (3.1)
1990	1730 (169)	6670 (295)	17.8 (2.3)
1991	1630 (184)	6130 (299)	17.6 (1.8)
1992	1150 (169)	5740 (332)	17.9 (1.7)
1993	630 (124)	5430 (391)	18.1 (1.8)
1994	394 (101)	4930 (459)	17.8 (2.1)
1995	365 (116)	4380 (518)	18.1 (2.6)
1996	302 (142)	3600 (563)	16.9 (3.1)
1997	491 (265)	2850 (598)	14.7 (3.7)
1998	1440 (1040)	2070 (611)	10.9 (4.1)

Table 15. Status of southern lingcod spawning potential in 1998.

Relative Spawning Potential (1998/Unfished)	**Probability of being less**	**Probability of being greater**
40%	0.98	0.02
25%	0.94	0.06
10%	0.64	0.36
7.5%	0.50	0.50

Table 16. Parameter estimates with associated error estimates for the southern lingcod base model run (M=0.25).

Parameter Description	Estimate	Standard Deviation	Coefficient of Variation	Parameter Description	Estimate	Standard Deviation	Coefficient of Variation
Ln (Average Recruitment)	4.974	0.087	1.8%	Average Fishing Fraction	0.349	0.205	58.7%
Ln (Recruitment Deviation) for 1973-78	0.665	0.131	19.7%	Fishing Fraction Deviation for 1973-78	0.892	0.180	20.2%
Ln (Recruitment Deviation) for 1979	0.331	0.758	228.9%	Fishing Fraction Deviation for 1979	0.624	0.195	31.3%
Ln (Recruitment Deviation) for 1980	0.388	0.660	170.0%	Fishing Fraction Deviation for 1980	-0.042	0.257	607.6%
Ln (Recruitment Deviation) for 1981	0.313	0.578	185.0%	Fishing Fraction Deviation for 1981	-0.065	0.274	421.5%
Ln (Recruitment Deviation) for 1982	0.062	0.513	831.8%	Fishing Fraction Deviation for 1982	-0.304	0.295	97.0%
Ln (Recruitment Deviation) for 1983	0.415	0.387	93.4%	Fishing Fraction Deviation for 1983	0.014	0.241	1721.4%
Ln (Recruitment Deviation) for 1984	0.934	0.254	27.1%	Fishing Fraction Deviation for 1984	-0.003	0.232	8656.7%
Ln (Recruitment Deviation) for 1985	0.943	0.201	21.3%	Fishing Fraction Deviation for 1985	-0.292	0.255	87.3%
Ln (Recruitment Deviation) for 1986	0.562	0.185	32.9%	Fishing Fraction Deviation for 1986	-0.046	0.194	419.0%
Ln (Recruitment Deviation) for 1987	0.722	0.142	19.6%	Fishing Fraction Deviation for 1987	-0.181	0.173	95.6%
Ln (Recruitment Deviation) for 1988	0.510	0.126	24.8%	Fishing Fraction Deviation for 1988	-0.213	0.173	81.2%
Ln (Recruitment Deviation) for 1989	0.248	0.115	46.6%	Fishing Fraction Deviation for 1989	-0.479	0.177	37.0%
Ln (Recruitment Deviation) for 1990	0.177	0.106	59.8%	Fishing Fraction Deviation for 1990	-0.309	0.174	56.3%
Ln (Recruitment Deviation) for 1991	0.121	0.108	89.7%	Fishing Fraction Deviation for 1991	-0.117	0.170	145.3%
Ln (Recruitment Deviation) for 1992	-0.232	0.131	56.4%	Fishing Fraction Deviation for 1992	0.013	0.163	1273.4%
Ln (Recruitment Deviation) for 1993	-0.831	0.172	20.7%	Fishing Fraction Deviation for 1993	0.042	0.157	375.6%
Ln (Recruitment Deviation) for 1994	-1.299	0.227	17.4%	Fishing Fraction Deviation for 1994	0.279	0.152	54.5%
Ln (Recruitment Deviation) for 1995	-1.377	0.285	20.7%	Fishing Fraction Deviation for 1995	0.151	0.160	106.0%
Ln (Recruitment Deviation) for 1996	-1.566	0.434	27.7%	Fishing Fraction Deviation for 1996	0.070	0.198	282.1%
Ln (Recruitment Deviation) for 1997	-1.080	0.501	46.4%	Fishing Fraction Deviation for 1997	-0.278	0.328	118.0%
Ln (Recruitment Deviation) for 1998	-0.005	0.687	15234.0%	Fishing Fraction Deviation for 1998	0.244	0.387	158.6%
Logistic Selectivity, Slope, Female, Trawl	0.026	0.005	18.8%	Catchability for Triennial Trawl Survey	0.092	7.600	8234.0%
Logistic Selectivity, Slope, Male, Trawl	0.033	0.007	20.3%	Catchability for Trawl Logbook CPUE	0.005	0.003	59.2%
Logistic Selectivity, L50, Female, Trawl	526	15.8	3.0%	Catchability for MRFSS Index	0.352	1.180	335.2%
Logistic Selectivity, L50, Male, Trawl	487	11.3	2.3%				
Logistic Selectivity, Slope, Female, Recreational	0.0895	0.0216	24.1%				
Logistic Selectivity, Slope, Male, Recreational	0.0559	0.0152	27.2%				
Logistic Selectivity, L50, Female, Recreational	512	4.74	0.9%				
Logistic Selectivity, L50, Male, Recreational	501	8.83	1.8%				

Table 17. Likelihood values, biomass, and spawning potential estimates from the model for various values of natural mortality, *M* (base model, *M* = 0.25) and jacknife deletions of each data set. Shaded values represent the best fit (lowest value) within the range of natural mortality.

							Jacknife Deletions				
Natural Mortality	**0.35**	**0.3**	**Base 0.25**	**0.2**	**0.15**	**0.1**	**-Trawl Ages**	**-Rec Ages**	**-Triennial**	**-Logbook CPUE**	**-MRFSS Index**
Trawl Length Compositions	804.9	804.9	805.1	805.4	805.9	806.5	797.9	804.8	805.1	805.1	805.1
Recreational Length Comps	1194.6	1192.8	1191.3	1190.1	1189.3	1188.7	1182.1	1184.8	1191.3	1191.3	1191.3
Trawl Age Compositions	1045.7	1043.7	1041.7	1039.7	1037.8	1036.2		1047.2	1041.7	1041.7	1041.7
Recreational Age Comps	323.5	322.4	321.3	320.3	319.3	318.4	329.7		321.3	321.3	321.3
Landings	42.6	42.6	42.6	42.6	42.5	42.5	42.9	43.2	42.6	42.6	42.6
Triennial Survey	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6		45.6	45.6
Trawl Logbook CPUE	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3		13.3
MRFSS Index	48.1	48.1	48.1	48.1	48.1	48.1	48.1	48.1	48.1	48.1	
Total	3518.3	3513.4	3508.9	3505.0	3501.8	3499.3	2459.5	3186.9	3463.3	3495.6	3460.8
Age 3+ Biomass (1973)	13564.2	12152.7	11085.4	10247.1	9568.3	9001.8	11735.7	11484.5	11085.4	11086.6	11084.5
Age 3+ Biomass (1998)	2399.6	2194.0	2070.4	2001.0	1970.1	1968.0	3516.3	2569.1	2070.4	2067.6	2069.8
Ratio (1998/1973)	17.7%	18.1%	18.7%	19.5%	20.6%	21.9%	30.0%	22.4%	18.7%	18.6%	18.7%
Spawning Potential (1973)	59.5	57.3	56.6	56.8	57.6	58.8	62.4	60.3	56.6	56.6	56.6
Spawning Potential (1998)	13.4	11.9	10.9	10.3	10.0	9.9	18.6	13.5	10.9	10.9	10.9
Ratio (1998/1973)	22.6%	20.7%	19.3%	18.2%	17.4%	16.8%	29.8%	22.5%	19.3%	19.2%	19.3%

Table 18. Summary statistics from a stochastic projection of southern lingcod stock biomass (Age 3+), spawning potential, and total landings 10 years into the future.

		Spawning Potential			Stock Biomass (mt)			Landings (mt)		
	Year	Lower 95%	Mean	Upper 95%	Lower 95%	Mean	Upper 95%	Lower 95%	Mean	Upper 95%
F=0	2000	11.1	11.1	11.1	2503	2503	2503	0	0	0
	2001	13.5	13.6	13.9	2876	3485	4598	0	0	0
	2002	16.9	17.8	19.6	3438	4633	6521	0	0	0
	2004	26.4	32.3	41.9	4908	7058	10132	0	0	0
	2009	67.1	93.9	131.5	8469	11788	15981	0	0	0
F35%	2000	10.0	10.0	10.0	2363	2363	2363	175	177	181
	2001	11.0	11.2	11.4	2570	3176	4284	214	245	300
	2002	12.7	13.6	15.2	2924	4091	5912	247	329	463
	2004	17.3	22.1	29.7	3905	5822	8733	335	495	739
	2009	34.6	49.6	69.9	5860	8270	11477	513	737	1007
F40%	2000	10.1	10.1	10.2	2379	2379	2379	155	157	161
	2001	11.3	11.5	11.7	2605	3211	4320	192	219	268
	2002	13.1	14.0	15.6	2981	4151	5979	223	295	415
	2004	18.2	23.1	30.9	4005	5952	8892	305	449	669
	2009	37.5	53.4	75.4	6102	8597	11843	474	680	925
F45%	2000	10.2	10.2	10.3	2395	2395	2395	137	139	142
	2001	11.6	11.7	12.0	2638	3244	4353	171	194	237
	2002	13.6	14.5	16.1	3034	4207	6045	199	263	368
	2004	19.1	24.1	32.1	4101	6076	9022	275	403	600
	2009	40.2	57.2	80.6	6364	8920	12213	434	622	841

Figure 1. Lingcod population biomass (mt) trend from synthesis modeling for the Canada-Vancouver, US-Vancouver, and Columbia INPFC areas from the 1997 assessment (Jagielo et al. 1997). Pristine biomass was estimated at 54,544 mt and equilibrium biomass was estimated at 35,140 mt.

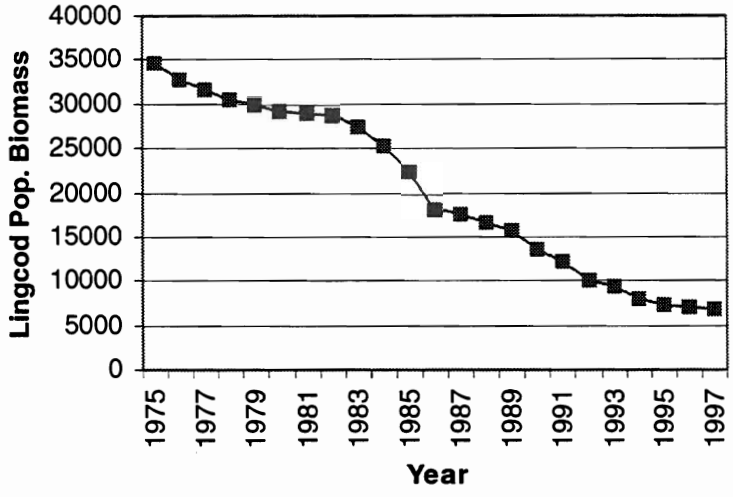


Figure 2. Assessment area covers the Eureka, Monterey, and Conception INPFC areas.

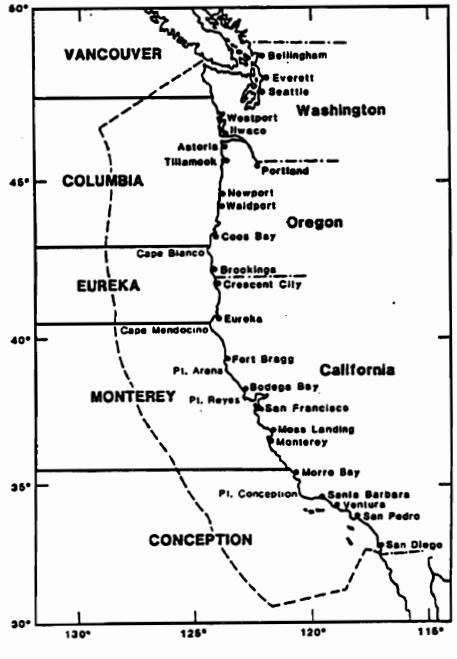


Figure 3. Lingcod length and age data from commercial and recreational landings from 1992 to 1997 and von Bertalanffy growth models fit for both females and males. The Estimate Length is from the Xiao (1994) model and the Corrected Estimate includes the first year size-at-age data from Jagielo et al. (1997).

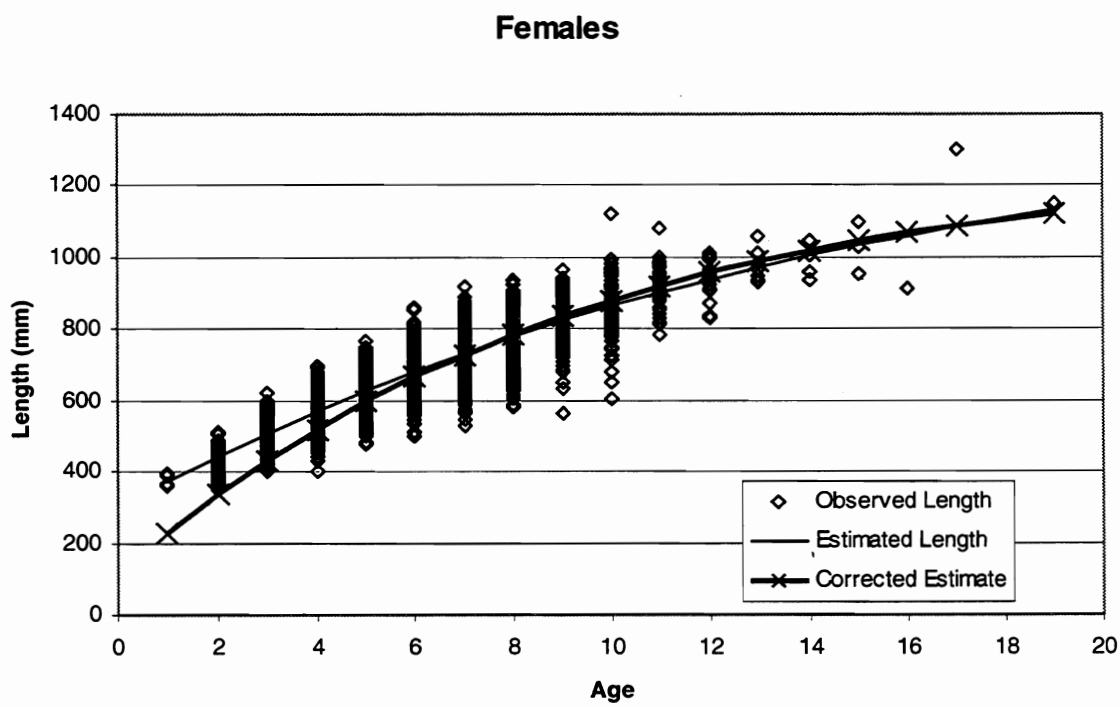
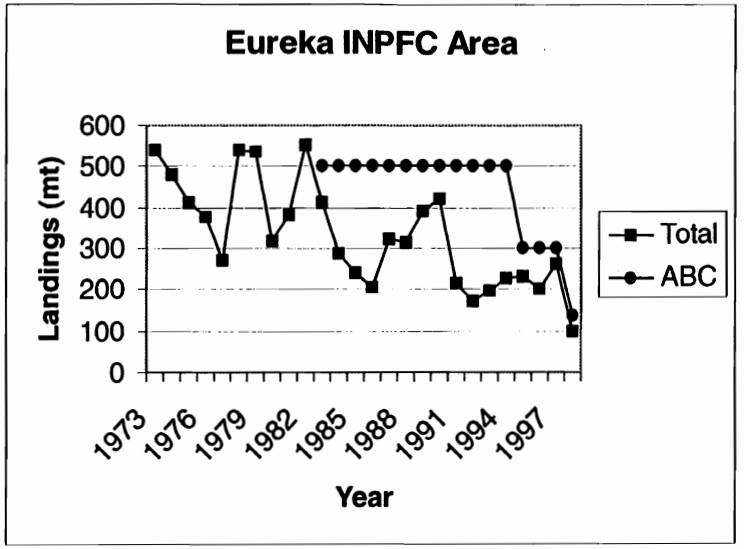
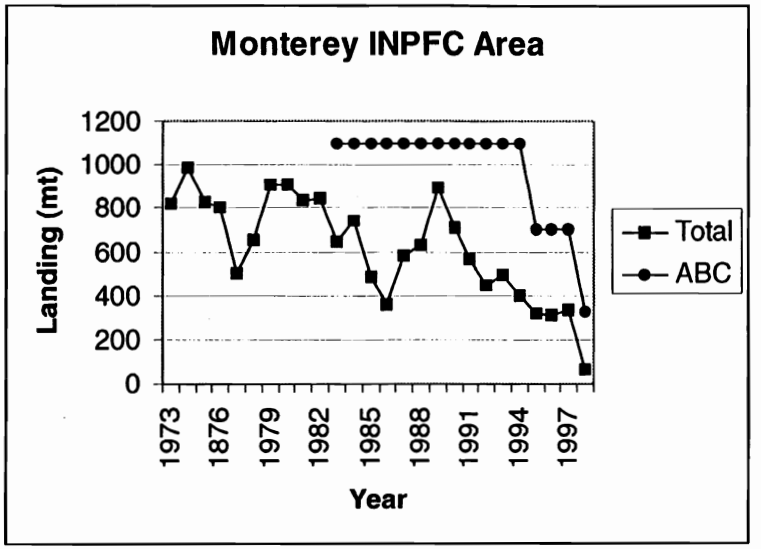
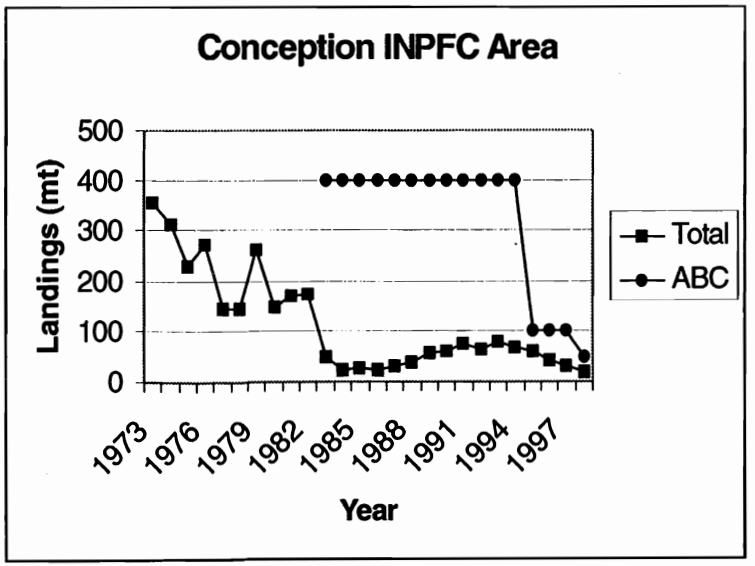


Figure 4. Total lingcod commercial landings and ABCs for Eureka, Monterey, and Conception INPFC area during the period 1973 to 1998.







