

**Report of the Pacific Cod Technical Workshop  
Held at the Alaska Fisheries Science Center  
April 24-25, 2007**

**Compiled by Grant G. Thompson and M. Elizabeth Conners**

**U.S. Department of Commerce  
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## Overview

At the request of the Scientific and Statistical Committee (SSC) of the North Pacific Fishery Management Council (SSC minutes, December, 2006), the Alaska Fisheries Science Center (AFSC) convened a public workshop to examine various technical issues pertaining to the assessments for Pacific cod in the Bering Sea (BS), Aleutian Islands (AI), and Gulf of Alaska (GOA). The workshop took place at the AFSC's Seattle lab of the AFSC over a two-day period, from Tuesday, April 24, through Wednesday, April 25. The workshop announcement is attached to this report as Appendix A, and the workshop agenda is attached as Appendix B. SSC chair Pat Livingston served as chair of the workshop. Liz Connors served as rapporteur. A list of workshop participants is attached as Appendix C (total attendance = 44).

The workshop considered a wide variety of technical issues. Results of various model configurations were presented and are included in this report. It is important to emphasize that these results are highly preliminary, were not subject to formal review, and should not be taken as a likely indication of results that will be obtained in this year's final assessments. The workshop was not intended to produce consensus recommendations. Rather, all participants were invited to provide suggestions for this year's assessments. The stock assessment authors will consider all of these suggestions in producing this year's assessments. However, some prioritization will inevitably be necessary, so it should be understood that not all suggestions will actually be implemented in this year's assessments; nor will the models used in this year's assessments necessarily be limited to suggestions made at the workshop.

## Tuesday morning session

The Tuesday morning session featured presentations by AFSC and other scientists on issues that have current or potential implications for the structure of the BSAI and GOA assessments. Each of these presentations is represented below by a summary of the presentation itself and a list of questions and answers that arose during the discussion of the presentation.

### *Survey catchability/availability*

--David Somerton and Dan Nichol (AFSC)

## Summary

### *Trawl Efficiency Research*

The efficiency of a trawl (proportion of fish captured within the swept area) is related to horizontal herding by the bridles and escapement over the headrope, through the meshes and under the footrope. Experiments have been completed to estimation of the quantitative effects of these processes. Herding is examined by varying the width of the bottom area that the bridles stimulate a fish herding response by systematically changing the length of the bridles. When this is done for the trawls used for both the EBS and GOA surveys, an increase in catch with increasing bridle is clearly evident with flatfish species but totally absent with cod. This indicates

that cod are not herded by the bridle configuration used on AFSC survey trawls. Escapement under the trawl footrope is examined by attaching an auxiliary net underneath the trawl net to capture fish escaping under the footrope. Such experiments indicate flatfish have length-dependent escapement under both of the AFSC trawl designs, yet not a single cod of any size has escaped under the footrope in these experiments. This indicates that cod do not possess the appropriate behaviors to allow escapement under the types of footropes used on AFSC trawls. Escapement through the mesh of the trawls has been examined by sewing collecting bags to the outside of the trawl mesh, however cod were not caught during these experiments, so the question of cod mesh escapement is still unanswered.

### *Archival Tag Research*

The percentage of Pacific cod available to Alaskan bottom trawl surveys was estimated from the proximity of tagged cod to the seafloor. Archival tags recorded time and depth data at 15- or 30-min intervals. The distance of a cod above the bottom was computed by subtracting tag depth from bottom depth, estimated as the maximum depth recorded during each 24-h day. These estimates of bottom depth are based on the assumption that cod approach the seafloor at least once a day, and do not undergo migrations up or down bottom gradients. To ensure that migrations over variable bottom gradients did not confound our estimates of bottom depth, we narrowed our analysis to 11 tagged cod that were recaptured in areas of flat bathymetry, and only analyzed data recorded within 1 month prior to recapture ( $N = 29,462$  depth recordings, range of individual fish lengths = 60-81 cm). Pacific cod maintained short distances above the seafloor that often differed between day and night. Over 95% of the daytime tag recordings occurred within 10 m of the seafloor. Average effective headrope heights for survey bottom trawls currently used in the eastern Bering Sea and Alaska Gulf/Aleutian Islands groundfish surveys are approximately 2.5 and 7 m, respectively. In the absence of any behavior responses to an approaching trawl, we would expect 47.3% of the cod within the water column are available to the trawl used on the eastern Bering Sea Survey and 91.6% are available to the trawl used on the Gulf/Aleutian Islands surveys. This study demonstrated that Pacific cod are highly demersal, and current values of trawl survey catchability ( $Q$ ) used in current stock assessments are consistent with estimates of cod availability to the trawl gear.

### **Discussion**

Q: Are there any studies for species that don't dive? A: Pollock will dive in response to vessel noise from large boats (e.g., factory trawlers) but not small survey boats. The big question is how they respond vertically to warps. However, given that they don't seem to herd horizontally, it seems likely that vertical responses will also be small.

Q: Will the AFSC surveys continue to use the same nets in the future? A: Yes. The net we use is not a commercial quality net, but we stay with it so that we have a consistent time series.

Q: With respect to the archival tag study, is a sample size of 11 fish statistically defensible? A: Yes. The sample size is small but usable, so long as the limitations are recognized.

Q: Can the time resolution of archival tags be increased so you can pick up behavior right before

capture to look for diving? A: There is a limit to the amount of data that can be stored. As the limit is approached, the tag automatically changes the resolution and begins overwriting parts of the old data. It may not be possible to set the resolution at a scale fine enough to permit observation of a dive response.

Q: Are there differences in size frequency of catch between the BS and GOA that might be based on catchability differences? A: Yes.

Q: Can you use temperature data from the tag to tell if the fish is on bottom? A: Temperatures typically do not change enough to make this distinction.

Q: Might it be possible to conduct side-by-side trawls between commercial and survey nets? A: Yes. We have talked about conducting parallel-trawl experiments to see if cod are out-swimming the net. However, sample size can be a problem for trawl comparison studies.

Q: What about using the Didson camera/acoustic system? A: It may be worth trying. However, there may be a problem distinguishing cod from pollock.

Q: What is the future of cod tagging experiments? A: We have proposed work to look at horizontal movements, but have not proposed to do any more tagging work on vertical movements.

Q: Are Pacific cod different from Atlantic cod with respect to vertical distribution? A: Different species, and even different populations within a species, have different behavior. Some populations of Atlantic cod spend lots of time on the bottom, but the populations off Norway tend to be much more pelagic.