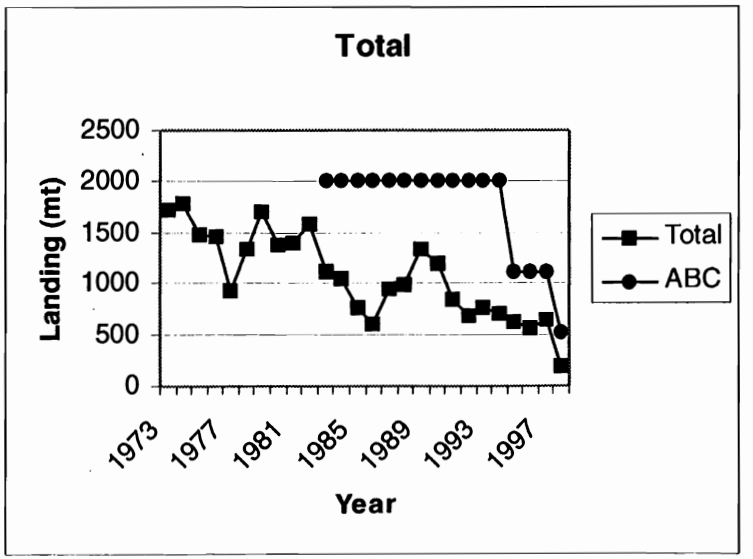


Figure 5. Marine Recreational Fishery Statistical Survey lingcod landings (mt) for the period from 1973 to 1998

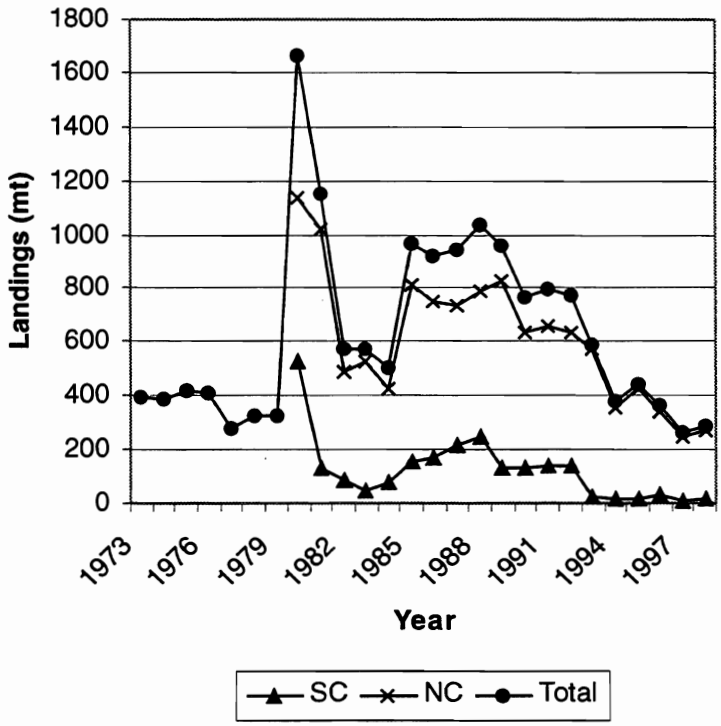
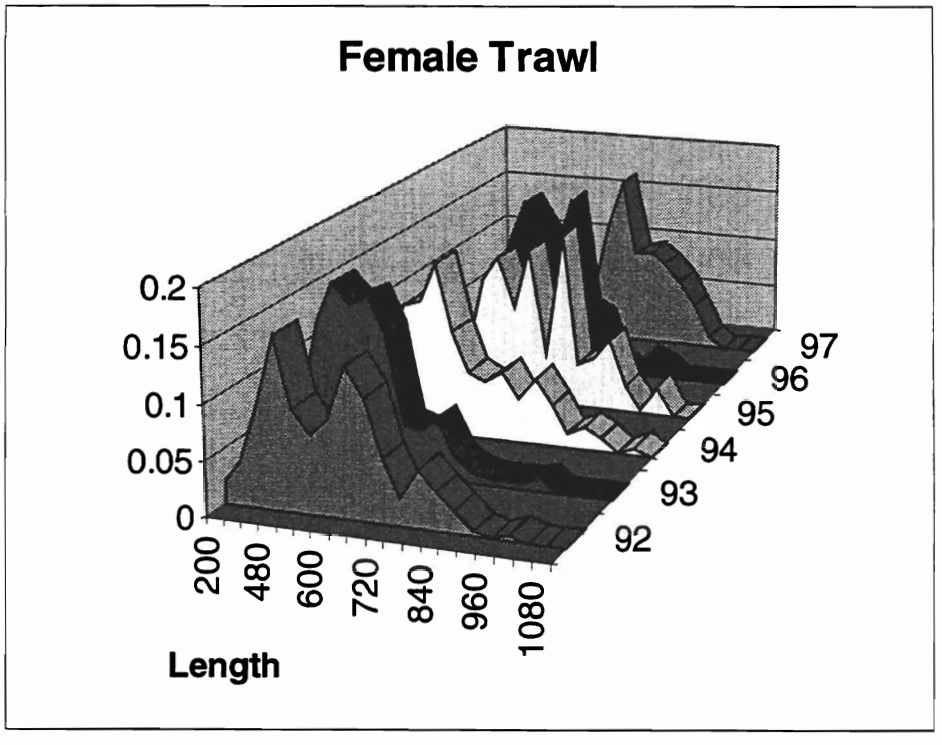


Figure 6. Lingcod length frequency of trawl samples from the Eureka, Monterey, and Conception INPFC areas, 1992-1997. Frequencies are weighted by sample landing weight.



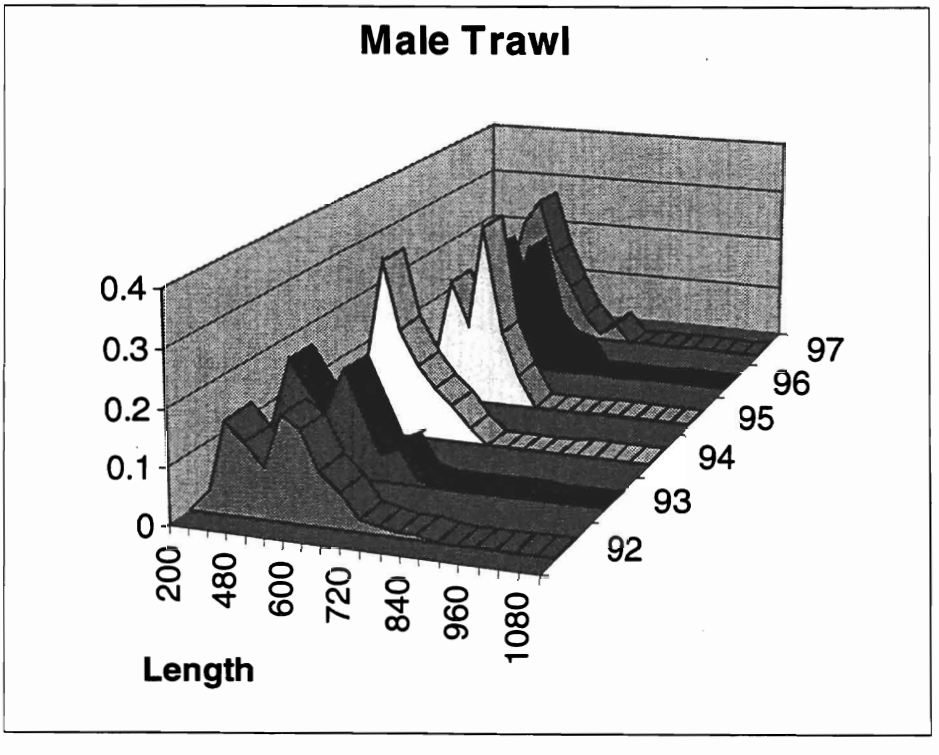
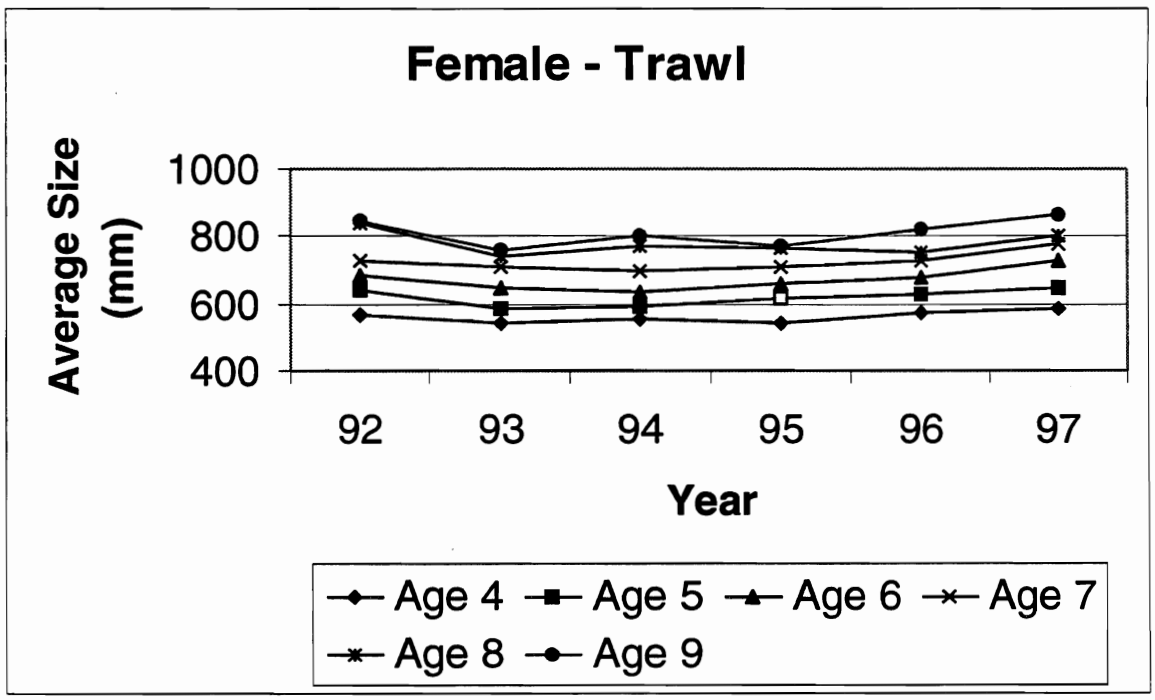


Figure 7. Female and male lingcod average size (mm) at age by year (1992-1997) from CDF&G trawl samples.



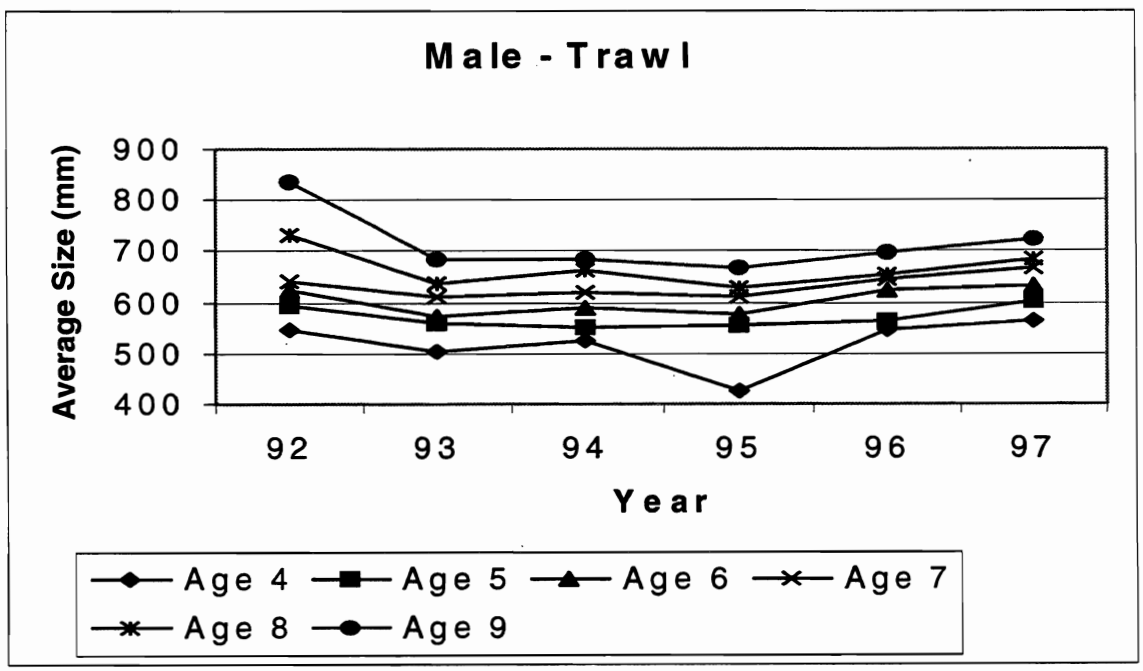
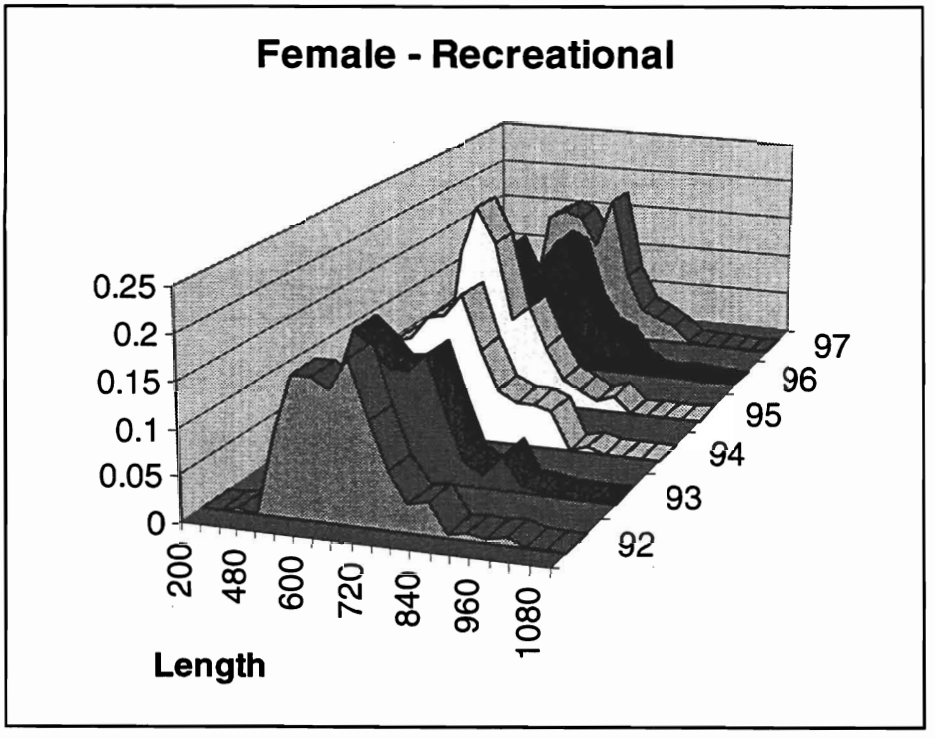


Figure 8. Lingcod length frequency of recreational samples from the Northern and Southern California, 1992-1997. Frequencies are individual fish.



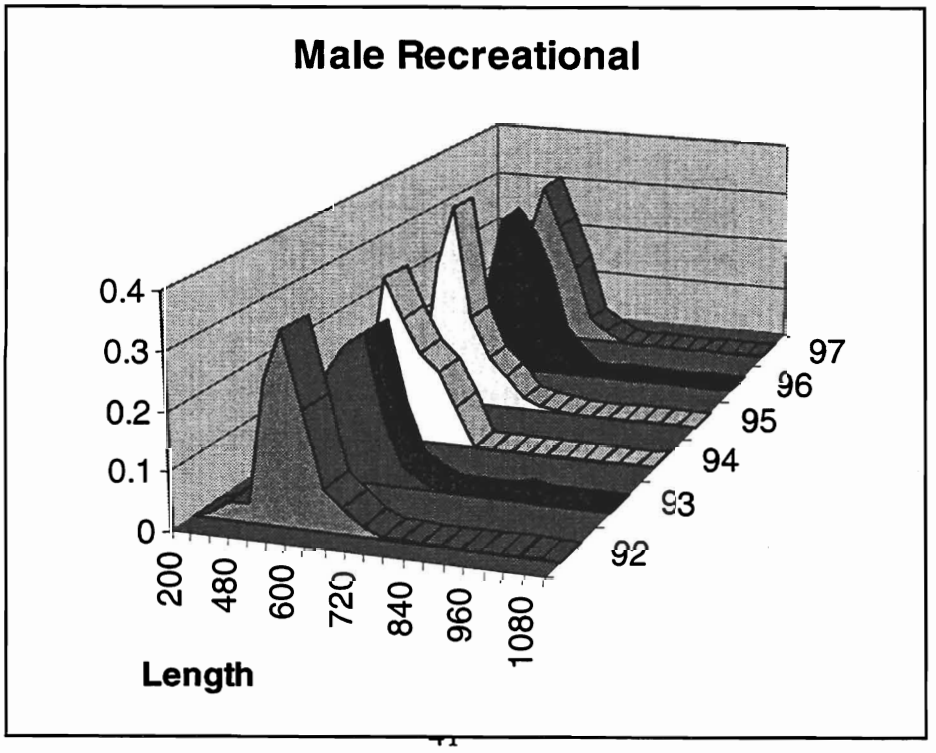
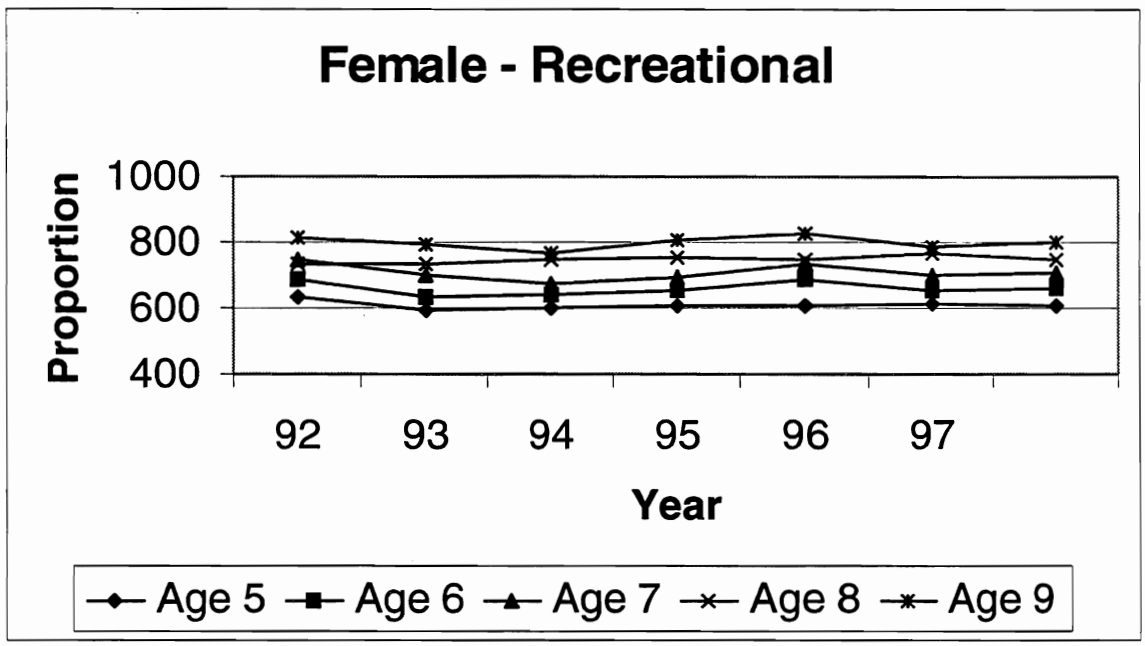


Figure 9. Female and male lingcod average size (mm) at age by year (1992-1997) from CDF&G recreational samples.



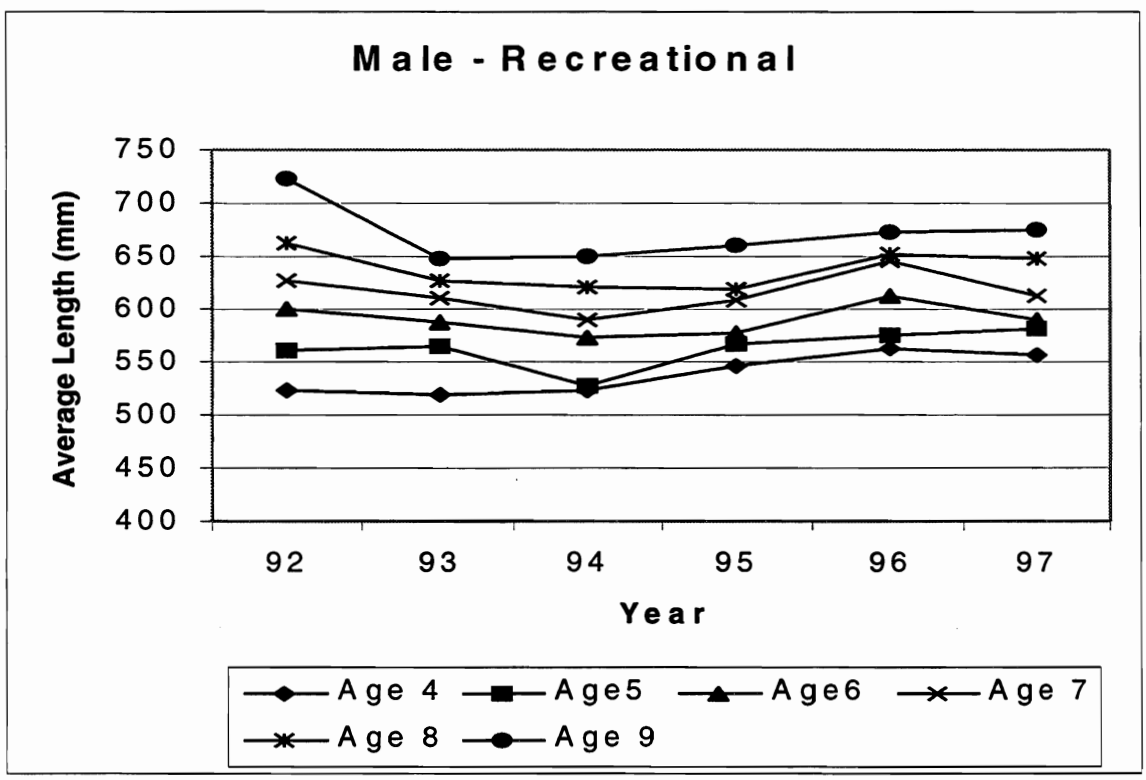


Figure 10. Comparison of MRFSS CPUE and CDF&G CPUE indices. The MRFSS CPUE index is number of lingcod per 1,000 angler trips and includes both the partyboat and skiff fishery throughout California. The CDF&G CPUE index is the number of lingcod per angler day and includes Northern and Central California partyboat catch. The MRFSS CPUE index is divided by 100 to scale it to the CDF&G index.