Q: If you were to use the data from all of the archival tags, then classify these by bathymetric complexity of the recovery locations, how would the results compare to the 11 fish used in your study? A: It would be worth looking at.

Q: In the archival tag study, how much of the variability in observed depths is due simply to changes in bottom depth? A: It was rare to find a tag whose depth profile simply followed the tide signature. However, for fish that spend part of their time at liberty over terrain with variable depth, it is difficult to distinguish bottom depth variability and fish-distance-off-bottom variability. It should be emphasized that the variance associated with the mean estimate of 47% on bottom is very important. Atka mackerel and flatfish were also equipped with archival tags but, in contrast to Pacific cod, these species exhibited much less variability in depth. tagged with same equipment, results very similar fish to fish, but cod very variable. For cod, there were often substantial day-night differences as well.

Q: Do cod from the same area tend to behave similarly? A: We need to look at that further. All 11 recoveries used in this study were from the same area. Even among these 11, though, there was lots of variability in fish behavior.

Q: If the geographic distribution of the 11 tag recoveries is different from the geographic

distribution of the commercial catch, wouldn't this tend to bias the results? A: No, because this study is intended to shed light on the catchability of Pacific cod with respect to the trawl survey, not the commercial fishery.

### *Estimation of movement and survival rates from tagging data*

--Yunbing Shi, Peter Munro, Elizabeth Conners, Sandi Neidetcher (AFSC)

## **Summary**

This presentation was based on four Pacific cod tagging studies conducted since the 1980s in Alaskan waters. 1) Between 1982 and 1990, AFSC RACE released approximately 12,396 anchor tags or lock-on spaghetti tags in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA). A total of 375 tags were recovered between 1982 and 1992. The recovery rate was 3.03%. 2) Between 2001 and 2005, AFSC RACE released 635 archival tags in both EBS and GOA with 287 reported recoveries. The recovery rate was 45.20%. 3) ADF&G have been releasing tags in GOA and EBS since 1997. A total of 13,093 lock-on spaghetti tags have been released between 1997 and 2005 with 790 reported recoveries. The recovery rate was 6.03%. 4) Between April 2002 and November 2003, AFSC FIT released 6394 usable tags in EBS and GOA with 2,160 reported recoveries, a recovery rate of 33.78%.

The presentation covered cod movement, recovery rate by size at release (a potential surrogate for selectivity), and survival and exploitation rate estimation.

### *Cod Movement*

There are two types of movement that both the scientific and industrial communities are interested in, the exchange between large ecosystems and within-ecosystem seasonal movement. Based on the tagging data, Pacific cod exhibits limited between-ecosystem exchange. In general, about 5% to 8% of the tagged cod released in the EBS were recovered in the GOA, mainly in the western GOA. The reverse migration is inconclusive, perhaps due to small sample size or non-representative release locations. There is no information available to describe exchange between EBS and AI or GOA and AI.

Seasonal migration of Pacific cod in the EBS can be summarized as three stages of movement. In winter, mature cod move to spawning ground, with large portion of EBS cod spawning near Unimak Pass, though the percentage cannot currently be estimated. In spring and summer (after spawning), cod disperse to vast feeding grounds over the EBS shelf. In fall, as temperature drops, cod move toward deeper water on the EBS slope. This pattern of movement is consistent with the study published by Shimada and Kimura (1994).

### *Recovery Rate by Size at Release*

Recovery rate by size at release could serve as a surrogate for a selectivity curve. With the AFSC FIT tagging data, the recovery rate by size at release showed general dome shape curves by recovery fishing gear type, which is somewhat in agreement with stock assessment results. It is also noticed that, in general, the longline fishery selects large cod to a greater extent than the

trawl and pot fisheries. To use the recovery rate curve as a surrogate for the selectivity curve, one should carefully examine other factors that may affect the apparent selectivity curve. The decreased recovery rates at large sizes may be due to the following factors other than gear selectivity: 1) size-specific geographical distribution makes large fish unavailable to the fishery; 2) larger (older) fish may suffer higher natural mortality; and 3) larger (older) fish may suffer from higher tag-induced acute mortality, which effectively reduces the number of tags released.

### *Survival and Exploitation Rate Estimation*

A modified Brownie model was used to estimate survival rate and exploitation rate. We estimated tagging induced acute mortality ( $\phi$ ) and reporting rate ( $\lambda$ ) outside the model. The tagging induced acute mortality rates were estimated using on-deck monitoring of fish. Those fish were kept in on-deck portable live tanks for one to several days after being tagged. The tagging induced acute mortality rates for FIT-tagged cod were from 0% to 27.5% depending on culling criteria when selecting live cod for tagging. The reporting rate ( $\lambda$ ) was estimated by comparing the recovery rate to that of high-reward tags (archival tags). The reporting rate for archival tags was assumed to be 100%. The reporting rate for FIT-tagged cod was estimated to be 100%. The model estimated that Pacific cod survival rates were between 0.344 (2003) and 0.538 (2002), and exploitation rates were between 0.161 (2002) and 0.322 (2003). These results are biased due to serious violations of model assumptions. One of the violations is especially serious, which is the violation of the fully mixing assumption. All releases except one took place during the peak commercial fishing season and on key fishing ground. In 2002, tagged fish were released in April, the end of a season. Therefore, the estimated survival and exploitation for 2002 are not annual rates. Further analyses are needed. In winter 2003, tagged fish were released on the major fishing ground during the early part of the peak commercial fishing season. The estimate of survival rate is probably biased too low and exploitation rate is biased too high.

### **Discussion**

Q: Why would the percent recovery by size be dome shaped? A: Larger fish may be less available to the gear, or they may have higher natural mortality.

Q: If natural mortality increases with size, could this confound the assessment's estimates of selectivity? A: Yes, that is possible.

Q: Are there enough data to look at year-to-year differences in movement? A: No. However, the movement patterns in the most recent data tend to match those from previous experiments.

*Can ecosystem models provide a prior distribution for  $M$ ?*

--Kerim Aydin (AFSC)

### **Summary**

For age 2+ cod, very little mortality seems to come from the predation. The estimate of  $M$  used in the assessment is routinely in the neighborhood of 0.4, while predation  $M$  (from other predators) is near 0.04. This isn't necessarily a problem (by definition, a top predator has a

predation  $M$  of 0, and cod are nearly top predators). Other predatory fish (e.g. halibut) have similarly low estimates for predation  $M$ . But many of the other top predators have total  $M$  closer to 0.2, so perhaps total  $M$  for cod is on the high end for a fish at that trophic level. Still, it's within the range of some other fish. Placing a lower bound of 0.04 on the prior for  $M$  isn't very informative. An upper bound for  $M$  based on consumption would probably be much higher than 0.4, which again would not be very informative.

For age 0-1 cod, a minimum predation  $M$  is 1.0, and could be as high as 2.0 or 2.5. Other than affecting absolute recruit numbers, this probably wouldn't affect spawning biomass or other reference point calculations much (compared to leaving age 0-1  $M$  at 0.4), but it is conceivable that fixing  $M$  for young cod at a high value might improve estimates of  $M$  for older ages.

## Discussion

Q: Shouldn't halibut account for a large share of Pacific cod mortality? A: Our best information is that halibut account for about 1% of cod mortality in the BS and 4% in the GOA.

Q: Given that ICES found temporal and spatial variability of stomach content data to be so high that usefulness of these data for estimating  $M$  was extremely limited, what do you think the prospects are for using stomach content data to estimate  $M$  in Pacific cod? A: There is indeed a large amount of variability in the data. It is most useful in looking at time series across regimes.

Q: If  $M$  for 1 and 2 year olds is very high, might this tend to increase the uncertainty in the assessment model's estimates of recruitment? A: Yes.

Q: If there is no substantial predation on large cod, what is the source of natural mortality for large cod? A: This is a puzzle. Other top predators have long life spans. However, the estimated predation rates on Pacific cod are subject to a great deal of uncertainty, particularly with respect to the marine mammal component.

## *Reproductive potential of Pacific cod in Alaska: maternal and area effects*

--Olav Ormseth (AFSC)

## Summary

Pacific cod in Alaska spawn in February and March. They produce 1-15 million eggs approximately 1 mm in diameter. Understanding the factors that influence female reproductive potential- the number of eggs a female produces (fecundity), as well as the likelihood of those eggs' survival- is crucial for fisheries management. My recent work using samples collected from the Gulf of Alaska (GOA), eastern Bering Sea (EBS), and western Aleutian Islands (AI) has produced the following information regarding area, year, and maternal effects on Pacific cod reproductive potential:

- Fecundity increases with female age and size. Length and somatic weight (body weight minus gonad weight) are particularly good predictors of fecundity (e.g., in the EBS in 2004 the length/ somatic weight relationship had an  $R^2$  of 0.94).
- Egg dry weight, which I used as a proxy for egg quality, is highly variable. In some areas



egg dry weight is unrelated to age or size, while in other areas it declines slightly with size (e.g. in the AI in 2005, the egg dry weight/length relationship had an  $R^2$  of 0.14).

- Arachidonic acid, an essential fatty acid that has been linked to egg quality, declined slightly with female size in eggs collected in the AI ( $R^2 = 0.27$ ). This suggests that eggs from older and larger females may be of somewhat lower quality.
- Relative fecundity (fecundity per gram of body weight) is variable and increases slightly in older and larger females ( $R^2 = 0.07$  in the EBS in 2004). This suggests that a population of older females will produce more eggs than a population of younger females. However the increase is small enough that the assumption that spawning stock biomass is proportional to reproductive potential is still valid.
- Reproductive potential varies among areas and years. This appears to be due to variability in egg size, while fecundity remains fairly constant.
- The fatty acid composition of egg lipids is very different between the EBS and AI. While some of this may be due to variation in diet, there also appears to be evidence of adaptation in each area. This suggests that there are genetic differences between females from the EBS and AI.
- Pacific cod appear to maximize their reproductive potential by increasing egg production, even at the cost of producing smaller (and potentially lower quality) eggs.

## Discussion

Q: Since the age composition of the population is different between the EBS and AI, does this account for the difference in egg composition between the two areas? A: Probably not. The difference in arachidonic acid (AA) content between the areas is much bigger than the age-related differences in AA content. Also there is overlap in the age and size distributions between the two areas, but there is no overlap in the fatty acid profiles between the areas.

Q: Are fatty acid concentrations consistent year to year? A: There are not enough data from Alaska to tell, but polar lipids are highly regulated and usually do not show large interannual differences (a study in Atlantic cod showed identical fatty acid composition over 3 years under very different conditions).

Q: So, is the assessment model's assumption of constant reproductive output per unit spawning biomass probably OK? A: Yes. When I did see trends they were slight. Any variability due to failure of this assumption is probably small relative to other parts of the model.

Q: Has the sex ratio in Pacific cod changed much over time? A: No. It has been pretty close to 50/50 over time.

### *Multispecies Aleutian Islands assessment model*

--Doug Kinzey (University of Washington)

## Summary

Data from stomach samples, fisheries, and research surveys for Pacific cod, Atka mackerel, and walleye pollock in the Aleutians were combined with 7 different predation models in a

multispecies extension to the age-structured assessment model, Amak.

The incorporation of data on diets along with predator-prey interactions into an age-structured assessment produces parameter estimates that can be compared to single-species models.

Different predation models were able to fit the observed sampling data from fisheries and surveys reasonably well.

To date, the assessments that included predation fit the diet data less well.

Effective sample size was an important factor in determining how well a source of data was fit by the model.

Different choices of predation model can have huge effects on unobserved, derived outputs such as recruitment.

## **Discussion**

Q: Does your model include predation from pinnipeds? A: Potentially. We are not fitting diet data from pinnipeds but the effects of other predators, including pinnipeds, are represented in the model by the estimates for natural mortality.

Q: Given that cod abundance in the various models appears pretty much the same with or without predation (because most mortality is on juveniles, where it affects estimation of recruitment rather than mortality), how will a multispecies model improve stock assessment? A: Don't know yet. We will be looking at simulations comparing parameter estimates from the multispecies configurations to estimates from the single species configurations. There are several uses for multispecies models other than stock assessment; for example, to evaluate the roles species play in the trophic dynamics of the ecosystem.

Q: Is the uncertainty in the food habits data large enough that we would not be able to detect an existing trend, and would the multispecies model allow you to detect a trend that would be missed in a single species model? A: Don't know yet. We will be evaluating this with the data we have by comparing the outputs of different configurations and by using simulated data sets to represent the potential effects of differing amounts and kinds of data.

### *Ageing issues and progress*

--Delsa Anderl (AFSC)

## **Summary**

### *Overview of Pacific cod ageing at AFSC*

Annual production age data from otoliths are available from 1984 to date. Age data prior to 1984 were determined from scales and/or otoliths. All RACE Bering Sea survey otolith collections since 1984 have been aged. Aleutian Islands RACE survey collections are yet to be aged. We are

systematically ageing RACE GOA collections from recent to past surveys and are currently working on the 1993 collection. We have 2 more collection years to complete. After completion, we plan to work on sub-sampled fishery collections.