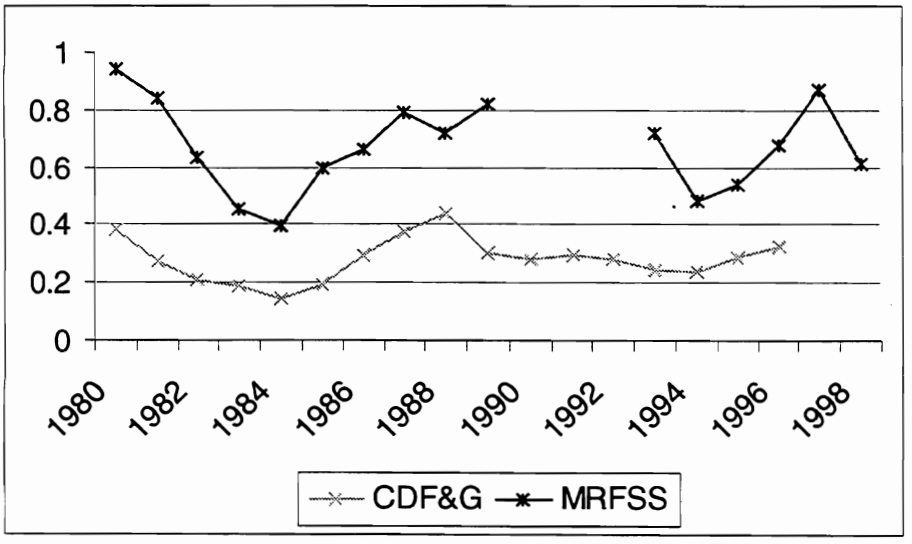


Figure 11. Base model estimates (M=0.25) for recruitment at (age 1) for years 1973-1998. Dotted lines represent 95% confidence intervals of model estimates.

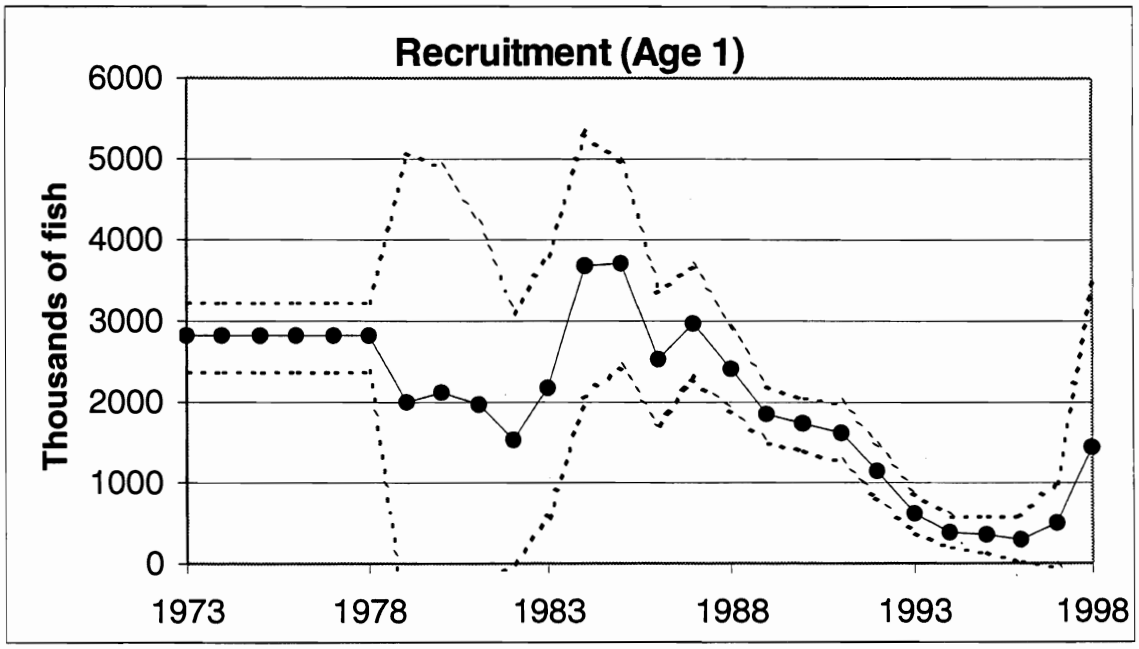
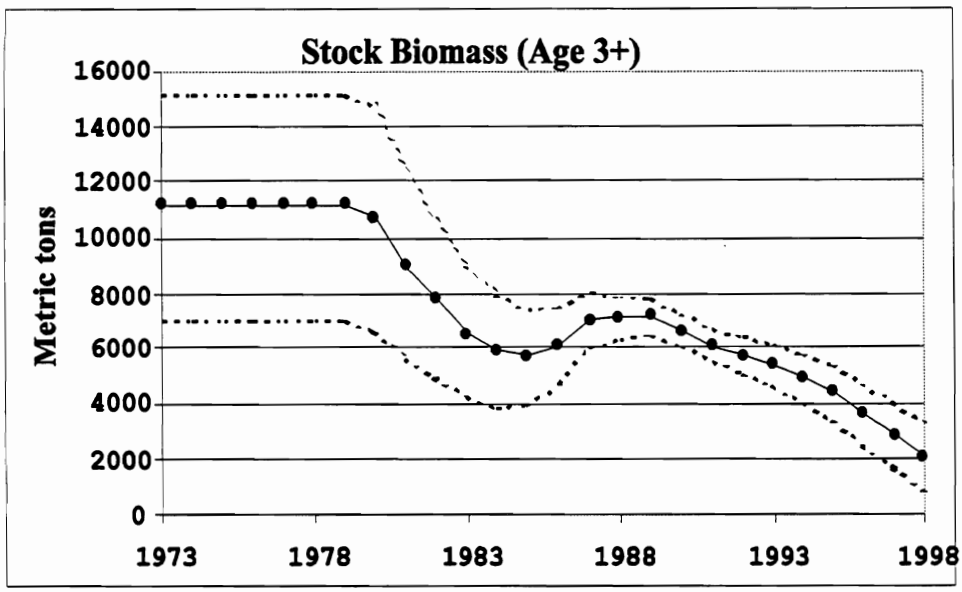


Figure 12. Base model estimates (M=0.25) for stock biomass (age 3+) and spawning potential for years 1973-1998. Dotted lines represent 95% confidence intervals of model estimates.



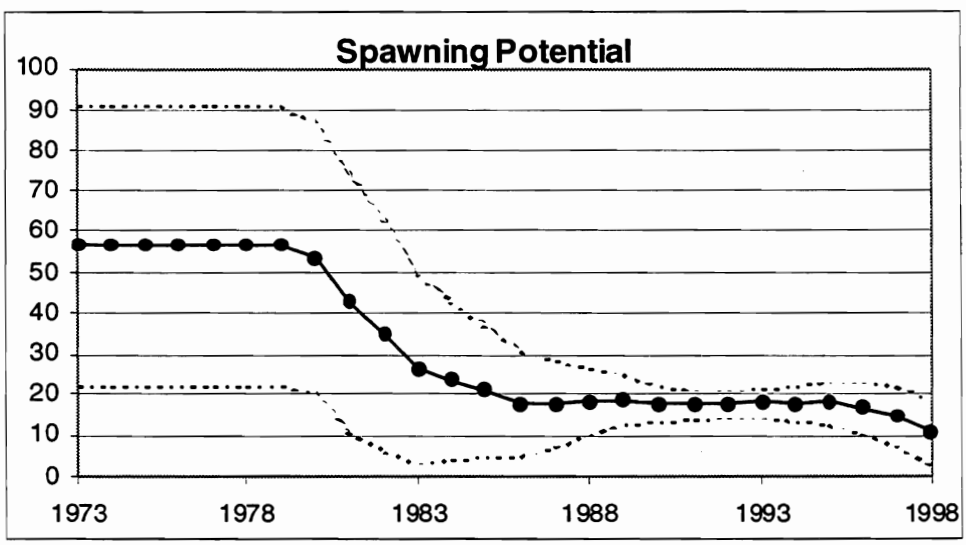
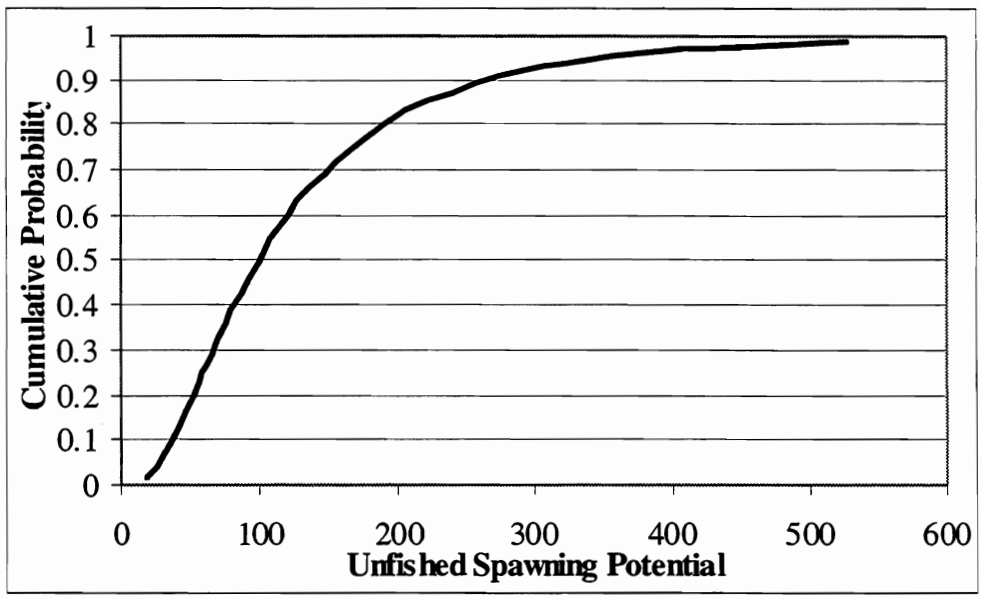


Figure 13. Estimates of unfished spawning potential and relative status for 1998 based on a lognormal distribution of model recruitment estimates. The 25% overfishing definition is indicated by a dotted line in the lower panel.



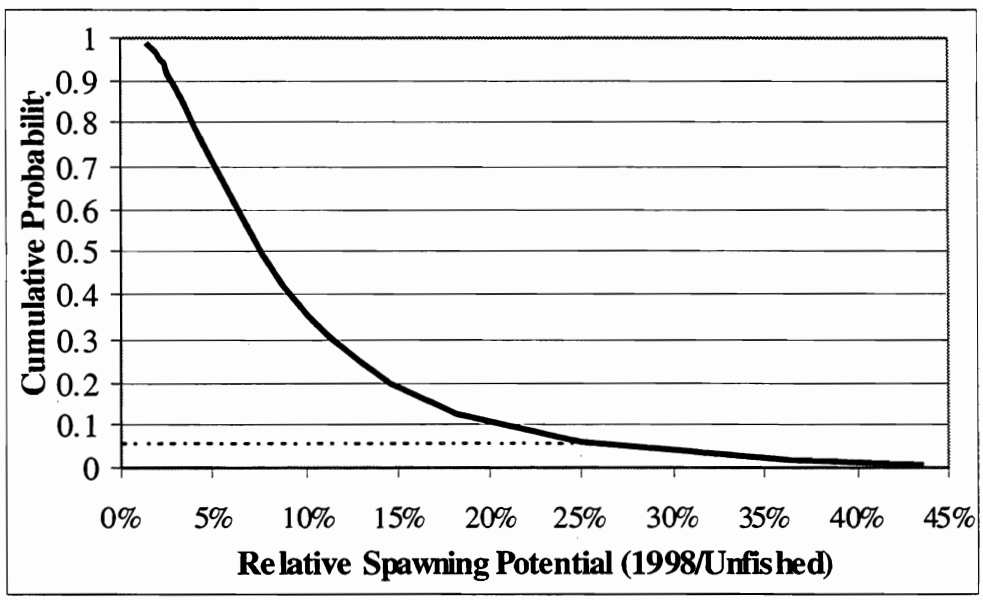
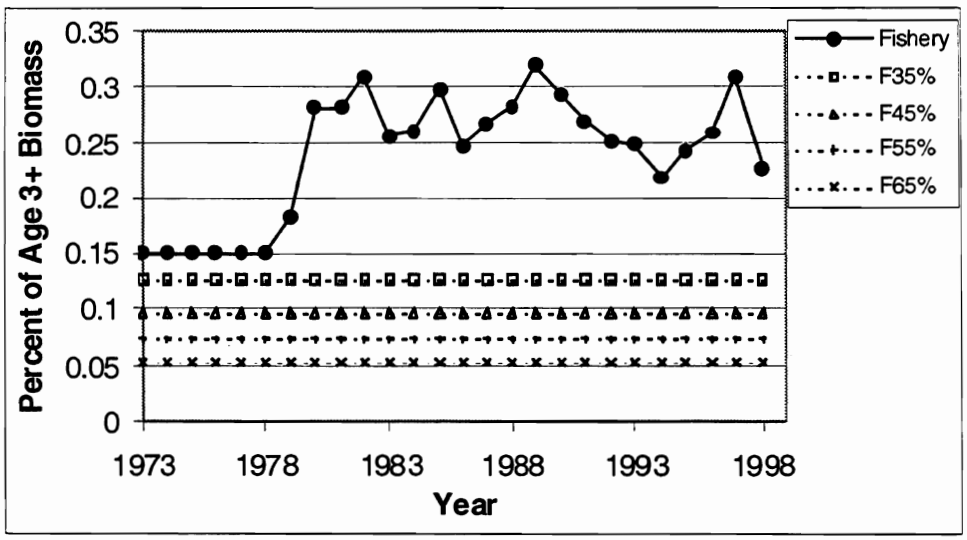


Figure 14. Exploitation rates for the combined fisheries relative to constant harvest rate policies (top panel) and exploitation rates for each fishery (bottom panel) for years 1973-1998.



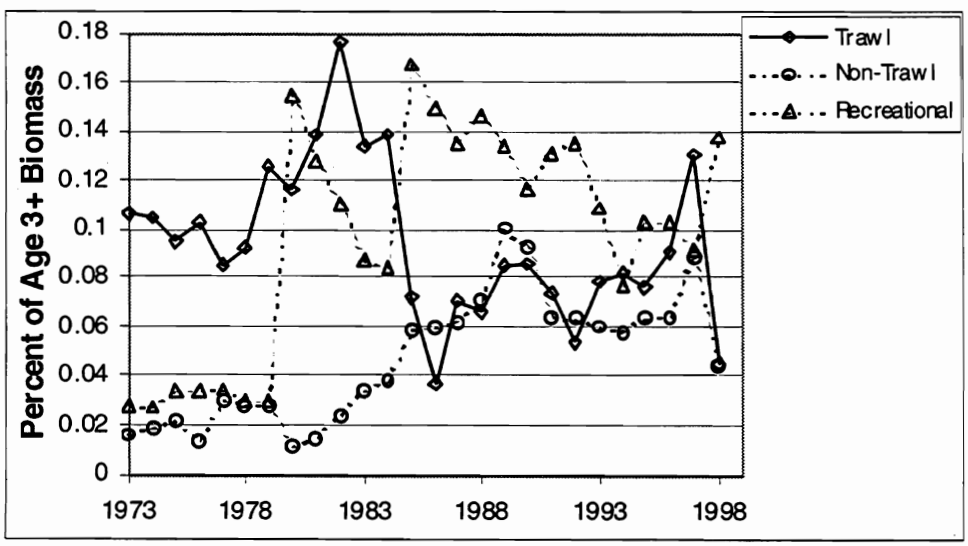


Figure 15. Observed and base model estimated fishery landings from the trawl, non-trawl, and recreational fisheries for southern lingcod.

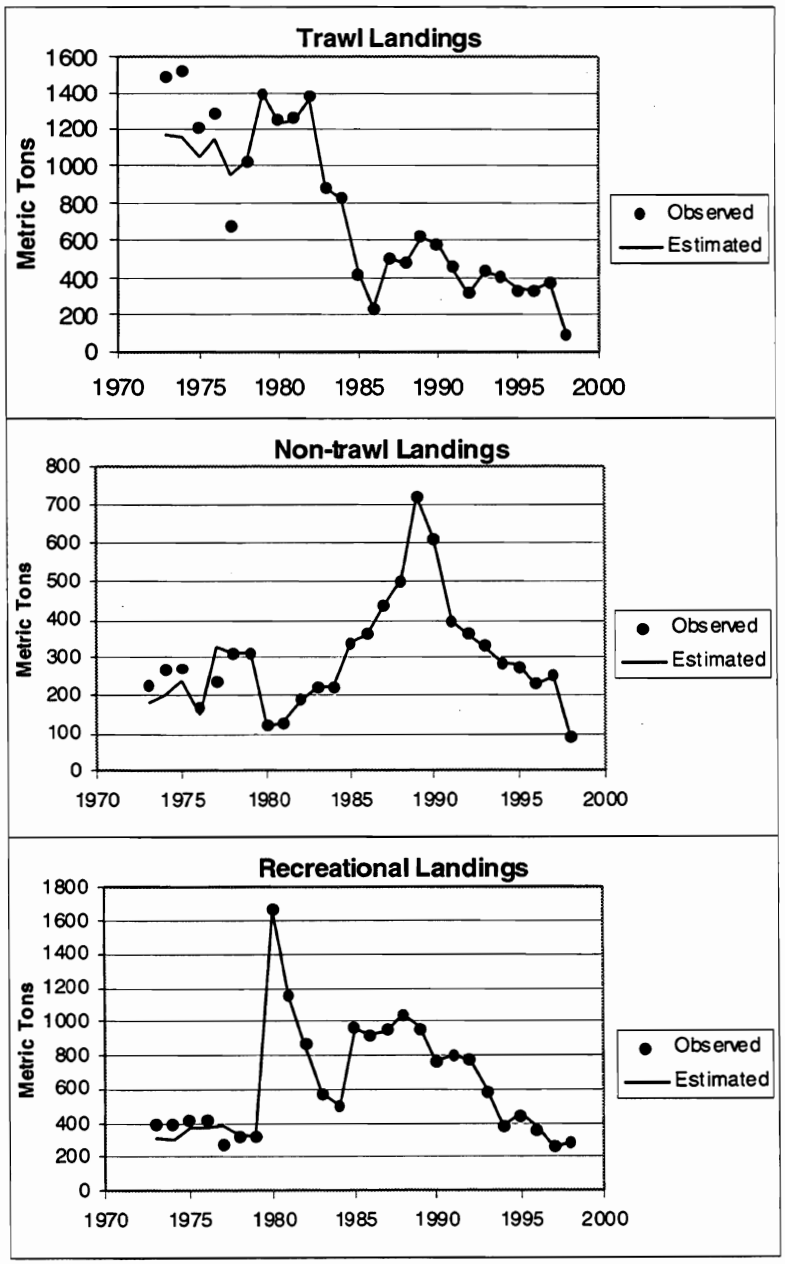


Figure 16. Base model (M=0.25) fit to the Alaska Fisheries Science Center triennial trawl survey.

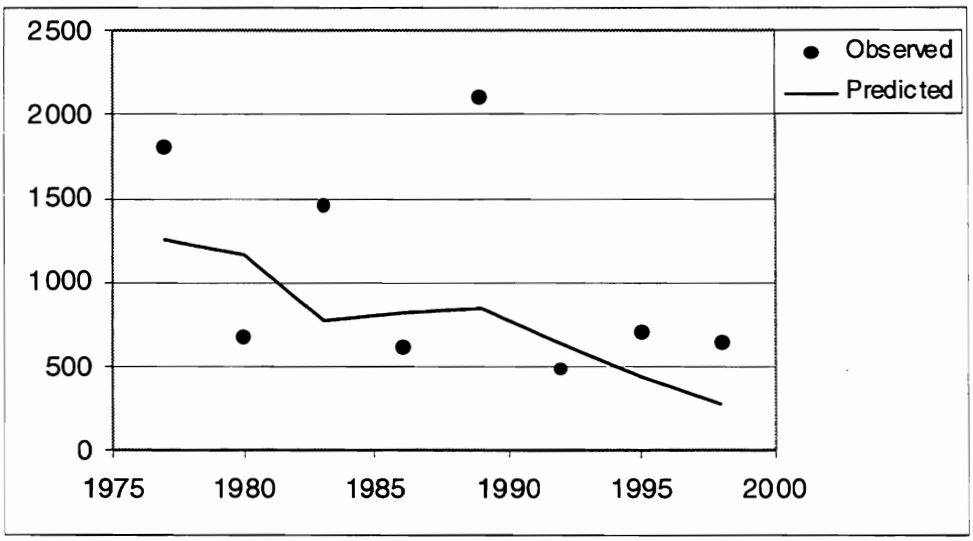
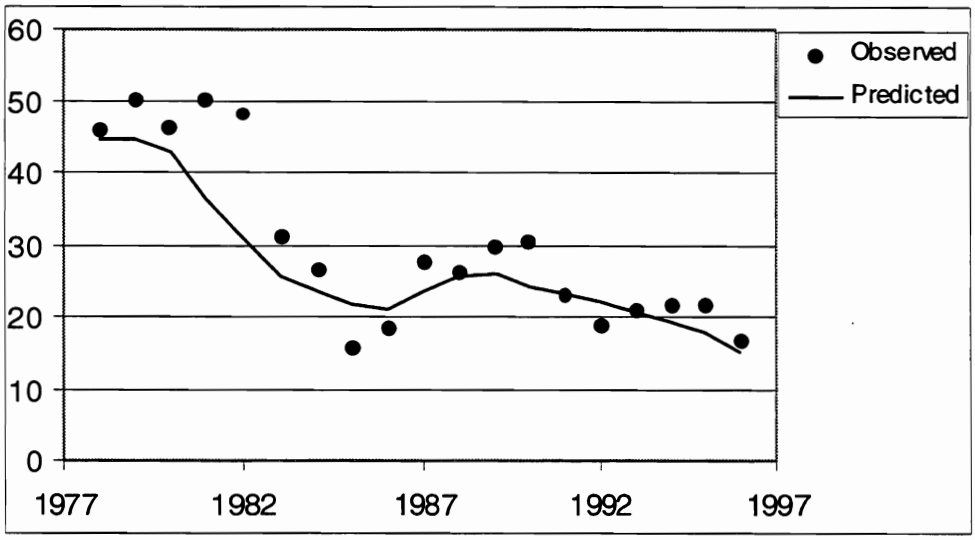


Figure 17. Base model (M=0.25) fit to the trawl logbook CPUE (top panel) and Marine Recreational Fisheries Statistics Survey (MRFSS)(bottom panel) indices.



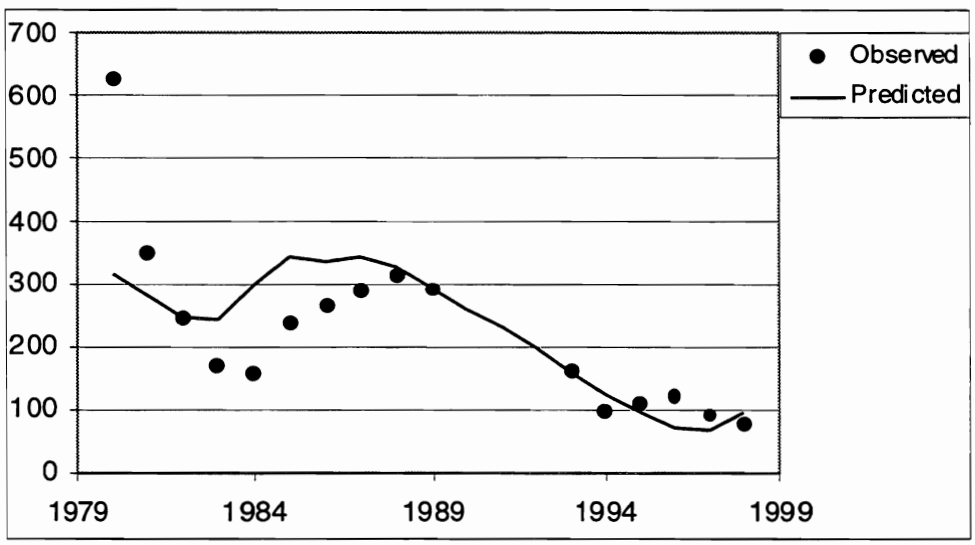
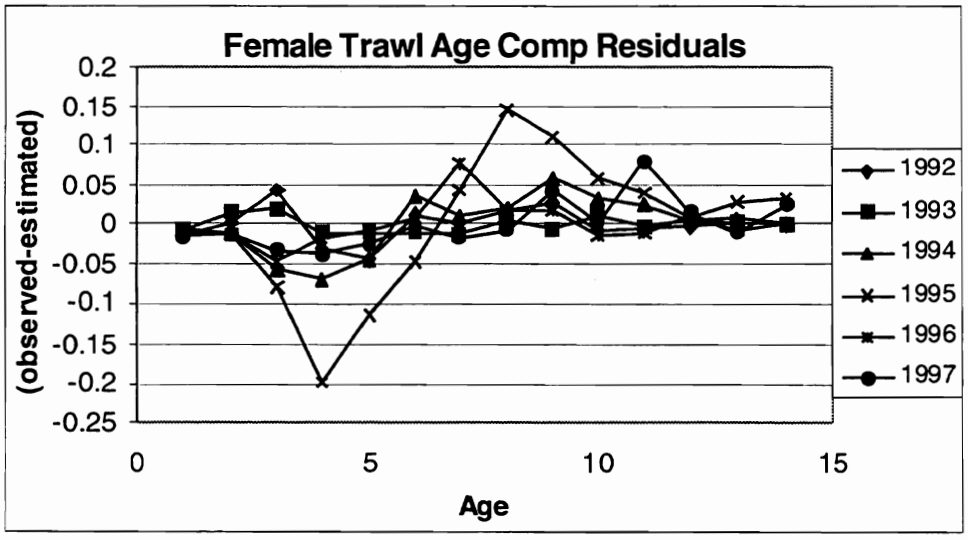


Figure 18. Female and male trawl age composition residuals from base model results.



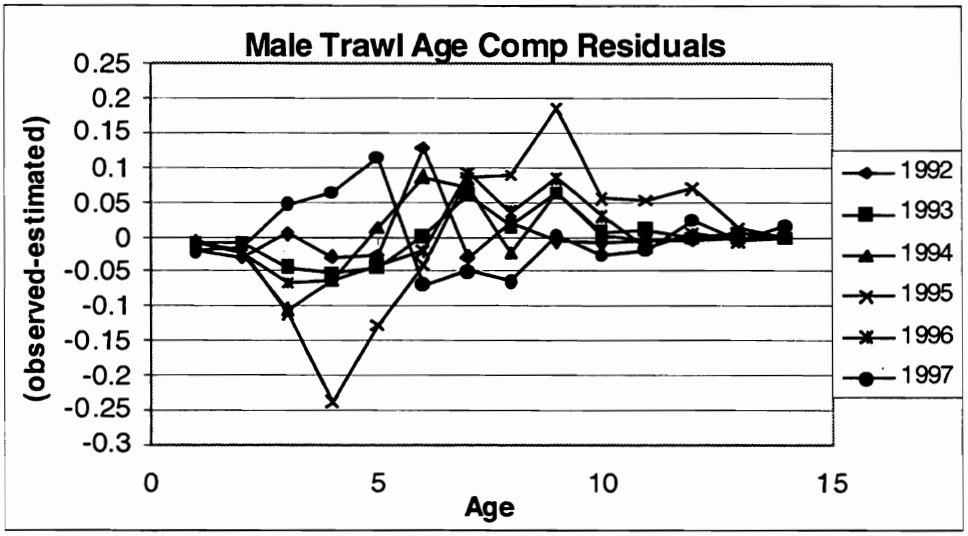
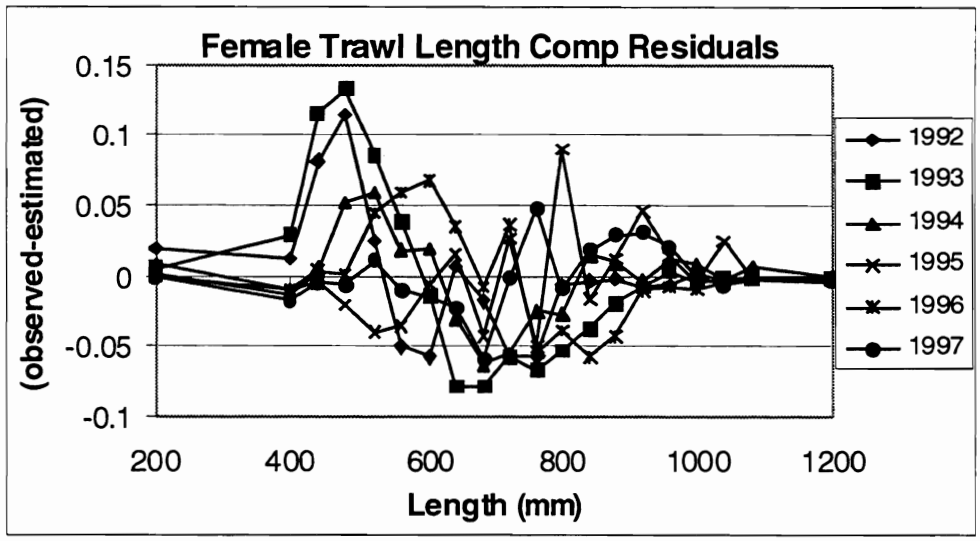


Figure 19. Female and male trawl length composition residuals from base model results.



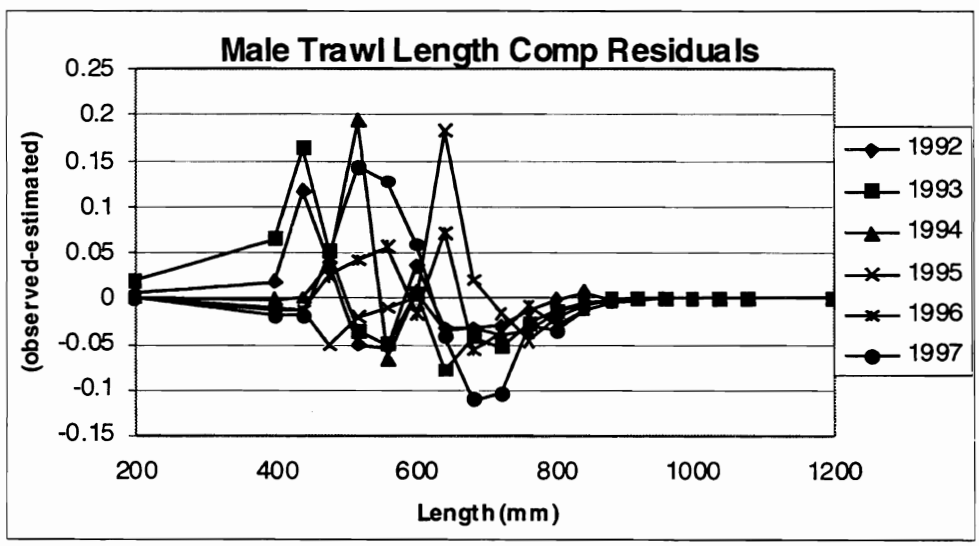
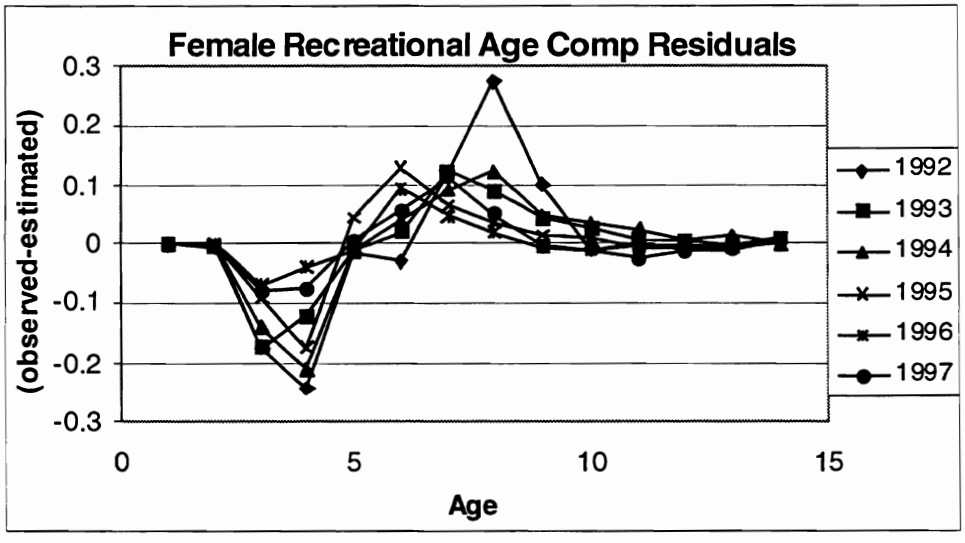


Figure 20. Female and male recreational age composition residuals from base model results.



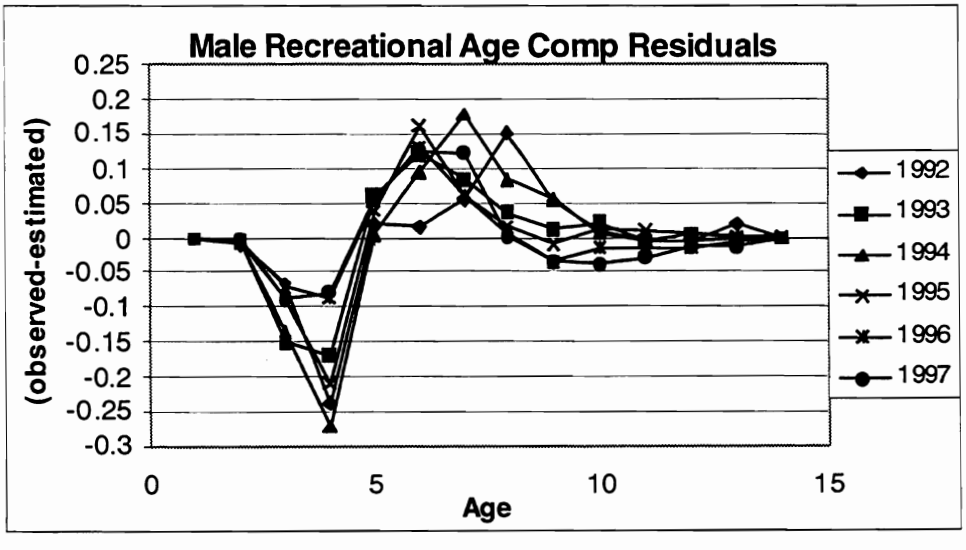
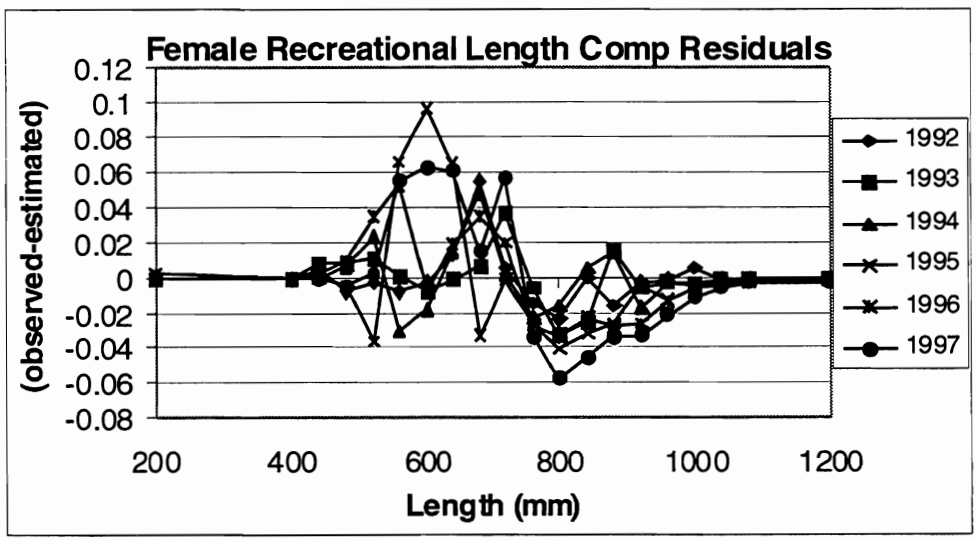


Figure 21. Female and male recreational length composition residuals from base model results.



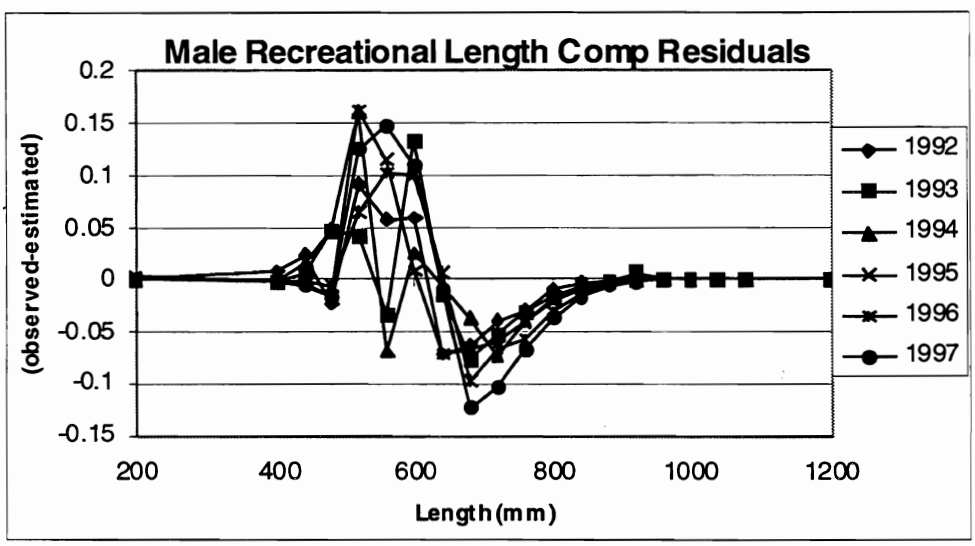
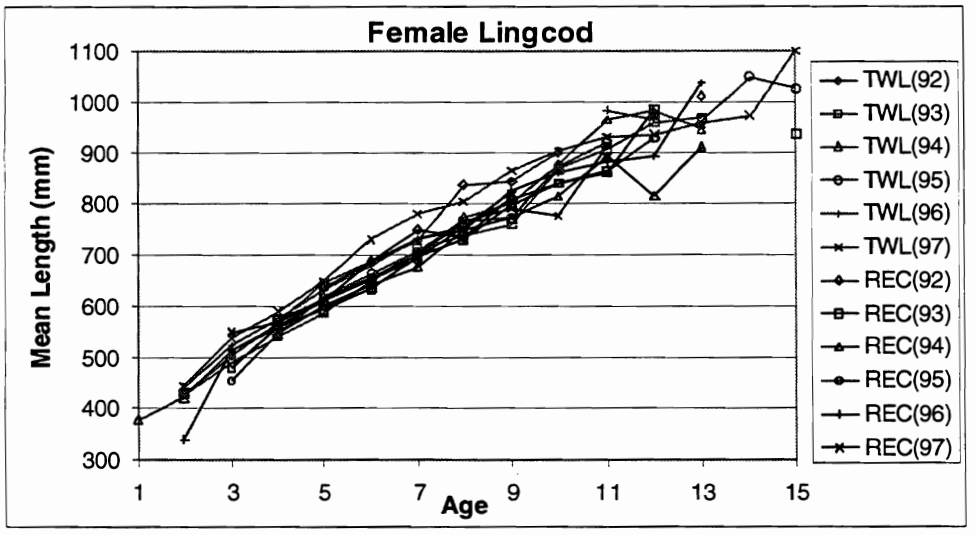


Figure 22. Female and male age-length data by year (parentheses) and fishery (TWL = trawl, REC = recreational) used in this model for growth function and composition computations.