Since 1984, there have been 9 Pacific cod age readers. Historically, new age readers were trained by working with experienced readers for 6 months to a year.

#### *Problems with Pacific cod ageing*

In 1994, it was noticed by data users that the length at age of Pacific cod had been declining from 1989 to 1993 so that by 1993 the size at age of 2, 3, and 4 yr old fish were similar to size at age of 1, 2, and 3 yr old fish from the dominant 1977 year class.

Possible causes identified were: environmental effects, ageing preparation & methodology, edge type decisions, consistency in the application of ageing criteria, and problematic otolith patterns.

A number of papers have been published regarding environmental changes (regime shifts) affecting marine biological growth. An appropriate comparison is the similar decline in length at age of Pacific halibut which occurred at about the same time as the decline in Pacific cod.

A new otolith preparation method (oven toasting) was found to produce better pattern definition for Pacific cod.

Edge type decisions are problematic and need to be further investigated using seasonally collected fishery samples. We are not including edge counts in young fish from survey samples which are generally collected from May to August.

#### *Validation studies*

Two recent age validation studies have helped us to interpret problematic otolith patterns of Pacific cod:

Andrews, A.H. 2002. Preliminary radiometric ageing of the Pacific cod. Final report to the Alaska Department of Fish and Game. This study confirmed that Pacific cod are fast growing, short-lived fish and not long-lived fish.

Roberson, N. 2001. Pacific cod: The ageing of a difficult species. This study helped identify checks from annuli by back-calculating fish age at length using otoliths from known length at tagging and recapture of tagged Pacific cod.

#### *Addressing the ageing problems*

We have changed our methodology from breaking and burning otolith cross-sections to oven toasting, resulting in better otolith patterns. We have established stronger protocol and criteria to better identify the early annuli. An ageing manual has been drafted to include in the training of new Pacific cod age readers and also to be used as a review reference by seasoned age readers.

### *Future work*

We want to do a comprehensive study of edge types when we begin ageing fishery samples. We are currently collecting otoliths to include in a reference collection to be used as refresher specimens for seasoned age readers. We would like to incorporate recently found otoliths that include fish from the 1977 year class in a new study. Lastly, it would be nice to investigate the feasibility of further age validation studies using stable isotope and possibly known-age tagging.

### **Discussion**

Q: What proportion of otoliths have edge type problems? A: Above age 3, maybe 50%.

Q: Are the checks distributed throughout all ages, or mostly in the young fish? A: In all ages.

Q: Do length modes in re-aged otoliths fit the same modes seen in the past? A: Pretty much, but the range of length at age is wide.

Q: Are you confident about estimates of age 3 fish? A: Yes, pretty confident.

### **Tuesday afternoon session**

The Tuesday afternoon session consisted of presentations by AFSC scientists involved in developing model runs in preparation for the workshop and an opportunity for workshop participants to suggest additional model runs to be conducted prior to the Wednesday morning session.

### *Fishery and catch sampling issues*

--Jim Ianelli (AFSC)

### **Summary**

Patterns in the different Pacific cod fisheries were examined seasonally and spatially with a goal to provide some insight on how things have changed over time and if the current seasonal and fishery breakouts are reasonable. Overall, data from 1991-2006 indicated that the main gear types (trawl, longline, and pot) had a seasonal pulse during the first four months of the year, followed by a period of about 4 months of low fishing levels, and then an increase in removals starting September through the remainder of the year (Figure 1). This second season was strongest for longline gear, followed by only relatively moderate removals by trawls and pot gear. The “second season” was variable in different years for all gear types. Early in the time series (1991 and 1992) the longline fishery operated at steady monthly levels throughout the year prior to switching to the current seasonal pulse pattern.

The fishery data was also recompiled and examined for patterns in size and sex and length-weight relationships. On average, the sex ratio observed in the fishery is very consistently 50:50.

However, broken out by size categories revealed a higher proportion of males for the largest Pacific cod (>69cm) and that the sex ratio for this size category increased from about 54% during the 1990s to nearly 60% since then (Figure 2).

Length weight data for Pacific cod from observer data show distinct seasonal patterns of mean weight given length. It appears that the highest weights conditioned on length occur in March, followed by a drop to the lowest observed weights during early summer (Figure 3). Presumably this is related to spawning activity and possibly changes in where the fishery is prosecuted. Seasonal observer data length frequency and length-weight data were combined with official catch data (for the same seasons) and analyzed in a two-stage sampling routine developed at the AFSC. This was modified to allow for two-stage resampling as an alternative means for obtaining levels of sampling error (e.g., Figure 4). Overall, the data recomputations resulted in minor differences from the current length frequencies. The alternative approach for examining the sampling error should be useful for specifying the dispersion parameters in the assessment model (e.g., the effective sample size for the multinomial likelihood components).

## **Discussion**

Q: Does the low trawl fishery catch observed in the winter of 2007 forecast a small survey biomass for 2007? A: Not necessarily.

Q: Is length at age or gear selectivity different for males and females? A: The possibility of sex-specific differences in weight at length and length at age was examined in the 2005 assessments, at which time it was concluded that there did not appear to be any. However, the possibility of sex-specific natural mortality was not examined.

Q: What proportion of the length frequency data can be stratified by sex? A: Nearly all of it.

### *Modeling issues and progress*

--Grant Thompson, Jim Ianelli, and Martin Dorn (AFSC)

## **Summary**

### *What's new in SS2*

The Stock Synthesis 2 (SS2) assessment program has undergone substantial revision since last year's assessments were conducted. A major upgrade was released in February, and various changes to the code have been made since, some as recently as a few days before the workshop. While it would not be appropriate to describe all of the changes in this report, a few of the changes with significant potential impact on the Pacific cod assessments are described below.