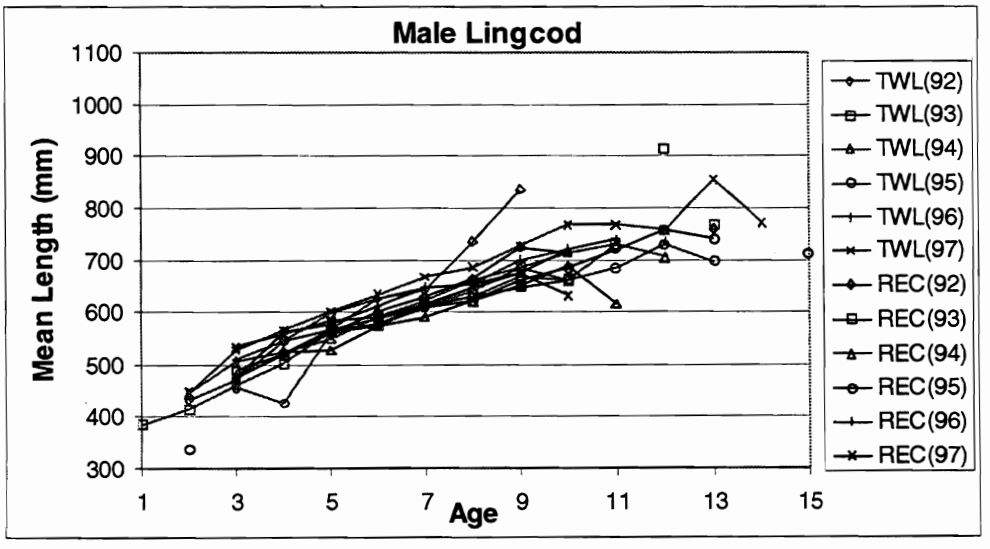
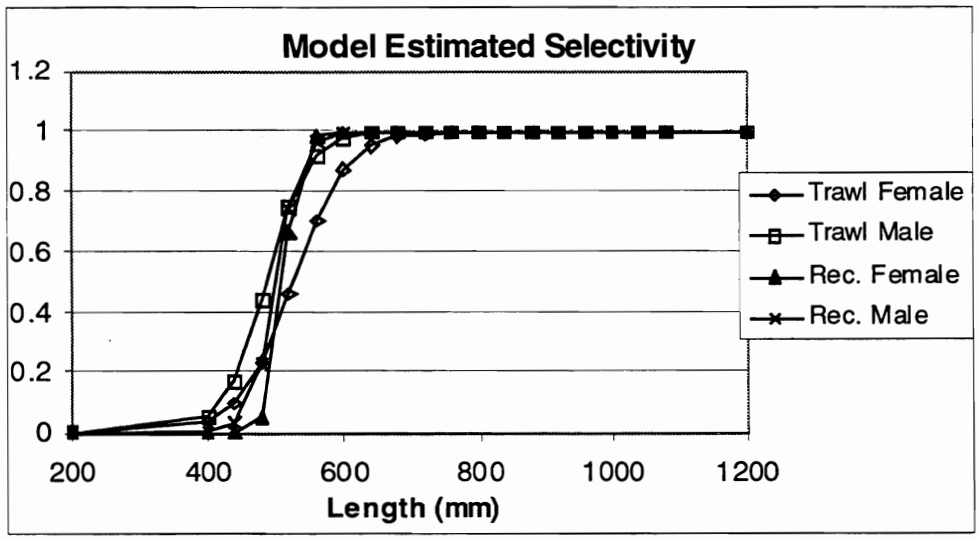


Figure 23. Selectivity functions for the trawl and recreational fisheries by sex, estimated by the base model and fixed selectivity functions for the non-trawl fishery and triennial trawl survey.



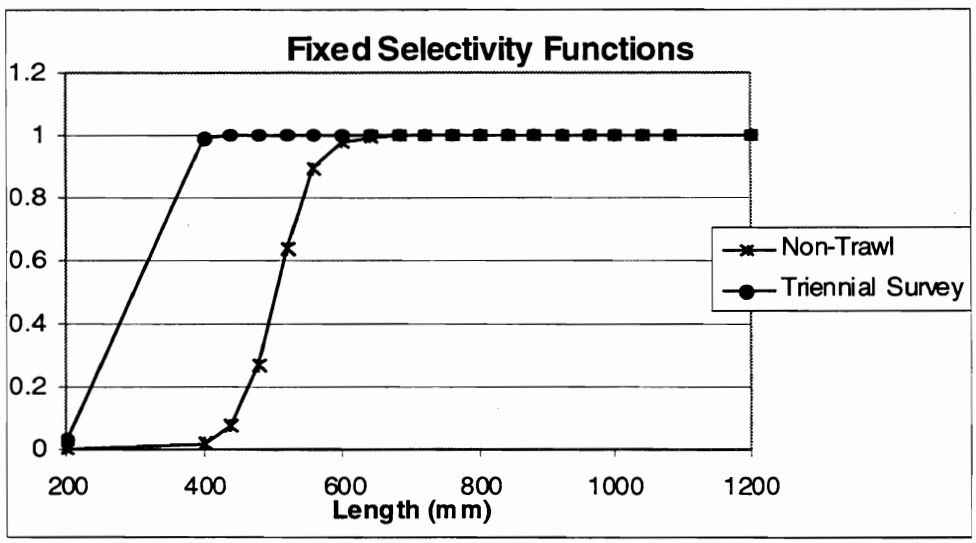


Figure 24. Selectivity functions for the trawl and recreational fisheries by sex, estimated by a model run using a parameter for each length.

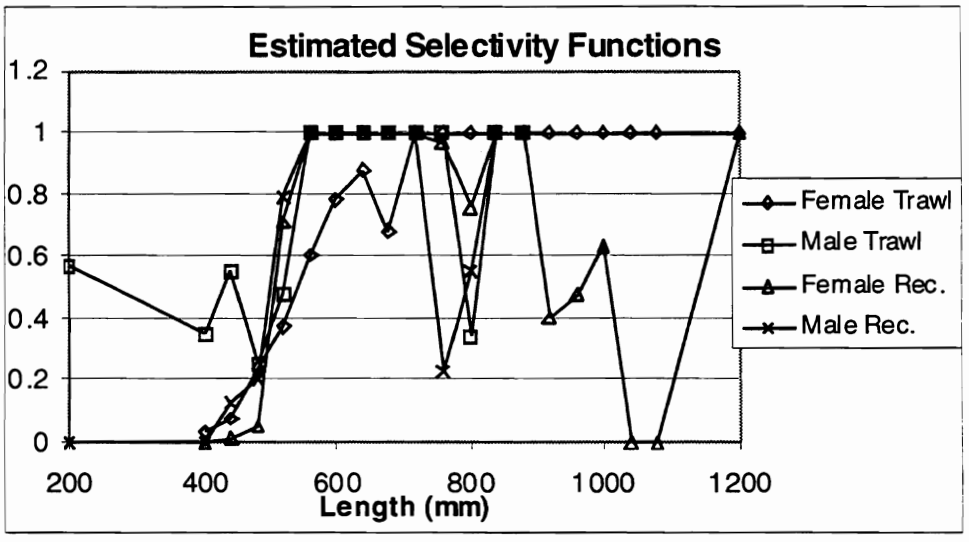
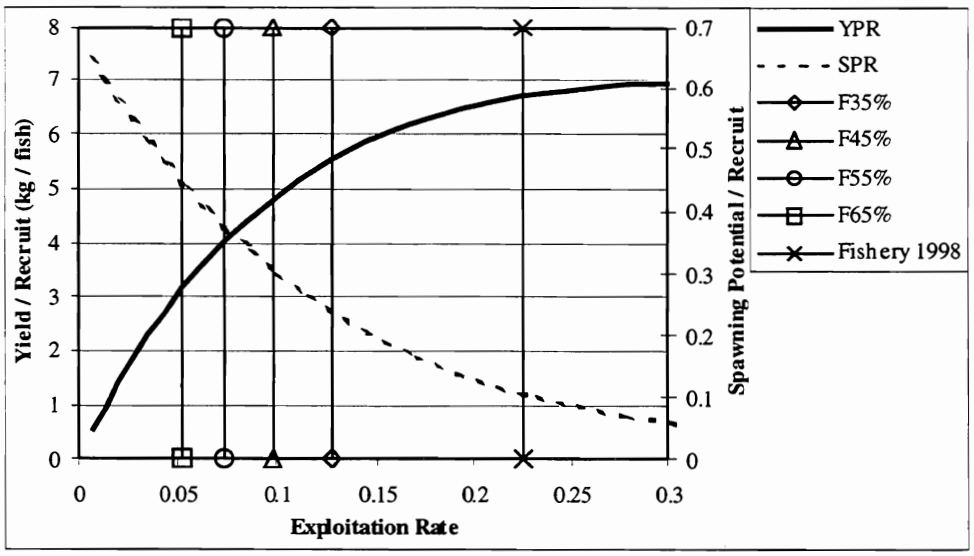


Figure 25. Yield and spawning potential per recruit (top panel) and spawner-recruit relationship (bottom panel) with various constant rate harvest policies marked.



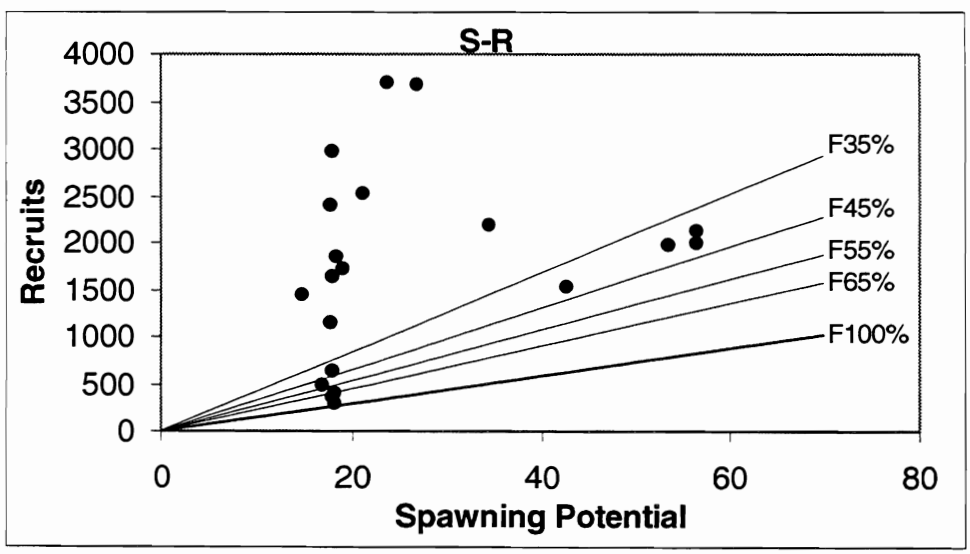


Figure 26. Projections of spawning potential for southern lingcod based on a parametric bootstrap (n=500). The solid and dotted lines represent the mean and 95% confidence bounds, respectively.

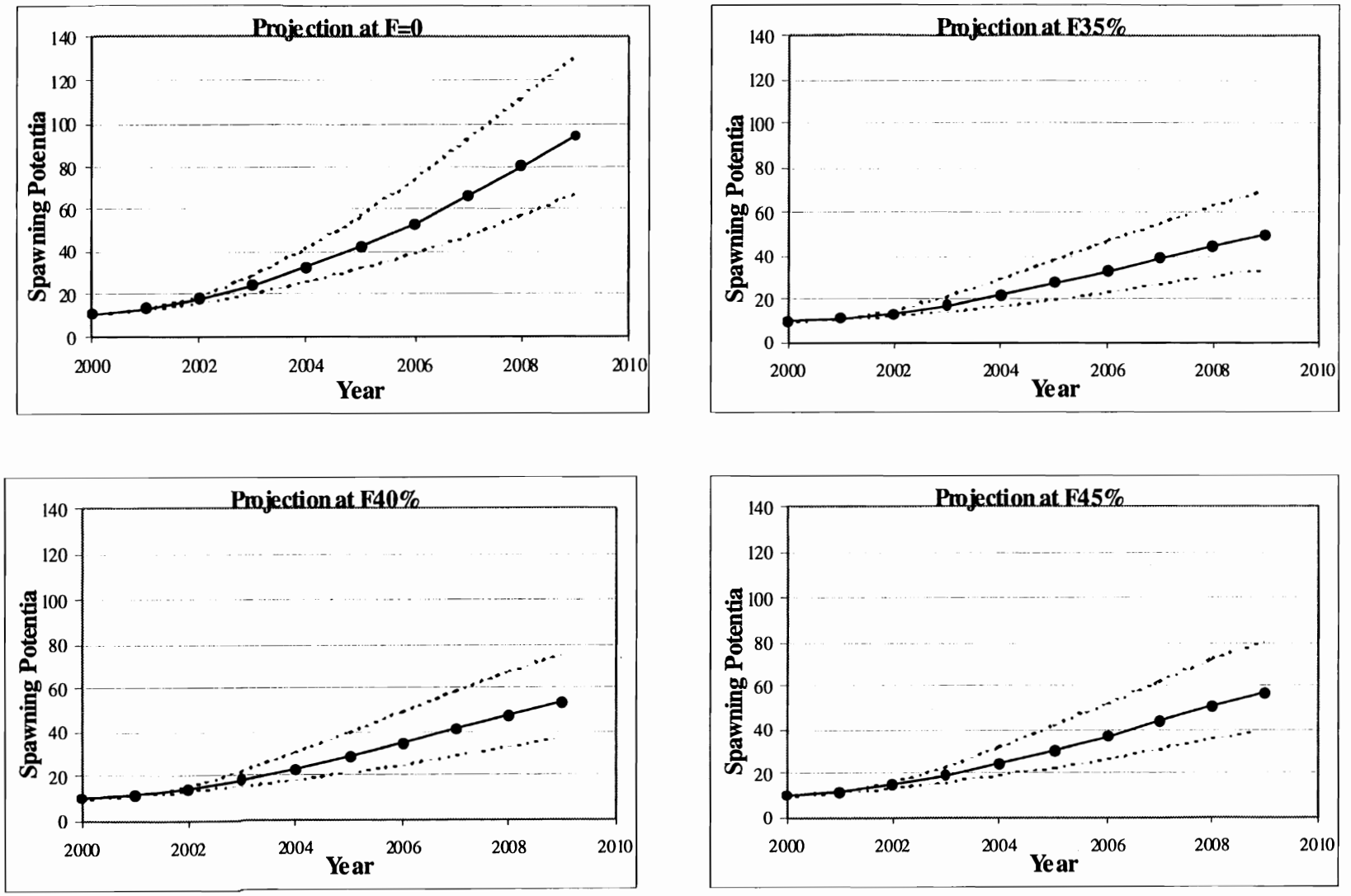
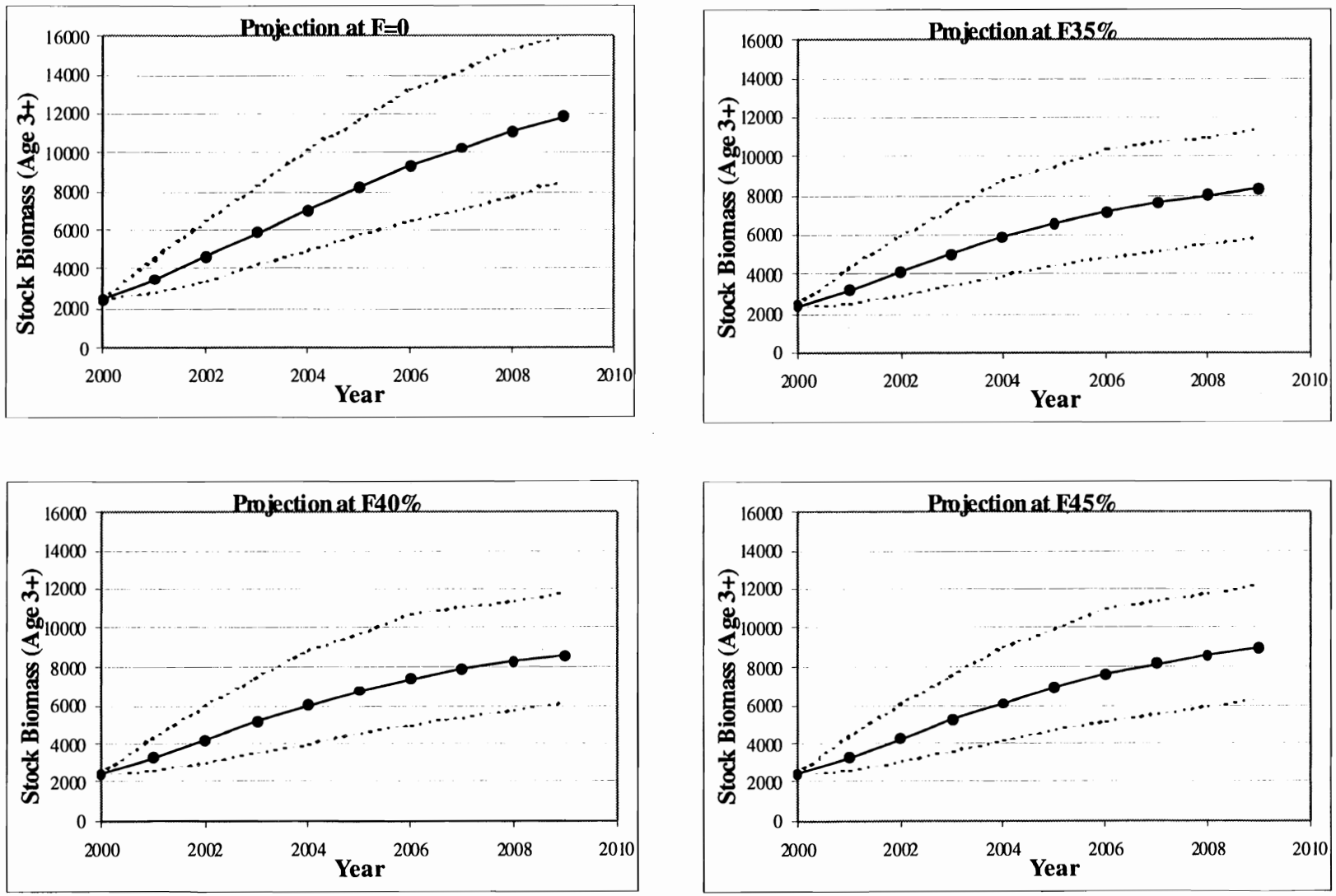


Figure 27. Projections of stock biomass (mt) for southern lingcod based on a parametric bootstrap (n=500). The solid and dotted lines represent the mean and 95% confidence bounds, respectively.



Appendix 1. Equations for the fishery model used in this assessment.

Equation Indexing	Values
Year index: y	1973, 1974,…1998
Age index: a	1, 2,…14+ (age 14+ is an accumulator)
Length index: len	200, 400,…1200mm (length 1200mm is an accumulator)
Fraction of year index: f	1 = first fraction (0.5), 2 = second fraction (1-first)
Fishery: $fish$	1 = trawl, 2 = non-trawl, 3 = recreational
Survey: $surv$	1 = AFSC triennial, 2 = trawl logbook CPUE, 3 = MRFSS recreational CPUE

Biological Functions	Equations
Length-Weight Relationship Length: len Weight: W	$W_{len} = \alpha_W len^{\beta_W}$
Percent Maturity at length: ρ_{len}	$\rho_{len} = \dfrac{1}{\left[1 + e^{(\alpha_\rho (len) + \beta_\rho)}\right]}$
Fecundity at length: ϕ_{len}	$\phi_{len} = \alpha_\phi len^{\beta_\phi}$
Growth Transition Arrays: Proportion at age 1: P'_{len} Proportion at age+1: $P_{a,len(a),len(a+f)}$	P'_{len} and $P_{a,len(a),len(a+1)}$ computed from Monte Carlo estimation (see text description)

Data Estimates	Equations
Numbers of Fish: $N_{a,y,len}$	$N_{1,y,len} = R_y P'$
	$N_{a+f,y+f,len(a)} = \sum_{len(a)=200}^{1200} N_{a,y,len} P_{a,len(a),len(a+f),1} e^{-Mf}$
	$N_{a+1,y+1,len(a+f)} = \sum_{len(a+f)=200}^{1200} \left(N_{a+f,y+f,len(a)} - \sum_{fish} C_{a,y,len,fish} \right) P_{a,len(a+f),len(a+1)} e^{-M(1-f)}$
	$N_{a+1,1,len} = N_{a+1,y+1,len}$
	$N_{14+,y+1,len(a+f)} = N_{a+f,y+f,len(a)} + \sum_{len(a+f)=200}^{1200} \left(N_{a+f,y-1+f,len(a)} - \sum_{fish} C_{a,y,len,fish} \right) P_{a,len(a+f),len(a+1)} e^{-M(1-f)}$

Biomass of fish:

$B_{a,y,len}$

$$B_{a,y,len} = N_{a,y,len} W_{len}$$

Spawning biomass:

S_y

$$S_y = \sum_a \sum_{len} N_{a,y,len} \rho_{len} \phi_{len}$$

Catch in numbers:

$\hat{C}_{a,y,len,fish}$

$$\hat{C}_{a,y,len,fish} = \sum_{fish=1}^{3} N_{a+f,y+f,len} \mu_{y,len,fish} D_y$$

where, D_y is a discard factor used to increase the catch in the trawl fishery only.