1. Variability in length at age can now be specified as any of four functions
  - a. coefficient of variation (CV) is a linear function of length (this was the only option in previous versions of SS2)
  - b. CV is a linear function of age
  - c. standard deviation (SD) is a linear function of length

- d. SD is a linear function of age.
- 2. Maturity can now be specified as either of two functions
  - a. logistic function of length (this used to be only option)
  - b. logistic function of age
- 3. Recruitment
  - a. “Regime shifts” are now easier
  - b. Previously, pre-shift median recruitment and regime “link” were independent, so had to be estimated iteratively
  - c. Now, regime link can be defined to apply directly to the pre-shift median
  - d. Disequilibrium initial agecomp devs can now be defined relative to pre-shift median (this was a very recent code change)
- 4. Other changes
  - e. “Symmetric beta” option for priors (now possible to have fairly large CV--up to about 0.58--without hitting bounds)
  - f. New preferred selectivity function (this is described in detail below)

### *SSC Requests*

The SSC requested that the following topics be addressed during the workshop:

1. Estimation of growth inside/outside the model
2. Conditional estimation of the natural mortality rate  $M$  and survey catchability  $Q$ 
  - a. Models that fix  $Q$  and estimate  $M$
  - b. Models that fix  $M$  and estimate  $Q$
3. Model sensitivity to weights assigned to the priors and data components
4. Use of a logistic form for survey selectivity and estimability of the descending portions of the survey and fishery selectivity schedules
5. Models that fix both  $M$  and  $Q$  at different values within a factorial design

In preparing for the workshop, the following general strategy was used to make sure that the SSC requests were addressed:

1. Create a “base model” (one for the BS and another for the GOA) capable of being tweaked in all of the ways requested.
2. Change one thing at a time.
3. List the resulting changes in key outputs (e.g., biomass)

It should be emphasized that this strategy does *not* provide an exhaustive exploration of all possible models. Rather, it develops a baseline from which further points of departure can be explored (ideas for departures are welcome!).

### *Description of Base Model*

The first step in the strategy outlined above is to create a base model. One possibility would be to use last year’s models (i.e., the models recommended by the assessment authors and adopted by the Plan Teams). However, there are at least a couple of reasons why this would likely be an unproductive approach:

1. Convergence problems. The objective function in last year’s BS model exhibited multiple minima. This may have been due in part to problems with differentiability of the

selectivity function used in last year's version of SS2 (version 1.23). In any case, it would probably be unwise to start with a model that has difficulty finding the global minimum of the objective function.

2. The new features of SS2 version 2.00 make SS2 version 1.23 obsolete. It is impossible to get an exact match between models developed under the two versions. Moreover, it would be inefficient to stick with version 1.23 for the workshop, only to abandon it for version 2.00 immediately thereafter.

Therefore, instead of using last year's models as the base models, new base models were developed for the workshop. In developing these base models, the following features were desired:

1. No radical changes from previous models
2. 2006 biomass similar to estimate given in last year's SAFE report
3. Capable of being tweaked in lots of ways
4. Evidence of convergence stability
5. Priors that are:
  - a. Easily interpretable, to the extent possible
  - b. Moderate (i.e., CVs neither extremely small nor extremely large)

The basic idea is that the base model provides a convenient starting point for exploration of alternatives. It is also important to keep in mind what the base model is *not*. In particular, the base model is not necessarily any of the following:

1. The model that will be used to set next year's ABC and OFL
2. The assessment authors' current favorite model
3. The central tendency of all possible models

The main data structure used in the base models is unchanged from that used in last year's assessments. The data types consist of the following:

1. Total catch
2. Catch length composition, structured by:
  - a. three eras (foreign, domestic, and "new" (post-1999))
  - b. three seasons (Jan-May, Jun-Aug, Sep-Dec)
  - c. four gears (Jan-May trawl, Jun-Dec trawl, longline, pot)
3. Survey relative biomass
4. Survey length composition
5. Survey age composition
6. Survey mean length at age

A few individual data did change, however. These were as follow:

1. New initial equilibrium catch (higher, because start year is later—discussed below)
2. Current environmental regime starts in 1976 rather than 1977 (discussed below)
3. One sizecomp record turned "off" in BS data
  - a. Record for Sep-Dec trawl fishery in 1989
  - b. Appeared to be outlier (no large fish)
  - c. Effect minor (input N already very small)

Relative to last year’s assessments, the following table describes the main new features of the control files used in the base models:

Feature	Base model	Last year’s assessment
$M$ , length-at-age parameters	Estimated internally	Estimated externally
Initial age structure	Disequilibrium	Equilibrium
Pre-shift median recruitment	Estimated internally	Estimated iteratively
Start year	1976	1964
Selectivity pattern	6-parameter double normal	4-parameter double normal
Priors	Consistent rule applied	Various rules applied

The rationale for each of the new features was as follows:

1. Given that internal estimation of  $M$  and length-at-age parameters was required in order to address some of the SSC requests, it was convenient to build these capabilities into the base models.
2. The version of SS2 used for the 2005 assessments required that the initial age composition be in equilibrium. This assumption was retained for the 2006 assessments. However, SS2 now has the capability of estimating each element of the initial age composition individually. Unless a fairly early starting year is specified in the model, assuming an equilibrium initial age structure can bias the estimates of recent age structures.
3. The 2005 and 2006 assessments used a very time-consuming procedure to tune the recruitment parameters manually in order to account for the effects of the environmental regime shift that occurred during the late 1970s. This procedure has been automated in the latest version of SS2.
4. Preliminary model runs for the BS, in addition to last year’s BS assessment, consistently found that the 1976 year class was much larger than any other in the time series. The pattern of recruitment residuals is much less extreme if the current environmental regime is defined to start in 1976, instead of the previously assumed date of 1977. Given SS2’s new ability to estimate a disequilibrium initial age composition, and given that there is very little catch data and no survey data prior to 1976, it seemed prudent to change the starting year to 1976.
5. The new selectivity pattern and prior distributions are described in detail in the following paragraphs.

As noted above, one of the things that may have led to convergence problems with the 2006 BS assessment model was that the 4-parameter double-normal selectivity function used in that assessment exhibited differentiability problems. For the base models developed here, a new, 6-parameter form of the double-normal selectivity pattern was used instead. As with the double-normal selectivity pattern used in last year’s assessments, the new form is constructed from two underlying and rescaled normal distributions, with a horizontal line segment joining the two peaks. Figure 5 shows an example of how the new double normal selectivity pattern is constructed. The new form uses the following six parameters:

1. Beginning of peak region
2. End of peak region
3. Ascending “width” (equal to twice the variance of the underlying normal distribution)
4. Descending width



5. Selectivity at minimum length (not used in old form)

6. Selectivity at maximum length (not used in old form)

All but the “beginning of peak region” parameter are transformed: The widths are log-transformed and the other parameters are logit-transformed.