Landings in weight:

$\hat{C}'_{y,fish}$

$$\hat{C}'_{y,fish} = \sum_a \sum_{len} \hat{C}_{a,y,len,fish} W_{len}$$

Selectivity functions:

$s_{y,len,fish}$

$$s_{y,len,(1,2,3)} = \frac{1}{\left[1 + e^{\left(\alpha_{y,fish} len + \beta_{y,fish}\right)}\right]}$$

Exploitation fractions:

$\mu_{y,len,fish}$

$$\mu_{y,len,fish} = \eta_{y,fish} s_{y,len,fish} \text{ where,}$$

$$\eta_{y,fish} = \frac{1}{\left[1 + \exp\left(\eta'_y\right)\right]} \left(\frac{C'_{y,fish}}{\sum_{fish} C'_{y,fish}} \right)$$

Surveys:

$\hat{U}_{y,surv}$

$$\hat{U}_{y,surv} = q_{surv} \left(\sum_a \sum_{len} B_{a,y,len} s_{len,surv} \right)^{\gamma_{surv}}$$

Proportions at length:

$\hat{\theta}_{len,y,fish}$

$$\hat{\theta}_{len,y,fish} = \frac{\sum_a \hat{C}_{a,y,len,fish}}{\sum_a \sum_{len} \hat{C}_{a,y,len,fish}}$$

Proportions at age:

$\hat{\theta}_{a,y,fish}$

$$\hat{\theta}_{len,y,fish} = \frac{\sum_{len} \sum_{a'} \hat{C}_{a,y,len,fish} A_{a,a'}}{\sum_a \sum_{len} \sum_{a'} \hat{C}_{a,y,len,fish} A_{a,a'}}$$

where, $A_{a,a'}$ is the ageing error matrix, specified as corrected age, a', for an estimated age, a.

Parameters estimated in the model	Description
R^{avg}, R_y^{dev} Recruitment at age 1:	$R_y = \exp\left(R^{avg} + R_y^{dev}\right)$ [y: 1973-1998]
η'_y	Overall exploitation fraction: bounded between –20 and 20 [y: 1973-1998]
$\alpha_{y,fish}$, $\beta_{y,fish}$	Logistic selectivity parameters: For fish = 1, parameters are constant For fish = 2, parameters are constant For fish = 3, parameters are constant
q_{surv}	Survey catchability parameter: [*surv*: 1, 2 or 3]

Likelihood Component	Equation
Length compositions:	
$L_1 = \sum_{fish} L_{1,fish}$	$L_{1,fish} = \sum_y n_{y,fish} \sum_{len} \theta_{len,y,fish} \log\left(\hat{\theta}_{len,y,fish}\right)$ where $n_{y,fish} = \dfrac{\sum_{len} \theta_{len,y}\left(1-\theta_{len,y}\right)}{\sum_{len}\left(\theta_{len,y} - \hat{\theta}_{len,y}\right)^2}$ is the effective sample size from an earlier model convergence.
Age compositions:	
L_2	$L_2 = \sum_y n_{y,1} \sum_a \theta_{a,y,1} \log\left(\hat{\theta}_{a,y,1}\right)$ where $n_{y,1} = \dfrac{\sum_a \theta_{a,y}\left(1-\theta_{a,y}\right)}{\sum_a\left(\theta_{a,y} - \hat{\theta}_{a,y}\right)^2}$ is the effective sample size from an earlier model convergence.
Landings:	
$L_3 = \sum_{fish} L_{3,fish}$	$L_{3,fish} = \sum_y \dfrac{\left(C'_{y,fish} - \hat{C}'_{y,fish}\right)^2}{2\sigma^{C'}_{y,fish}}$

Surveys:

$$L_4 = \sum_{surv} L_{4,surv} \qquad L_{4,surv} = \sum_y \left[\frac{\log\left(U_{y,surv} / \hat{U}_{y,surv}\right)^2}{2\left(\sigma^U_{y,surv}\right)^2} + \log\left(\sigma^U_{y,surv}\right) \right]$$

Overall objective function:

$$L \qquad L = \sum_x L_x$$

Appendix II. AD Model Builder template file used in this assessment.

```
////////////////////////////////////////////////////////////////////////////////////////////
//
// Template file for southern lingcod assessment model.
// Adams et al., 1999, Pacific Fish. Mgt Council
//
////////////////////////////////////////////////////////////////////////////////////////////
//
// Erik H. Williams (erik.williams@noaa.gov), June 1999.
// Thanks to Jim Ianelli for code improvements.
//
////////////////////////////////////////////////////////////////////////////////////////////

DATA_SECTION
 //---years to be modeled-----------------------------------------------
 init_int styr;
 init_int rtsyr;
 init_int endyr;
 init_int nlbins;
 init_int nabins;
 init_vector agebins(1,nabins);
 init_vector lenbins(1,nlbins);
 //---natural mortality-------------------------------------------------
 init_number M;
 //---sex ratio---------------------------------------------------------
 init_number sxr;
 //---fraction of year when fishing occurs------------------------------
 init_number yfrac;
 //---starting years for fisheries--------------------------------------
 init_int twlyr;
 init_int recyr;
 //---length-weight parameters a*L^b  [a,b]----------------------------
 init_vector lw_par_f(1,2);
 init_vector lw_par_m(1,2);
 //---get probability transition arrays---------------------------------
 //---(age, length, vector of proportions at length at time t+0.5)----
 init_3darray prob_trans1_f(1,nabins,1,nlbins,1,nlbins);
 init_3darray prob_trans1_m(1,nabins,1,nlbins,1,nlbins);
 //---(age+0.5, length, vector of proportions at length at time t+0.5)
 init_3darray prob_trans2_f(1,nabins,1,nlbins,1,nlbins);
 init_3darray prob_trans2_m(1,nabins,1,nlbins,1,nlbins);
 //---get probability of length at age 1-------------------------------
 init_vector lenprop_age1_f(1,nlbins);
 init_vector lenprop_age1_m(1,nlbins);
 //---get observed length comps (length,year)--------------------------
 init_matrix obs_lcomp_twl_f(1,nlbins,twlyr,endyr-1);
 init_matrix obs_lcomp_twl_m(1,nlbins,twlyr,endyr-1);
 init_matrix obs_lcomp_rec_f(1,nlbins,recyr,endyr-1);
 init_matrix obs_lcomp_rec_m(1,nlbins,recyr,endyr-1);
 //---get observed catch landings (mt) and std's----------------------
 init_vector obs_L_twl(styr,endyr);
 init_number obs_L_twl_cv;
 init_vector obs_L_ntwl(styr,endyr);
 init_number obs_L_ntwl_cv;
 init_vector obs_L_rec(styr,endyr);
 init_number obs_L_rec_cv;
 // logistic selectivity parameters for nontrawl fishery
 init_vector selpar_ntwl(1,2);
 // logistic selectivity parameters for recreational fishery
 init_vector selpar_rec(1,2);
 //---get age compositions data (age,year)----------------------------
 init_matrix obs_acomp_twl_f(1,nabins,twlyr,endyr-1);
 init_matrix obs_acomp_twl_m(1,nabins,twlyr,endyr-1);
 init_matrix obs_acomp_rec_f(1,nabins,recyr,endyr-1);
 init_matrix obs_acomp_rec_m(1,nabins,recyr,endyr-1);
 //---get survey indices----------------------------------------------
 // triennial for years 1977,80,83,86,89,92,95,98
 init_vector surv_trienn(1,8);
 init_vector surv_trienn_std(1,8);
 // logistic selectivity parameters for triennial survey
 init_vector selpar_trienn(1,2);
 // trawl logbook CPUE (1978-96)
 init_vector indx_twllog(1978,1996);
 init_vector indx_twllog_std(1978,1996);
 // MRFSS abundance index (1980-89,93-98)
 init_vector indx_mrfss(1980,1998);
 init_vector indx_mrfss_std(1980,1998);
 //---get effective sample sizes for multinomial likelihood----------
 init_vector effsamp_twl_f_lcomp(twlyr,endyr-1);
 init_vector effsamp_twl_m_lcomp(twlyr,endyr-1);
 init_vector effsamp_rec_f_lcomp(recyr,endyr-1);
 init_vector effsamp_rec_m_lcomp(recyr,endyr-1);
 init_vector effsamp_twl_f_acomp(twlyr,endyr-1);
 init_vector effsamp_twl_m_acomp(twlyr,endyr-1);
 init_vector effsamp_rec_f_acomp(recyr,endyr-1);
 init_vector effsamp_rec_m_acomp(recyr,endyr-1);
 //---maturity and fecundity parameters-------------------------------
 init_vector matur(1,2);
 init_vector fecund(1,2);
 //---iteration counter-----------------------------------------------
 int iter_count;

PARAMETER_SECTION
 //---length-weight relationships by sex------------------------------
```

```
vector wt_f(1,nlbins);
vector wt_m(1,nlbins);

//---numbers-----------------------------------------------------------
//---N_midpoint is only a temporary array not to be used as output----
init_number log_avg_N_rec(1);
init_bounded_dev_vector log_N_rec_dev(rtsyr,endyr,-5.0,5.0,2);
3darray N_c(1,nabins+1,styr,endyr+1,1,nlbins);
3darray N_f(1,nabins+1,styr,endyr+1,1,nlbins);
3darray N_m(1,nabins+1,styr,endyr+1,1,nlbins);
3darray N_midpoint_f(1,nabins,styr,endyr,1,nlbins);
3darray N_midpoint_m(1,nabins,styr,endyr,1,nlbins);
3darray B_f(1,nabins+1,styr,endyr+1,1,nlbins);
3darray B_m(1,nabins+1,styr,endyr+1,1,nlbins);
3darray B_c(1,nabins+1,styr,endyr+1,1,nlbins);
sdreport_vector N_c_ts(styr,endyr);
sdreport_vector B3_c_ts(styr,endyr);
sdreport_vector SSB_ts(styr,endyr);
sdreport_number SSB_per;
number prop_f;
number prop_m;

//---reported catch (numbers) = C, biomass landings (mt) = L--------
3darray C_twl_f(1,nabins,styr,endyr,1,nlbins);
3darray C_twl_m(1,nabins,styr,endyr,1,nlbins);
3darray C_ntwl_f(1,nabins,styr,endyr,1,nlbins);
3darray C_ntwl_m(1,nabins,styr,endyr,1,nlbins);
3darray C_rec_f(1,nabins,styr,endyr,1,nlbins);
3darray C_rec_m(1,nabins,styr,endyr,1,nlbins);
3darray L_twl(1,nabins,styr,endyr,1,nlbins);
3darray L_ntwl(1,nabins,styr,endyr,1,nlbins);
3darray L_rec(1,nabins,styr,endyr,1,nlbins);
matrix C_lcomp_twl_f(twlyr,endyr-1,1,nlbins);
matrix C_lcomp_twl_m(twlyr,endyr-1,1,nlbins);
matrix C_lcomp_rec_f(recyr,endyr-1,1,nlbins);
matrix C_lcomp_rec_m(recyr,endyr-1,1,nlbins);
matrix C_acomp_twl_f(1,nabins,twlyr,endyr-1);
matrix C_acomp_twl_m(1,nabins,twlyr,endyr-1);
matrix C_acomp_rec_f(1,nabins,recyr,endyr-1);
matrix C_acomp_rec_m(1,nabins,recyr,endyr-1);
number temp_acomp_f;
number temp_acomp_m;
number temp_acomp_f2;
number temp_acomp_m2;
vector pred_L_twl(styr,endyr);
vector pred_L_ntwl(styr,endyr);
vector pred_L_rec(styr,endyr);
vector sum_L(styr,endyr);

//---selectivity-------------------------------------------------------
vector sel_twl_f(1,nlbins);
vector sel_twl_m(1,nlbins);
vector sel_ntwl_c(1,nlbins);
vector sel_rec_f(1,nlbins);
vector sel_rec_m(1,nlbins);
//---selectivity (logistic) [female,male]------------------------------
```

```
init_bounded_vector selpar_slope_twl(1,2,.01,.2,3);
init_bounded_vector selpar_L50_twl(1,2,200.,800.,3);
init_bounded_vector selpar_slope_rec(1,2,.01,.2,3);
init_bounded_vector selpar_L50_rec(1,2,200.,800.,3);
//---lognormal selectivity function-----------------------------
//---1=mean, 2=std, 3=horizontal adjustment----------------------
//init_bounded_number selpar_1_rec_f(1,19,3);
//init_bounded_number selpar_2_rec_f(0.1,3,3);
//init_bounded_number selpar_3_rec_f(-10,10,3);
//number temp_selpar_f;
//init_bounded_number selpar_1_rec_m(1,19,3);
//init_bounded_number selpar_2_rec_m(0.1,3,3);
//init_bounded_number selpar_3_rec_m(-10,10,3);
//number temp_selpar_m;

//---mortality---------------------------------------------------
// twlyr is used here since it is the earliest occurring fishery
init_number ffrac_avg_par(1);
init_bounded_dev_vector ffrac_dev_par(rtsyr,endyr,-40,40,2);
vector ffrac_twl_f(styr,endyr);
vector ffrac_twl_m(styr,endyr);
vector ffrac_ntwl_c(styr,endyr);
vector ffrac_rec_f(styr,endyr);
vector ffrac_rec_m(styr,endyr);
3darray F_twl_f(1,nabins,styr,endyr,1,nlbins);
3darray F_twl_m(1,nabins,styr,endyr,1,nlbins);
3darray F_ntwl_c(1,nabins,styr,endyr,1,nlbins);
3darray F_rec_f(1,nabins,styr,endyr,1,nlbins);
3darray F_rec_m(1,nabins,styr,endyr,1,nlbins);

//---catchability/surveyability----------------------------------
init_bounded_number q_surv_trienn(0.01,40,1);
//init_bounded_number a_surv_trienn(0.5,1.5,4);
number a_surv_trienn;
init_bounded_number q_indx_twllog(0.0000001,10,1);
//init_bounded_number a_indx_twllog(0.5,1.5,4);
number a_indx_twllog;
init_bounded_number q_indx_mrfss(0.0000001,40,1);
//init_bounded_number a_indx_mrfss(0.5,1.5,4);
vector sel_trienn(1,nlbins);
vector pred_surv_trienn(1,8);
vector pred_indx_twllog(1978,1996);
vector pred_indx_mrfss(1980,1998);

//---maturity and fecundity--------------------------------------
vector matur_len(1,nlbins);
vector fecund_len(1,nlbins);

//---likelihood components---------------------------------------
number f_trienn;
number f_twllog;
number f_mrfss;
number f_lcomp_twl;
number f_lcomp_rec;
number f_acomp_twl;
number f_acomp_rec;
number f_landing;
number f_recdev;
number f_ffracdev;
objective_function_value f;

INITIALIZATION_SECTION
 log_avg_N_rec 5.0;
 q_surv_trienn 1;
 //a_surv_trienn 1;
 q_indx_twllog 1;
 //a_indx_twllog 1;
 q_indx_mrfss 1;
 //---initializers for lognormal selectivity function------------
 //selpar_1_rec_f 2.5;
 //selpar_2_rec_f 0.5;
 //selpar_3_rec_f 1;
 //selpar_1_rec_m 2.5;
 //selpar_2_rec_m 0.5;
 //selpar_3_rec_m 1;

RUNTIME_SECTION
 maximum_function_evaluations 100,400,2000;
 convergence_criteria 1e-8;

PRELIMINARY_CALCS_SECTION
 //---set survey power functions to 1----------------------------
 a_surv_trienn=1;
 a_indx_twllog=1;
 //---compute weight-length relationship-------------------------
 wt_f=lw_par_f(1)*pow(lenbins,lw_par_f(2));
 wt_m=lw_par_m(1)*pow(lenbins,lw_par_m(2));
 //---compute percent maturity----------------------------------
 matur_len=1/(1+exp(-matur(1)*(lenbins-matur(2))));
 fecund_len=pow((lenbins*fecund(1)),fecund(2));
 //---fixed triennial survey selectivity------------------------
 sel_trienn=1./(1.+exp(-selpar_trienn(1)*(lenbins-selpar_trienn(2))));
 //---fixed nontrawl fishery selectivity------------------------
 sel_ntwl_c=1./(1.+exp(-selpar_ntwl(1)*(lenbins-selpar_ntwl(2))));
 iter_count=0;
 //---compute sum of landings for ffrac proportioning------------
 sum_L=obs_L_twl+obs_L_ntwl+obs_L_rec;
 //---fixed recreational fishery selectivity---------------------
```

```
 //sel_rec_f=1./(1.+exp(-selpar_rec(1)*(lenbins-selpar_rec(2))));
 //sel_rec_m=sel_rec_f;

TOP_OF_MAIN_SECTION
 arrmblsize=2000000;
 gradient_structure::set_GRADSTACK_BUFFER_SIZE(2000000);
 gradient_structure::set_CMPDIF_BUFFER_SIZE(60000000);

PROCEDURE_SECTION
 cout << "Avg Rec   = " << log_avg_N_rec << endl;
 cout << "Avg Ffrac = " << ffrac_avg_par << endl;
 get_selectivity();
 get_mortality();
 get_survivors_and_catch();
 get_length_compositions();
 get_age_compositions();
 get_landings();
 get_survey_stuff();
 //---compute age 3+ stock biomass and recruitment---------------
 B3_c_ts.initialize();
 for(int a=3;a<=nabins;a++)
 {
  for(int y=styr;y<=endyr;y++)
  {
   B3_c_ts(y)+=sum(B_c(a,y));
   N_c_ts(y)=sum(N_c(1,y));
  }
 }
 //---compute spawning potential--------------------------------
 SSB_ts.initialize();
 for(int y=styr;y<=endyr;y++)
 {
  for(int a=1;a<=nabins;a++)
  {
   for(int len=1;len<=nlbins;len++)
   {
    SSB_ts(y)+=B_f(a,y,len)*matur_len(len)*fecund_len(len);
   }
  }
 }
 //---compute percent decline in SSB----------------------------
 SSB_per=SSB_ts(endyr)/SSB_ts(styr);
 evaluate_the_objective_function();
 cout << "SSB ending%= " << SSB_per << endl;
 iter_count+=1;
 cout << "iterations complete = " << iter_count << endl;
 cout << endl;

FUNCTION get_selectivity
 //---logistic selectivity function-----------------------------
 sel_twl_f=1./(1.+exp(-selpar_slope_twl(1)*(lenbins-selpar_L50_twl(1))));
 sel_twl_m=1./(1.+exp(-selpar_slope_twl(2)*(lenbins-selpar_L50_twl(2))));
 sel_rec_f=1./(1.+exp(-selpar_slope_rec(1)*(lenbins-selpar_L50_rec(1))));
 sel_rec_m=1./(1.+exp(-selpar_slope_rec(2)*(lenbins-selpar_L50_rec(2))));
 //---lognormal selectivity function----------------------------
 //for(int len=1;len<=nlbins;len++)
 //{
 //  temp_selpar_f=len+selpar_3_rec_f;
 //  temp_selpar_m=len+selpar_3_rec_m;
 //  if(temp_selpar_f<=1)
 //  {
 //    temp_selpar_f=pow(100,(temp_selpar_f-1));
 //  }
 //  if(temp_selpar_m<=1)
 //  {
 //    temp_selpar_m=pow(100,(temp_selpar_m-1));
 //  }
 //  sel_rec_f(len)=((1/(temp_selpar_f*pow(2*3.1415926,0.5)*selpar_2_rec_f))*exp(-
0.5*square(log(temp_selpar_f)-
selpar_1_rec_f)/square(selpar_2_rec_f)))/((1/(exp(selpar_1_rec_f-
square(selpar_2_rec_f))*pow(2*3.1415926,0.5)*selpar_2_rec_f))*exp(-
0.5*square(log(exp(selpar_1_rec_f-square(selpar_2_rec_f)))-
selpar_1_rec_f)/square(selpar_2_rec_f)));
 //  sel_rec_m(len)=((1/(temp_selpar_m*pow(2*3.1415926,0.5)*selpar_2_rec_m))*exp(-
0.5*square(log(temp_selpar_m)-
selpar_1_rec_m)/square(selpar_2_rec_m)))/((1/(exp(selpar_1_rec_m-
square(selpar_2_rec_m))*pow(2*3.1415926,0.5)*selpar_2_rec_m))*exp(-
0.5*square(log(exp(selpar_1_rec_m-square(selpar_2_rec_m)))-
selpar_1_rec_m)/square(selpar_2_rec_m)));
 //}

FUNCTION get_mortality
 //---complete fishing mortalities for all years----------------------------
 for(int y=styr;y<=endyr;y++)
 {
  ffrac_twl_f(y)=obs_L_twl(y)/sum_L(y);
  ffrac_twl_m(y)=obs_L_twl(y)/sum_L(y);
  ffrac_ntwl_c(y)=obs_L_ntwl(y)/sum_L(y);
  ffrac_rec_f(y)=obs_L_rec(y)/sum_L(y);
  ffrac_rec_m(y)=obs_L_rec(y)/sum_L(y);
 }
 for(int a=1;a<=nabins;a++)
 {
  for(int y=styr;y<=endyr;y++)
  {
   F_twl_f(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(rtsyr))))*ffrac_twl_f(y)*sel_twl_f;
   F_twl_m(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(rtsyr))))*ffrac_twl_m(y)*sel_twl_m;
```

```
F_ntwl_c(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(rtsyr))))*ffrac_ntwl_c(y)*sel_ntwl_c;
    F_rec_f(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(rtsyr))))*ffrac_rec_f(y)*sel_rec_f;

F_rec_m(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(rtsyr))))*ffrac_rec_m(y)*sel_rec_m;
    if (y>rtsyr)
    {
      F_twl_f(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(y))))*ffrac_twl_f(y)*sel_twl_f;
      F_twl_m(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(y))))*ffrac_twl_m(y)*sel_twl_m;
      F_ntwl_c(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(y))))*ffrac_ntwl_c(y)*sel_ntwl_c;
      F_rec_f(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(y))))*ffrac_rec_f(y)*sel_rec_f;
      F_rec_m(a,y)=(1/(1+exp(ffrac_avg_par+ffrac_dev_par(y))))*ffrac_rec_m(y)*sel_rec_m;
    }
  }
}


FUNCTION get_survivors_and_catch
 for(int a=1;a<=nabins;a++)
 {
  dvar_matrix pt1_f_tmp = trans(prob_trans1_f(a)); //JIM
  dvar_matrix pt1_m_tmp = trans(prob_trans1_m(a)); //JIM
  dvar_matrix pt2_f_tmp = trans(prob_trans2_f(a)); //JIM
  dvar_matrix pt2_m_tmp = trans(prob_trans2_m(a)); //JIM
  for(int y=styr;y<=endyr;y++)
  {
 //---age 1 recruitment numbers----------------------------------------
    if(a==1)
    {
      N_f(a,y)=lenprop_age1_f*(mfexp(log_avg_N_rec+log_N_rec_dev(rtsyr)))*sxr;
      N_m(a,y)=lenprop_age1_m*(mfexp(log_avg_N_rec+log_N_rec_dev(rtsyr)))*(1-sxr);
      if(y>rtsyr)
      {
        N_f(a,y)=lenprop_age1_f*(mfexp(log_avg_N_rec+log_N_rec_dev(y)))*sxr;
        N_m(a,y)=lenprop_age1_m*(mfexp(log_avg_N_rec+log_N_rec_dev(y)))*(1-sxr);
      }
    }
    for(int len=1;len<=nlbins;len++)
    {
      N_midpoint_f(a,y,len)=(N_f(a,y)*pt1_f_tmp(len))*exp(-M*yfrac); //JIM
      N_midpoint_m(a,y,len)=(N_m(a,y)*pt1_m_tmp(len))*exp(-M*yfrac); //JIM
      prop_f=(N_midpoint_f(a,y,len)/(N_midpoint_f(a,y,len)+N_midpoint_m(a,y,len)+1e-100));
      prop_m=(N_midpoint_m(a,y,len)/(N_midpoint_f(a,y,len)+N_midpoint_m(a,y,len)+1e-
100));
 //---re-compute F's to reflect sex ratio in population----------------------------
      F_twl_f(a,y,len)=F_twl_f(a,y,len)*prop_f;
      F_twl_m(a,y,len)=F_twl_m(a,y,len)*prop_m;
      F_rec_f(a,y,len)=F_rec_f(a,y,len)*prop_f;
      F_rec_m(a,y,len)=F_rec_m(a,y,len)*prop_m;
 //---compute catches for each fishery by sex-------------------------------------
      C_twl_f(a,y,len)=N_midpoint_f(a,y,len)*F_twl_f(a,y,len);
      C_twl_m(a,y,len)=N_midpoint_m(a,y,len)*F_twl_m(a,y,len);
      C_ntwl_f(a,y,len)=N_midpoint_f(a,y,len)*F_ntwl_c(a,y,len)*prop_f;
      C_ntwl_m(a,y,len)=N_midpoint_m(a,y,len)*F_ntwl_c(a,y,len)*prop_m;
      C_rec_f(a,y,len)=N_midpoint_f(a,y,len)*F_rec_f(a,y,len);
      C_rec_m(a,y,len)=N_midpoint_m(a,y,len)*F_rec_m(a,y,len);
 //---catches are removed----------------------------------------------------
      N_midpoint_f(a,y,len)-=(C_twl_f(a,y,len)+C_rec_f(a,y,len)+C_ntwl_f(a,y,len));
      N_midpoint_m(a,y,len)-=(C_twl_m(a,y,len)+C_rec_m(a,y,len)+C_ntwl_m(a,y,len));
 //---added to fill in earlier ages------------------------------------------
      if(y<=styr)
      {
        N_f(a+1,styr,len)=(N_midpoint_f(a,y)*pt2_f_tmp(len))*exp(-M*(1.-yfrac)); //JIM
        N_m(a+1,styr,len)=(N_midpoint_m(a,y)*pt2_m_tmp(len))*exp(-M*(1.-yfrac)); //JIM
      }
 //---advance to next age and year-------------------------------------------
      N_f(a+1,y+1,len)=(N_midpoint_f(a,y)*pt2_f_tmp(len))*exp(-M*(1.-yfrac)); //JIM
      N_m(a+1,y+1,len)=(N_midpoint_m(a,y)*pt2_m_tmp(len))*exp(-M*(1.-yfrac)); //JIM
 // ---Plus group calculations-----------------------------------------------
 // ---Note the midpoint is overwritten, hence is only a temporary array----
      if(a>=nabins && y>=styr+1)
      {
        N_midpoint_f(a,y,len)=(N_f(a,y-1)*pt1_f_tmp(len))*exp(-M*yfrac); //JIM
        N_midpoint_m(a,y,len)=(N_m(a,y-1)*pt1_m_tmp(len))*exp(-M*yfrac); //JIM
        prop_f=(N_midpoint_f(a,y,len)/(N_midpoint_f(a,y,len)+N_midpoint_m(a,y,len)+1e-
100));
        prop_m=(N_midpoint_m(a,y,len)/(N_midpoint_f(a,y,len)+N_midpoint_m(a,y,len)+1e-
100));
        F_twl_f(a,y,len)=F_twl_f(a,y,len)*prop_f;
        F_twl_m(a,y,len)=F_twl_m(a,y,len)*prop_m;
        F_rec_f(a,y,len)=F_rec_f(a,y,len)*prop_f;
        F_rec_m(a,y,len)=F_rec_m(a,y,len)*prop_m;
        C_twl_f(a,y,len)=N_midpoint_f(a,y,len)*F_twl_f(a,y,len);
        C_twl_m(a,y,len)=N_midpoint_m(a,y,len)*F_twl_m(a,y,len);
        C_ntwl_f(a,y,len)=N_midpoint_f(a,y,len)*F_ntwl_c(a,y,len)*prop_f;
        C_ntwl_m(a,y,len)=N_midpoint_m(a,y,len)*F_ntwl_c(a,y,len)*prop_m;
        C_rec_f(a,y,len)=N_midpoint_f(a,y,len)*F_rec_f(a,y,len);
        C_rec_m(a,y,len)=N_midpoint_m(a,y,len)*F_rec_m(a,y,len);
        N_midpoint_f(a,y,len)-=(C_twl_f(a,y,len)+C_rec_f(a,y,len)+C_ntwl_f(a,y,len));
        N_midpoint_m(a,y,len)-=(C_twl_m(a,y,len)+C_rec_m(a,y,len)+C_ntwl_m(a,y,len));
        N_f(a+1,y+1,len)+=(N_midpoint_f(a,y)*pt2_f_tmp(len))*exp(-M*(1.-yfrac)); //JIM
        N_m(a+1,y+1,len)+=(N_midpoint_m(a,y)*pt2_m_tmp(len))*exp(-M*(1.-yfrac)); //JIM
      }
    }
 //---compute catch in biomass-----------------------------------------------
    L_twl(a,y)=(elem_prod(C_twl_f(a,y),wt_f)+elem_prod(C_twl_m(a,y),wt_m))*0.001;
    L_ntwl(a,y)=(elem_prod(C_ntwl_f(a,y),wt_f)+elem_prod(C_ntwl_m(a,y),wt_m))*0.001;
    L_rec(a,y)=(elem_prod(C_rec_f(a,y),wt_f)+elem_prod(C_rec_m(a,y),wt_m))*0.001;
    B_f(a,y)=elem_prod(N_f(a,y),wt_f)*0.001;
```

```
    B_m(a,y)=elem_prod(N_m(a,y),wt_m)*0.001;
   }
  }
  B_c=B_f+B_m;
  N_c=N_f+N_m;

FUNCTION get_length_compositions
  C_lcomp_twl_f.initialize();
  C_lcomp_twl_m.initialize();
  C_lcomp_rec_f.initialize();
  C_lcomp_rec_m.initialize();
  //---twlyr is used in this case because it is the earliest occuring fishery---
  for(int y=twlyr;y<=endyr-1;y++)
  {
   for(int len=1;len<=nlbins;len++)
   {
    for(int a=1;a<=nabins;a++)
    {
     if(y<endyr)
     {
      C_lcomp_twl_f(y,len)+=C_twl_f(a,y,len);
      C_lcomp_twl_m(y,len)+=C_twl_m(a,y,len);
      C_lcomp_rec_f(y,len)+=C_rec_f(a,y,len);
      C_lcomp_rec_m(y,len)+=C_rec_m(a,y,len);
     }
    }
   }
    if(sum(C_lcomp_twl_f(y))>0)
    {
     C_lcomp_twl_f(y)=C_lcomp_twl_f(y)/sum(C_lcomp_twl_f(y));
    }
    if(sum(C_lcomp_twl_m(y))>0)
    {
     C_lcomp_twl_m(y)=C_lcomp_twl_m(y)/sum(C_lcomp_twl_m(y));
    }
    if(sum(C_lcomp_rec_f(y))>0)
    {
     C_lcomp_rec_f(y)=C_lcomp_rec_f(y)/sum(C_lcomp_rec_f(y));
    }
    if(sum(C_lcomp_rec_m(y))>0)
    {
     C_lcomp_rec_m(y)=C_lcomp_rec_m(y)/sum(C_lcomp_rec_m(y));
    }
  }

FUNCTION get_age_compositions
  for(int y=twlyr;y<=endyr-1;y++)
  {
   for(int a=1;a<=nabins;a++)
   {
    C_acomp_twl_f(a,y)=sum(C_twl_f(a,y));
    C_acomp_twl_m(a,y)=sum(C_twl_m(a,y));
    C_acomp_rec_f(a,y)=sum(C_rec_f(a,y));
    C_acomp_rec_m(a,y)=sum(C_rec_m(a,y));
   }
  }
  for(int y=twlyr;y<=endyr-1;y++)
  {
   temp_acomp_f=sum(trans(C_acomp_twl_f)(y));
   temp_acomp_m=sum(trans(C_acomp_twl_m)(y));
   temp_acomp_f2=sum(trans(C_acomp_rec_f)(y));
   temp_acomp_m2=sum(trans(C_acomp_rec_m)(y));
   for(int a=1;a<=nabins;a++)
   {
    if(temp_acomp_f>0)
    {
     C_acomp_twl_f(a,y)=C_acomp_twl_f(a,y)/temp_acomp_f;
    }
    if(temp_acomp_m>0)
    {
     C_acomp_twl_m(a,y)=C_acomp_twl_m(a,y)/temp_acomp_m;
    }
    if(temp_acomp_f2>0)
    {
     C_acomp_rec_f(a,y)=C_acomp_rec_f(a,y)/temp_acomp_f2;
    }
    if(temp_acomp_m2>0)
    {
     C_acomp_rec_m(a,y)=C_acomp_rec_m(a,y)/temp_acomp_m2;
    }
   }
  }

FUNCTION get_landings
  pred_L_twl.initialize();
  pred_L_ntwl.initialize();
  pred_L_rec.initialize();
  for(int y=styr;y<=endyr;y++)
  {
   for(int a=1;a<=nabins;a++)
   {
    pred_L_twl(y)+=sum(L_twl(a,y));
    pred_L_ntwl(y)+=sum(L_ntwl(a,y));
    pred_L_rec(y)+=sum(L_rec(a,y));
   }
  }

FUNCTION get_survey_stuff
```

```
//---triennial trawl survey-------------------------------------
pred_surv_trienn.initialize();
for(int y=1;y<=8;y++)
{
 for(int a=1;a<=nabins;a++)
 {
  for(int len=1;len<=nlbins;len++)
  {
   if(B_c(a,(1974+y*3),len)>0)
   {
    pred_surv_trienn(y)+=B_c(a,(1974+y*3),len)*sel_trienn(len);
   }
  }
 }
 pred_surv_trienn(y)=pow(pred_surv_trienn(y),a_surv_trienn)*q_surv_trienn;
}
//---trawl logbook CPUE-------------------------------------
pred_indx_twllog.initialize();
for(int y=1978;y<=1996;y++)
{
 for(int a=1;a<=nabins;a++)
 {
  for(int len=1;len<=nlbins;len++)
  {
   if(B_f(a,y,len)>0)
   {
    pred_indx_twllog(y)+=B_f(a,y,len)*sel_twl_f(len);
   }
   if(B_m(a,y,len)>0)
   {
    pred_indx_twllog(y)+=B_m(a,y,len)*sel_twl_m(len);
   }
  }
 }
 pred_indx_twllog(y)=pow(pred_indx_twllog(y),a_indx_twllog)*q_indx_twllog;
}
//---MRFSS abundance index-----------------------------------
pred_indx_mrfss.initialize();
for(int y=1980;y<=1998;y++)
{
 for(int a=1;a<=nabins;a++)
 {
  pred_indx_mrfss(y)+=sum(N_c(a,y));
 }
 pred_indx_mrfss(y)=pred_indx_mrfss(y)*q_indx_mrfss;
}

FUNCTION evaluate_the_objective_function
//---twlyr used because it is earliest occuring fishery-----------
dvar_matrix olc_twl_f = trans(obs_lcomp_twl_f);
dvar_matrix olc_twl_m = trans(obs_lcomp_twl_m);
f_lcomp_twl=0;
for(int y=twlyr;y<=endyr-1;y++)
{
 f_lcomp_twl+=-1*(olc_twl_f(y)*log(C_lcomp_twl_f(y)+.001))*effsamp_twl_f_lcomp(y);
 f_lcomp_twl+=-1*(olc_twl_m(y)*log(C_lcomp_twl_m(y)+.001))*effsamp_twl_m_lcomp(y);
}
f=f_lcomp_twl;
cout << "twl lcomps = " << f_lcomp_twl << endl;

dvar_matrix olc_rec_f = trans(obs_lcomp_rec_f);
dvar_matrix olc_rec_m = trans(obs_lcomp_rec_m);
f_lcomp_rec=0;
for(int y=recyr;y<=endyr-1;y++)
{
 f_lcomp_rec+=-1*(olc_rec_f(y)*log(C_lcomp_rec_f(y)+.001))*effsamp_rec_f_lcomp(y);
 f_lcomp_rec+=-1*(olc_rec_m(y)*log(C_lcomp_rec_m(y)+.001))*effsamp_rec_m_lcomp(y);
}
f+=f_lcomp_rec;
cout << "rec lcomps = " << f_lcomp_rec << endl;

dvar_matrix oac_twl_f = trans(obs_acomp_twl_f);
dvar_matrix oac_twl_m = trans(obs_acomp_twl_m);
dvar_matrix Cac_twl_f = trans(C_acomp_twl_f);
dvar_matrix Cac_twl_m = trans(C_acomp_twl_m);
f_acomp_twl=0;
for(int y=twlyr;y<=endyr-1;y++)
{
 f_acomp_twl += -1*(oac_twl_f(y)*log(Cac_twl_f(y)))*effsamp_twl_f_acomp(y);
 f_acomp_twl += -1*(oac_twl_m(y)*log(Cac_twl_m(y)))*effsamp_twl_m_acomp(y);
}
f+=f_acomp_twl;
cout << "twl acomps = " << f_acomp_twl << endl;

dvar_matrix oac_rec_f = trans(obs_acomp_rec_f);
dvar_matrix oac_rec_m = trans(obs_acomp_rec_m);
dvar_matrix Cac_rec_f = trans(C_acomp_rec_f);
dvar_matrix Cac_rec_m = trans(C_acomp_rec_m);
f_acomp_rec=0;
for(int y=recyr;y<=endyr-1;y++)
{
 f_acomp_rec+=-1*(oac_rec_f(y)*log(Cac_rec_f(y)))*effsamp_rec_f_acomp(y);
 f_acomp_rec+=-1*(oac_rec_m(y)*log(Cac_rec_m(y)))*effsamp_rec_m_acomp(y);
}
f += f_acomp_rec;
cout << "rec acomps = " << f_acomp_rec << endl;

f_landing=0;
```

```
 for(int y=styr;y<=endyr;y++)
 {
  f_landing+=square(obs_L_twl(y)-pred_L_twl(y))/(2*square(obs_L_twl(y)*obs_L_twl_cv));
  f_landing+=square(obs_L_ntwl(y)-
pred_L_ntwl(y))/(2*square(obs_L_ntwl(y)*obs_L_ntwl_cv));
  f_landing+=square(obs_L_rec(y)-pred_L_rec(y))/(2*square(obs_L_rec(y)*obs_L_rec_cv));
 }
 f+=f_landing;
 cout << "landings  = " << f_landing << endl;
 f_recdev=1*norm2(log_N_rec_dev);
 f+=f_recdev;
 cout << "rec dev   = " << f_recdev << endl;
 f_ffracdev=1*norm2(ffrac_dev_par);
 f+=f_ffracdev;
 cout << "ffrac dev = " << f_ffracdev << endl;
 f_trienn=0.;
 for(int y=1;y<=8;y++)
 {

f_trienn+=square(log(surv_trienn(y)/pred_surv_trienn(y)))/(2*square(surv_trienn_std(y)))+log(
surv_trienn_std(y));
 }
 f_trienn=1*f_trienn;
 f+=f_trienn;
 cout << "trienn surv = " << f_trienn << endl;
 f_twllog=0.;
 for(int y=1982;y<=1996;y++)
 {

f_twllog+=square(log(indx_twllog(y)/pred_indx_twllog(y)))/(2*square(indx_twllog_std(y)))+log(
indx_twllog_std(y));
 }
 f_twllog=1*f_twllog;
 f+=f_twllog;
 cout << "twllog surv = " << f_twllog << endl;
 f_mrfss=0.;
 for(int y=1980;y<=1989;y++)
 {

f_mrfss+=square(log(indx_mrfss(y)/pred_indx_mrfss(y)))/(2*square(indx_mrfss_std(y)))+log(i
ndx_mrfss_std(y));
 }
 for(int y=1993;y<=1998;y++)
 {

f_mrfss+=square(log(indx_mrfss(y)/pred_indx_mrfss(y)))/(2*square(indx_mrfss_std(y)))+log(i
ndx_mrfss_std(y));
 }
 f_mrfss=1*f_mrfss;
 f+=f_mrfss;
 cout << "mrfss surv = " << f_mrfss << endl;
 cout << "FINAL f = " << f << endl;

REPORT_SECTION
 //---tons of putput-----------------------------------------------
 report << "iterations " << iter_count << endl;
 report << "f_lcomp_twl " << f_lcomp_twl << endl;
 report << "f_lcomp_rec " << f_lcomp_rec << endl;
 report << "f_acomp_twl " << f_acomp_twl << endl;
 report << "f_acomp_rec " << f_acomp_rec << endl;
 report << "f_landing " << f_landing << endl;
 report << "rec_dev " << f_recdev << endl;
 report << "ffrac_dev " << f_ffracdev << endl;
 report << "trienn_f " << f_trienn << endl;
 report << "twllog_f " << f_twllog << endl;
 report << "mrfss_f " << f_mrfss << endl;
 report << "FINAL_f " << f << endl;

 report << "slope_twl " << selpar_slope_twl << endl;;
 report << "L50_twl " << selpar_L50_twl << endl;
 report << "slope_rec " << selpar_slope_rec << endl;;
 report << "L50_rec " << selpar_L50_rec << endl;
 //report << "f_recpar1 " << selpar_1_rec_f << endl;
 //report << "f_recpar2 " << selpar_2_rec_f << endl;
 //report << "f_recpar3 " << selpar_3_rec_f << endl;
 //report << "m_recpar1 " << selpar_1_rec_m << endl;
 //report << "m_recpar2 " << selpar_2_rec_m << endl;
 //report << "m_recpar3 " << selpar_3_rec_m << endl;

 report << lenbins << endl;
 report << "sel_twl_f " << sel_twl_f << endl;
 report << "sel_twl_m " << sel_twl_m << endl;
 report << "sel_rec_f " << sel_rec_f << endl;
 report << "sel_rec_m " << sel_rec_m << endl;
 report << "sel_ntwl_c " << sel_ntwl_c << endl;
 report << "sel_trienn " << sel_trienn << endl;

 report << " 1977 1980 1983 1986 1989 1992 1995 1998" << endl;
 report << "Observed " << surv_trienn << endl;
 report << "Predicted " << pred_surv_trienn << endl;
 report << " 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991
1992 1993 1994 1995 1996" << endl;
 report << "Observed " << indx_twllog << endl;
 report << "Predicted " << pred_indx_twllog << endl;
 report << " 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993
1994 1995 1996 1997 1998" << endl;
 report << "Observed " << indx_mrfss << endl;
 report << "Predicted " << pred_indx_mrfss << endl;
```

```
report << "triennial trawl survey q " << q_surv_trienn << " a " << a_surv_trienn << endl;
report << "trawl logbook CPUE q " << q_indx_twllog << " a " << a_indx_twllog << endl;
report << "MRFSS index q " << q_indx_mrfss << endl;

report << "female trawl length comps (residuals)" << endl;
report << lenbins << endl;
report << trans(obs_lcomp_twl_f)-C_lcomp_twl_f << endl;
report << "male trawl length comps (residuals)" << endl;
report << lenbins << endl;
report << trans(obs_lcomp_twl_m)-C_lcomp_twl_m << endl;
report << "female rec length comps (residuals)" << endl;
report << lenbins << endl;
report << trans(obs_lcomp_rec_f)-C_lcomp_rec_f << endl;
report << "male rec length comps (residuals)" << endl;
report << lenbins << endl;
report << trans(obs_lcomp_rec_m)-C_lcomp_rec_m << endl;

report << "female trawl age comps (residuals)" << endl;
report << " 1992 1993 1994 1995 1996 1997" << endl;
report << obs_acomp_twl_f-C_acomp_twl_f << endl;
report << "male trawl age comps (residuals)" << endl;
report << " 1992 1993 1994 1995 1996 1997" << endl;
report << obs_acomp_twl_m-C_acomp_twl_m << endl;
report << "female rec age comps (residuals)" << endl;
report << " 1992 1993 1994 1995 1996 1997" << endl;
report << obs_acomp_rec_f-C_acomp_rec_f << endl;
report << "male rec age comps (residuals)" << endl;
report << " 1992 1993 1994 1995 1996 1997" << endl;
report << obs_acomp_rec_m-C_acomp_rec_m << endl;

report << "Recruitment (age 1) time series (1973-98)" << endl;
report << " 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998" << endl;
report << N_c_ts << endl;
report << "Age 3+ Biomass time series (1973-98)" << endl;
report << " 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998" << endl;
report << B3_c_ts << endl;

report << "Spawning Biomass time series" << endl;
report << " 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998" << endl;
report << SSB_ts << endl;

report << "Exploitation Fraction time series" << endl;
report << " 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998" << endl;
report << "Trawl " << elem_prod(pred_L_twl,1/B3_c_ts) << endl;
report << "Non-Trawl " << elem_prod(pred_L_ntwl,1/B3_c_ts) << endl;
report << "Recreational " << elem_prod(pred_L_rec,1/B3_c_ts) << endl;

report << "N_c" << endl;
report << N_c << endl;
report << "N_f" << endl;
report << N_f << endl;
report << "N_m" << endl;
report << N_m << endl;

report << "F_twl_f" << endl;
report << F_twl_f << endl;
report << "F_twl_m" << endl;
report << F_twl_m << endl;
report << "F_ntwl_c" << endl;
report << F_ntwl_c << endl;
report << "F_rec_f" << endl;
report << F_rec_f << endl;
report << "F_rec_m" << endl;
report << F_rec_m << endl;

report << "C_twl_f" << endl;
report << C_twl_f << endl;
report << "C_twl_m" << endl;
report << C_twl_m << endl;
report << "C_ntwl_f" << endl;
report << C_ntwl_f << endl;
report << "C_ntwl_m" << endl;
report << C_ntwl_m << endl;
report << "C_rec_f" << endl;
report << C_rec_f << endl;
report << "C_rec_m" << endl;
report << C_rec_m << endl;

report << "biomass (females)" << endl;
report << B_f << endl;
report << "biomass (males)" << endl;
report << B_m << endl;
report << "biomass (combined sex)" << endl;
report << B_c << endl;

report << " 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998" << endl;
report << "Trawl Landings (observed)" << endl;
report << obs_L_twl << endl;
report << "Trawl Landings (estimated)" << endl;
report << pred_L_twl << endl;
report << "Non-Trawl Landings (observed)" << endl;
report << obs_L_ntwl << endl;
report << "Non-Trawl Landings (estimated)" << endl;
```

```
report << pred_L_ntwl << endl;
report << "Rec Landings (observed)" << endl;
report << obs_L_rec << endl;
report << "Rec Landings (estimated)" << endl;
report << pred_L_rec << endl;
```