In last year’s assessments, prior distributions were assigned to various parameters based on a fairly complicated set of rules (e.g., BSAI SAFE Report pages 251-253). In order to make the prior distributions more readily interpretable and to facilitate consideration of the SSC’s request to examine the influence of the prior distributions, the base model made use of a consistent rule for specifying the prior distributions for nearly all parameters. This rule specified that prior distributions exhibit a CV of 50% on the “natural” scale. Here, the “natural” scale refers to the back-transformed value of any parameter that is transformed for estimation within SS2, or to the parameter itself if it is not transformed for estimation within SS2. For example, SS2 estimates the natural log of  $Q$  rather than  $Q$  itself, so the prior distribution specified for  $\ln(Q)$  was structured so as to imply a 50% CV for the corresponding prior distribution for  $Q$ . The only parameters to which the “50% CV” rule was not applied were the standard deviation of log-scale recruitment deviations (which was estimated iteratively with no prior distribution, converging on a value of 0.63 in the BS base model and a value of 0.22 in the GOA base model), the median log recruitment in the current environmental regime, and the Bering Sea slope bottom trawl survey  $Q$ . The estimated parameters, distributional forms, and “natural” scale CVs are summarized below (note that the selectivity priors apply to each fishery and survey):

Parameter	Distribution	“Natural” scale CV
sdev(ln(recruits) deviations)	n/a	n/a
post-75 median(ln(recruits))	normal	very large (noninformative prior)
BS slope trawl survey $\ln(Q)$	normal	very large (noninformative prior)
$M$	symmetric beta	50%
length at age 1 (cm)	symmetric beta	50%
length at age 12 (cm)	symmetric beta	50%
Brody growth coefficient $K$	symmetric beta	50%
shelf trawl survey $\ln(Q)$	symmetric beta	50%
beginning of peak region	symmetric beta	50%
logit(end of peak region)	normal	50%
ln(ascending width)	normal	50%
ln(descending width)	normal	50%
logit(selectivity at 10 cm)	normal	50%
logit(selectivity at 110 cm)	normal	50%

It should be emphasized that the “50% CV” rule is a pragmatic convenience adopted for the purposes of the workshop, and should not be taken as an empirical estimate of the prior uncertainty associated with each of the parameters to which it was applied in the base models.

For each of the parameters, a prior mean was specified as follows:

Parameter	BS	GOA	Rationale
sdev(ln(rec) devs)	n/a	n/a	parameter fixed iteratively (no prior)

post75 med(ln(rec))	10	10	arbitrary (noninformative prior)
slope survey ln( $Q$ )	-4.52	n/a	arbitrary (noninformative prior)
$M$	0.37	0.37	traditional value
len@age1 (cm)	11.1	13.8	external maximum likelihood estimate
len@age12 (cm)	93.3	93.0	external maximum likelihood estimate
Brody growth $K$	0.113	0.108	external maximum likelihood estimate
shelf survey ln( $Q$ )	-0.288	-0.288	best guess = ln(0.75)
begin peak	60	60	sets begin peak midway between $L_{min}$ , $L_{max}$
logit(end peak)	0	0	sets end peak midway between beginning, $L_{max}$
ln(asc width)	7.131	7.131	sets inflection at midpoint of ascending limb
ln(des width)	5.745	5.745	sets inflection at midpoint of descending limb
logit(sel@ $L_{min}$ )	-6.907	-6.907	sets selectivity at $L_{min}$ equal to 0.001
logit(sel@ $L_{max}$ )	2.197	2.197	sets selectivity at $L_{max}$ equal to 0.9

Two points should be noted with respect to the above table: First, for the shelf survey in both the BS and GOA, the mean for logit(sel@ $L_{min}$ ) was set at -2.197 (rather than the value of -6.907 used for the fishery selectivity schedules), corresponding to a 10% selectivity at 10 cm. Second, the mean values for the selectivity parameters listed above correspond to the red curve in Figure 5. Third, some of the selectivity parameters, or at least the implications thereof, are interdependent. For example, the location of the end of the peak region is conditional on the location of the beginning of the peak region. Also, while the width parameters are not conditional on other parameters, the locations of the inflection points are determined jointly by the beginning/end of the peak region and the corresponding width parameter.

Finally, bounds were placed on each parameter as follows:

Parameter	BS	GOA	Rationale
sdev(ln(rec) devs)	n/a	n/a	parameter fixed iteratively (no prior)
post75 med(ln(rec))	0,20	0,20	arbitrary non-binding values
slope survey ln( $Q$ )	-10,10	-10,10	arbitrary non-binding values
$M$	0,0.74	0,0.74	maximum feasible range given specified mean
len@age1 (cm)	0,22.2	0,27.6	maximum feasible range given specified mean
len@age12 (cm)	0,186.6	0,186.0	maximum feasible range given specified mean
Brody growth $K$	0,0.226	0,0.216	maximum feasible range given specified mean
shelf survey ln( $Q$ )	-0.576,0	-0.576,0	maximum feasible range given specified mean
begin peak	10,110	10,110	maximum feasible range given specified mean
logit(end peak)	-10,10	-10,10	arbitrary non-binding values
ln(asc width)	-10,10	-10,10	arbitrary non-binding values
ln(des width)	-10,10	-10,10	arbitrary non-binding values
logit(sel@ $L_{min}$ )	-10,10	-10,10	arbitrary non-binding values
logit(sel@ $L_{max}$ )	-10,10	-10,10	arbitrary non-binding values

With respect to the above table, it should be noted that the upper end of the maximum feasible range for shelf survey  $Q$  was assumed to be 1.0 (meaning that the upper end of the maximum feasible range for ln( $Q$ ) is zero), based on the herding studies described in the presentation by Somerton and Nichol.

As noted previously, some of the critical points of the selectivity curve depend on more than one parameter, which means that the prior distribution of selectivity at each length interval is difficult to infer from the above tables. This problem was addressed in the following steps: 1) A large number of sets of selectivity parameters were drawn randomly from the prior distributions. 2) Selectivity at length was computed for each set of parameters. 3) Distributions of selectivity at length were constructed. This resulted in the distributions shown in Figure 6, where the red curve represents the selectivity curve with parameters equal to the means of their respective prior distributions, the blue dots represent median selectivity at length, and the blue error bars represent the inter-quartile range of selectivity at length. It should be noted that the selectivity curve with parameters equal to the means of the respective prior distributions (red curve) will typically not be a good predictor of the median selectivity at length, because the selectivity curve is constrained to equal 1.0 over a portion of the range, but selectivity can never exceed 1.0, so median selectivity will tend to be less than the selectivity defined by setting the parameters equal to the means of their respective prior distributions, at least over a portion of the range.