Appendix III. AD Model Builder data file used in this assessment. Growth transition arrays are not shown due to space limitations.

```
# starting year of model
1973
# starting year for recruitment time series
1978
# ending year of model
1998
# number of length and age bins
20
14
# age bins
1 2 3 4 5 6 7 8 9 10 11 12 13 14
# length bins
200    400    440    480    520    560    600    640    680    7
20
760    800    840    880    920    960    1000   1040   1080
1200
# natural mortality
0.25
# sex ratio (females/males)
0.5
# fraction year when fishing occurs
0.5
# year when fishery started
1992
1992
# length-weight parameter vector for females [a,b]
0.0000007042  3.3978
# length-weight parameter vector for males [a,b]
0.00000241  3.2149
# probability transition array 1 females [age(t),length(t),length
proportions(t+1)]
        [not shown]
# probability transition array 1 males [age(t),length(t),length
proportions(t+1)]
        [not shown]
# probability transition array 2 females [age(t),length(t),length
proportions(t+1)]
        [not shown]
# probability transition array 2 males [age(t),length(t),length
proportions(t+1)]
        [not shown]
# length proportions for the first age (females)
0.14865 0.85135 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
# length proportions for the first age (males)
0.005 0.995 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
# observed length comps trawl female (1992-1997) [length,year]
0.019841553    0.005889882    0.007670399    0        0.000560049    0
0.040727523    0.049497431    0.003269359    0.001029528    0
0.003856616
0.097654928    0.13146568     0.017869686    0.004148148    0.011222
457    0.004098127
0.154371782    0.169724203    0.081376367    0.002088106    0.020634
189    0.013574696
0.092266971    0.151715922    0.119556568    0.007099347    0.082813
418    0.047721202
0.071271387    0.16059731     0.124976881    0.048578873    0.128373
355    0.060026833
0.085804612    0.127492665    0.162617084    0.11794734     0.166738
341    0.073340668
0.134104299    0.045853903    0.100043499    0.140425619    0.141595
983    0.067874321
0.109090568    0.04230425     0.062336569    0.093118955    0.118681
       0.047544052
0.057373698    0.05349547     0.054149559    0.149730252    0.170580
```

136 0.121159936
0.024360442 0.022136453 0.065034403 0.049870026 0.061070
042 0.165906298
0.050979766 0.010886151 0.041782768 0.16737391 0.052437
534 0.092595909
0.034160924 0.00525569 0.063167399 0.04159487 0.010896
176 0.095306199
0.019343756 0.006535788 0.039551564 0.050091873 0.003947
992 0.08503211
0.003762517 0.00630435 0.014180977 0.068801582 0.019965
181 0.067282839
0 0.010844854 0.022166723 0.025882381 0.010484141
0.042413118
0.00412163 0 0.012783965 0.004049905 0
0.01088736
0 0 0 0.028169286 0 0
0 0 0.00746623 0 0 0.001379714
0 0 0 0 0 0
observed length comps trawl male (1992-1997) [length,year]
0.004328502 0.020196622 0 0 0 0.000944686
0.041916668 0.081261306 0.008672595 0.001409977 0
0.004800025
0.165145645 0.202273489 0.024548303 0.003022327 0.007825
745 0.005976948
0.130307466 0.147928325 0.115437982 0.000986237 0.067417
237 0.101218357
0.092463673 0.112473781 0.32360862 0.074262198 0.119149
957 0.227454955
0.184593833 0.192158825 0.199283007 0.22940298 0.238220
075 0.278734796
0.164516874 0.12420007 0.135689692 0.15204815 0.130782
081 0.174756417
0.097301951 0.046326042 0.095244115 0.338583713 0.239835
104 0.105722479
0.064469266 0.061286892 0.069199301 0.140806639 0.095216
446 0.048255674
0.022588242 0.009159575 0.028316426 0.059477802 0.055646
807 0.011908567
0.015249981 0.002735102 0 0 0.045906494
0.036605602
0.00819528 0 0 0 0 0
0.008922612 0 0 0 0 0.003621525
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
observed length comps recreational female (1992-1997) [length,year]
0 0 0 0 0.002409639 0
0 0 0 0 0 0
0.003984064 0.007936508 0 0 0.002409639 0
0 0.015873016 0.0125 0 0.014457831 0
0.091633466 0.103174603 0.10625 0.028061224 0.086746
988 0.054982818
0.155378486 0.162698413 0.1125 0.178571429 0.146987952
0.151202749
0.155378486 0.146825397 0.1375 0.232142857 0.103614458
0.161512027
0.143426295 0.123015873 0.14375 0.191326531 0.127710
843 0.154639175
0.179282869 0.123015873 0.16875 0.099489796 0.159036
145 0.120274914
0.115537849 0.142857143 0.10625 0.117346939 0.151807
229 0.178694158
0.06374502 0.079365079 0.0625 0.068877551 0.084337349
0.082474227
0.03187251 0.027777778 0.05 0.033163265 0.053012048
0.041237113
0.035856574 0.015873016 0.05 0.022959184 0.043373494
0.030927835
0.003984064 0.03968254 0.04375 0.010204082 0.016867
47 0.020618557
0.007968127 0.007936508 0 0.017857143 0.002409639
0.003436426

```
0.003984064 0.003968254 0.00625 0 0.002409639 0
0.007968127 0 0 0 0.002409639 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
# observed length comps recreational male (1992-1997) [length,year]
0 0 0 0.002525253 0 0
0.01056338 0 0 0 0 0
0.031690141 0.014285714 0.020408163 0 0.003225806 0
0.031690141 0.1 0.091836735 0.012626263 0.019354839
0.014035088
0.246478873 0.2 0.295918367 0.26010101 0.14516129
0.214035088
0.330985915 0.242857143 0.224489796 0.376262626 0.3
0.315789474
0.204225352 0.264285714 0.163265306 0.166666667 0.254838
71 0.235087719
0.073943662 0.121428571 0.132653061 0.090909091 0.183870
968 0.150877193
0.045774648 0.035714286 0.071428571 0.060606061 0.061290
323 0.045614035
0.017605634 0.014285714 0 0.02020202 0.032258065
0.021052632
0.003521127 0 0 0.007575758 0 0.003508772
0.003521127 0 0 0.002525253 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0.007142857 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
# observed landings (mt) trawl (combined) (1973-1998)
1488 1514 1200 1279 678 1022 1388 1249 1257.9 1
381 883 822.2 413.3 225.4 498.8 474.3 615.1 574 4
54.3 311.4 433.8 405.7 334.1 328.7 372.9 93
# trawl landings cv
0.1
# observed landings (mt) non-trawl (combined) (1973-1998)
227 265 269 168 236 311 313 118 127.1 1
88.4 221.8 223.4 337.8 364.1 434.6 501.5 724 612.3 3
92.8 364.2 331.3 284.3 274.2 229.4 252.3 90.4
# trawl landings cv
0.1
# observed landings (mt) recreational (1973-1998)
394 390 420 413 275 327 325 1658.4 1150.9 860.4 574.4 501.4 965 918
944.5 1035.1 955.4 765.2 794.5 772.2 589.0 376.1 441.1 365.6 260.5
284.2
# recreational landings cv
0.1
# logistic selectivity parameters for nontrawl fishery (slope,L50)
0.038751 505.5262
# logistic selectivity parameters for recreational fishery (slope,L50)
0.079 524.63
# female trawl age compositions (1992-97) [age,year]
0 0.000113183 0.000150258 0 0 0
0.038736125 0.043374453 0.007651938 0 0.001532893
0.00426101
0.198686032 0.180921177 0.070951339 0.00242727 0.020642
805 0.049079824
0.193571048 0.222472652 0.181672689 0.014827071 0.130999
93 0.084653718
0.165126529 0.172847718 0.153597861 0.116138203 0.201429
809 0.123027021
0.175856452 0.144725642 0.174282829 0.116752403 0.211405
493 0.182766765
0.079232361 0.096227075 0.115310965 0.145992629 0.206162
169 0.146747036
0.080368263 0.054427201 0.091689472 0.223359211 0.096637
588 0.092885201
0.059692103 0.034622086 0.090619194 0.161567935 0.074173
731 0.102520137
0.003796125 0.032926603 0.058746727 0.078983222 0.022733
45 0.047720843
0 0.00511884 0.0376941 0.05800953 0.007091114
```

0.110247739
0 0.007087016 0.00836554 0.01802543 0.027191019
0.028246541
0.004934962 0.005136354 0.009267089 0.030629878 0 0
.002001749
0 0 0 0.033287 0 0.025842
male trawl age compositions (1992-97) [age,year]
0 0.000449776 0 0 0 0
0.025371852 0.030167143 0.003551962 0 0
0.010060582
0.204686699 0.163284245 0.061237416 0.00160622 0.026812
852 0.15937807
0.214511713 0.201056411 0.214925861 0.001070813 0.110156
982 0.206594916
0.162062787 0.123778085 0.196477088 0.091303548 0.162950
093 0.257626114
0.263157194 0.132260957 0.206478938 0.106204581 0.165069
804 0.099351632
0.035436664 0.149170572 0.158127802 0.174493455 0.207969
517 0.097715771
0.071512786 0.056433736 0.036616563 0.155482061 0.108100
99 0.028219988
0.023260306 0.096026708 0.090452405 0.230502557 0.136313
53 0.057815278
0 0.02682189 0.023165144 0.075191157 0.065014369
0.013394454
0 0.015394149 0.005928404 0.068833204 0
0.008589662
0 0 0.003038416 0.078303207 0.017611864
0.035799289
0 0.005156329 0 0.017009197 0 0.006702008
0 0 0 0 0 0.018752236
female recreational age compositions (1992-97) [age,year]
0 0 0 0 0 0
0 0 0 0 0.00243309 0
0 0.00456621 0 0 0.00729927 0.016129032
0 0.127853881 0.056737589 0.053050398 0.121654501
0.060483871
0.2 0.173515982 0.191489362 0.278514589 0.201946472
0.157258065
0.133333333 0.173515982 0.177304965 0.289124668 0.294403
893 0.245967742
0.2 0.228310502 0.191489362 0.164456233 0.172749392
0.274193548
0.333333333 0.136986301 0.191489362 0.108753316 0.099756
691 0.149193548
0.133333333 0.082191781 0.078014184 0.061007958 0.051094
891 0.056451613
0 0.0456621 0.056737589 0.031830239 0.02676399
0.032258065
0 0.01369863 0.035460993 0.01061008 0.01703163
0.004032258
0 0.00456621 0.007092199 0.00265252 0.00243309 0
0 0 0.014184397 0 0.00243309 0
0 0.009132 0 0 0 0.004032
male recreational age compositions (1992-97) [age,year]
0 0 0 0 0 0
0 0 0 0.002583979 0 0
0.104166667 0.024390244 0 0 0.003246753
0.003968254
0.041666667 0.113821138 0.031578947 0.049095607 0.097402
597 0.075396825
0.229166667 0.243902439 0.2 0.271317829 0.266233766
0.21031746
0.166666667 0.260162602 0.221052632 0.315245478 0.324675
325 0.305555556
0.125 0.178861789 0.273684211 0.15503876 0.181818182
0.277777778
0.208333333 0.081300813 0.147368421 0.085271318 0.081168
831 0.099206349
0.083333333 0.048780488 0.084210526 0.036175711 0.019480
519 0.023809524
0.020833333 0.040650407 0.031578947 0.033591731 0.022727
273 0.003968254
0 0 0.010526316 0.028423773 0.003246753 0
0 0.008130081 0 0.015503876 0 0

```
0.020833333   0        0        0.005167959   0        0
0        0        0        0.002583979   0        0
# triennial survey (monterey, 1977,80,83,86,89,92,95,98)
1800   671    1467   611    2107   484    703    651
# triennial survey standard deviations of estimates
659.7 213.2 623.0 179.0 508.2 144.0 243.0 223.0
# triennial logistic selectivity parameters (slope,L50)
0.04101  289.730
# trawl logbook CPUE (lbs./hr.) (1978-96)
46.02  50.15  46.29  50.15  48.31  31.31  26.5  15.87  18.5  27.56  26.4
29.83  30.46  22.96  18.89  20.97  21.73  21.61  17.06
# trawl logbook CPUE standard deviations (based on cv = 0.1)
4.602   5.015   4.629   5.015   4.831   3.131   2.65    1.587   1.85    2
.756    2.64    2.983   3.046   2.296   1.889   2.097   2.173   2.161
1.706
# MRFSS abundance index (# fish caught) (1980-89,93-98)
626.9 347.4 244.0 168.4 158.0 237.1 265.9 287.3 315.3 292.0 0 0 0
159.6 96.4 108.9 122.1 89.5 79.8
# MRFSS abundance index std
68.959  20.844  14.64   20.208  15.8    28.452  55.839  40.222  44.142  4
6.72    0       0       0       12.768  9.64    11.979  10.989  8.055
6.384
# effective sample sizes for age and length comp data (1992-97)
# trawl length female and male
34.43936552    12.16469753    30.49200401    46.92351969    26.11217
3       55.24651188
28.69353381    15.0618156     15.37764725    21.84876149    32.40773
451     9.961335334
# recreational length female and male
131.473598     82.4031234     103.0373361    23.60988146    54.19496
37      40.73531545
20.37021476    31.65306872    16.3968828     8.182343019    16.15211
931     9.281823171
# trawl age female and male
67.45057653    91.67532376    59.97318508    12.19045305    48.30642
612     56.68590211
14.58767433    33.9709357     20.13284485    8.989115875    35.78976
267     22.69200679
# recreational age female and male
4.468562931    12.4610291     11.74604668    11.78085545    24.68007
56      17.31585587
12.957523      11.82512966    8.487568164    10.71734313    12.62877
006     12.38780918
# female length maturity relationship
0.021  557.318
# male length maturity relationship
# 0.016  461.109
# length fecundity relationship (E=aL^b, a,b)
0.000282406  3.0011
```