The issue of whether the model converges on the global minimum is potentially a difficult one. In general, there is no way to guarantee that a highly nonlinear, high-dimensional model will converge to the global minimum. However, the following steps were taken to provide added confidence that the base models were converging to the global minimum:

1. Initial parameter values were chosen at random from a region with width equal to 10% of the distance between the bounds, centered on the mean of the prior distribution. This was done several times. In all cases, the base model converged to the same place.
2. Random phases were assigned to all model parameters, with equal numbers of parameters entering the estimation at each phase. This was done several times. In all cases, the base model converged to same place. This is not to suggest that models should be constructed without paying careful attention to phases, nor is it to suggest that all “good” models should converge satisfactorily under randomly assigned phases. However, in the event (as occurred here) that random assignment of phases makes no difference in the solution, this can be taken as evidence that the model is converging properly.
3. While each base model was being run, as it neared completion the analytic derivatives were compared with the finite difference derivatives as the optimization neared the minimum. The values were extremely close for all parameters.

### *Description of Alternative Models*

A large number of modifications to the base model were made in an attempt to address the SSC’s requests for the workshop. These are listed below by category, with each individual run given a label (in italics) for ease of reference:

1. “Growth” runs
  - a. *FixedGro*: Length-at-age parameters fixed at outside-the-model estimates
  - b. *FreeGroCV*: CV of length at age 1 fixed at outside-the-model estimate (0.16 in BS, 0.14 in GOA), but CV of length at age 12 estimated internally
2. “Fixed  $M$  and  $Q$ ” runs
  - a. *FixedM*:  $M$  fixed at the prior mean of 0.37,  $Q$  free

- b. *FixedQ*:  $Q$  fixed at the prior median of 0.75,  $M$  free
- c. (No label): Large number of models based on factorial grid with  $M$  and  $Q$  fixed
- 3. “Prior” runs (these do *not* constitute an exhaustive exploration of all possible priors)
  - a. *PriorCV30*: CV = 30% for all informative priors
  - b. *PriorCV40*: CV = 40% for all informative priors
  - c. *PriorWt20*: Weight given to priors in objective function = 0.2
  - d. *PriorWt40*: Weight given to priors in objective function = 0.4
  - e. *PriorWt60*: Weight given to priors in objective function = 0.6
  - f. *PriorWt80*: Weight given to priors in objective function = 0.8
- 4. “Asymptotic” runs
  - a. *AsympTFsry*: Jan-May trawl fishery selectivity forced to be asymptotic
  - b. *AsympLFsry*: Longline fishery selectivity forced to be asymptotic
  - c. *AsympPFsry*: Pot fishery selectivity forced to be asymptotic
  - d. *AsympTSrvy*: Shelf trawl survey selectivity forced to be asymptotic

Although not specifically requested by the SSC for consideration at this workshop, the SSC had previously expressed an interest in estimating a stock-recruitment relationship within the Pacific cod models. Therefore, an additional “Tier 1” run (label: *Ricker*) was made in which a Ricker stock-recruitment relationship was estimated within the model.

Finally, a set of “other” runs were made, for the BS model only, to consider suggestions made by an external reviewer. These were as follow:

1. *IteratedN*: For likelihood components based on the multinomial distribution, the input sample sizes were iteratively re-weighted until the average input sample size for each fishery and survey equaled the corresponding average output (“effective”) sample size.
2. *DecSizAgeN*: The input sample size for the mean-size-at-age likelihood component was decreased by an order of magnitude.
3. *2xSurveySE*: The standard error from the shelf bottom trawl survey was doubled.
4. *NoAgeData*: The age composition data were removed, and the corresponding length composition records were restored.
5. *NoSlope*: The slope bottom trawl survey data were removed.
6. *StartYr1982*: The start year was changed to 1982.

## Results

The base models’ estimates of the female spawning biomass time series are shown with 95% confidence intervals in Figures 7a (BS) and 7b (GOA). The base models’ estimates of the age 0 recruitment time series are shown with 95% confidence intervals in Figures 8a (BS) and 8b (GOA). The base models’ estimates of the fishery and survey selectivity schedules are shown in Figures 9a (BS) and 9b (GOA).

All of the alternative models appeared to converge successfully.

Key results for the base model and the alternative models are summarized for the BS in Tables 1a-1d and for the GOA in Tables 2a-2c. Tables 1a and 2a compare the base model to the “growth” runs and the “fixed  $M$  and  $Q$ ” runs (except for the models based on a factorial grid of

$M$  and  $Q$  values, because there are too many of them), Tables 1b and 2b compare the base model to the “prior” runs, Tables 1c and 2c compare the base model to the “asymptotic” and “Tier 1” runs, and Table 1d compares the base model to the “other” runs (BS only).

For each model, Tables 1a-1d and 2a-2c provide results for specific items within the following general categories:

1. Objective function and its components (15 items in the BS, 11 in the GOA)
2. Life history parameters (6 items in both the BS and GOA)
3. Recruitment (3 items in both the BS and GOA)
4. Catchability (3 items in the BS, 1 in the GOA)
5. Selectivity (28 items in the BS, 22 in the GOA)
6. Biomass (9 items in both the BS and GOA)

To help focus attention on areas where the alternative models tended to differ from the base model, each cell whose value is more than 10% greater than the corresponding base model value is shaded green with bold font, and each cell whose value is more than 10% less than the corresponding base model value is shaded pink with italic font.

The only alternative models whose results are not shown in Tables 1a-1d and 2a-2c are those based on factorial grids of  $M$  and  $Q$  values. Because there were so many of these models, it is not practical to display all of the results. Instead, just the objective function values are displayed in Figures 10a (BS) and 10b (GOA).

## Discussion

Note: The discussion of this topic focused entirely on the BS models.

Q: Did you try a run with no priors? A: Yes, but it crashed. However, the *PriorWt20* run is close to a model with no priors.

Q: Is there a one-to-one match between changing the CV of the priors and changing the weight assigned to the priors in the objective function? A: No, because different functional forms (symmetric beta and normal) are used and because many of the parameters on which the priors are specified have been transformed.

Q: Did you try AIC or something similar to see which model is “best?” A: No.

Q: Why do the age data appear to have so little impact? A: There are some internal inconsistencies in the age data (more than, for example, the age data for BS or GOA pollock), so it is impossible to fit them very well even if the weight assigned to the age data in the objective function is increased dramatically.

### *Suggestions for Tuesday night model runs*

Based on the results presented so far and the associated discussion, the assessment authors were requested to complete, time permitting, the following model runs for the BS stock before

Wednesday morning's session (these will be referenced hereafter by run number):

- 1) Base model with old (pre-2005) maturity schedule
- 2) Base model with priors turned off and nonconstraining bounds, and with a separate  $M$  estimated for ages 1 and 2
- 3) Base model with priors turned off and nonconstraining bounds, and including commercial longline CPUE as an index of abundance
- 4) Base model with priors turned off and nonconstraining bounds, and including cod bycatch from the IPHC survey as an index of abundance
- 5) Base model with priors turned off and nonconstraining bounds, and removing ages 1 and 2 from the age composition data
- 6) Annual survey selectivity devs on the ascending width parameter
- 7) Base model with priors turned off and nonconstraining bounds, and fix either  $Q$  (at a value of 0.5 or 0.75) or  $M$  (at a value of 0.37)
- 8) Base model with priors turned off and nonconstraining bounds, except put a prior on terminal selectivity for the Jan-May trawl fishery
- 9) Base model with survey selectivity forced to be asymptotic and  $Q$  fixed at 0.5
- 10) Base model with a separate  $M$  estimated for ages 9 and above

## **Wednesday morning session**

The Wednesday morning session included a free-form discussion regarding the feasibility of a dedicated Pacific cod longline survey and a report on Tuesday night's model runs.

### *Discussion on feasibility of a dedicated Pacific cod longline survey*

Some participants in the longline fishery have expressed interest in a dedicated Pacific cod longline survey. The following is a summary of some of the comments made during the discussion, which covered both the idea of a new longline survey dedicated to assessment of Pacific cod and use of existing or augmented data from the IPHC halibut longline survey (it should be emphasized that these are comments made by individuals, not consensus conclusions of the workshop).

### **Establishing a new survey**

A dedicated Pacific cod longline survey might be primarily funded by industry if boats were allowed to keep fish. The existing sablefish longline survey operates smoothly and basically pays for itself, although there are costs in terms of agency time commitments, overtime, and travel. Auke bay puts one scientist on board, and the boat provides two additional samplers. Some of money generated by the contract is put into scientific projects (tags, additional days).

Start with a pilot operation to work out logistical issues. If we start to plan for a dedicated Pacific cod longline survey now, we might be able to have usable data within three years.

One alternative to establishing a survey of indefinite duration would be to focus on a short-term

project designed to resolve the question of size selectivity. On the other hand, this might just add another selectivity schedule to estimate.

Is a new, dedicated survey the best place to allocate research resources? We should look at other options also, and prioritize based on the greatest sources of uncertainty in the assessments.

It might be useful to compare longline survey data and trawl survey data collected from the same locations at the same time.

Additional tagging research is also of interest. A new survey might provide opportunity for this.

### **Using the existing IPHC survey**

The IPHC has provided data on Pacific cod CPUE from the halibut longline survey. The CPUE trend is similar to that from the commercial longline fishery (Figure 11). However, there are no Pacific cod length frequency data from the IPHC survey, which poses two problems: 1) selectivity of the IPHC survey gear cannot currently be estimated, and 2) incorporation of the IPHC CPUE time series into the assessment model would not be straightforward.

The IPHC is willing to discuss the possibility of obtaining Pacific cod length frequency data from this year's survey, but plans would have to be made soon, as the survey starts in June. Some of the cod taken during IPHC surveys are retained and could be sampled on shore. Fish could potentially be tagged to identify which set they come from. The IPHC survey has two scientists at sea and sometimes has space for an additional person, depending on the vessel used. Deliveries from the survey are made in Adak, Dutch Harbor, and St. Paul. However, the fish are delivered headed and gutted, so round weights will not be available. Industry may be willing to provide financial support if additional personnel are needed to obtain lengths from the survey.

Potential problems with using the IPHC CPUE data as an index of Pacific cod abundance include the following: 1) The hook size used in the IPHC survey may not be optimal for Pacific cod. 2) The IPHC survey does not sample waters shallower than 75 fathoms, whereas a survey designed to assess Pacific cod would probably need to go much shallower. 3) Local availability of feed can affect catch rates.

### *Results from Tuesday night's model runs*

--Grant Thompson (AFSC)

### **Summary**

The results from Tuesday night's modeling efforts were presented. As it turned out, there was not sufficient time to attempt two of the models. Of the eight models that were attempted, all of them converged, but five of them failed to result in a positive definite Hessian matrix. The breakdown was as follows:

- Converged with positive definite Hessian matrix: Runs 1, 9, and 10
- Converged, but without positive definite Hessian matrix: Runs 2, 3, 4, 7, and 8
- Not attempted: Runs 5 and 6

Some points to notes regarding individual runs include the following:

- Run 1: No estimated parameters changed; the only outputs that changed were those pertaining to spawning biomass.
- Run 7: All three of the suggested versions for this run were attempted. The version with  $M$  fixed at 0.37 and  $Q$  free failed. The version with  $Q$  fixed at 0.50 and  $M$  free failed. The version with  $Q$  fixed at 0.75 and  $M$  free converged, but did not result in a positive definite Hessian matrix.
- Run 8: Once a strong prior distribution was placed on terminal selectivity of the January-May trawl fishery such that the selectivity of that fishery tended toward an asymptotic form, two problems arose: 1) Certain parameters of the double-normal function used to model the selectivity of the January-May trawl fishery became superfluous, and therefore needed to be removed from the estimation process. 2) The selectivities of other fisheries also tended toward an asymptotic form even with no prior distribution placed on their respective terminal selectivities, meaning that certain parameters of the double-normal function used to model the selectivities of those fisheries also became superfluous, and therefore needed to be removed from the estimation process.

Tables 3a and 3b summarize the results of runs 1-4 and 7-10, using the same format of Tables 1a-1d and 2a-2c. It should be emphasized that those runs that failed to result in a positive definite Hessian matrix should not necessarily be viewed as reliable.

## Discussion

The following is a summary of some of the comments made during the discussion of Tuesday night's model runs (it should be emphasized that these are comments made by individuals, not consensus conclusions of the workshop).

The new "regime shift" options of SS2 should be explored further to make sure that they have been implemented correctly in the Pacific cod models developed in the context of this workshop. In particular, it should be determined whether both the "R1" and "env\_link" parameters need to be active in order to estimate the effects of a regime shift, or whether the R1 parameter might in some sense be superfluous to this exercise.

The results of Run 10 (with a separate  $M$  estimated for ages 9 and above) tended to result in asymptotic selectivities, as was conjectured during the discussion of yesterday's presentation on estimation of movement and survival rates from tagging data.

What is the biological explanation for a higher  $M$  at older ages? Isn't it more likely that  $M$  is higher at very young ages? Maybe the model should be run with selectivity forced to be asymptotic and a separate  $M$  estimated for ages 1-2. Another option would be to undertake a physiological study of older fish to see if there is evidence of senescent mortality. In halibut, natural mortality appears to be higher at the oldest ages, which has created problems in fitting the halibut model.

Only about 3% of Pacific cod in the commercial catch are larger than 90 cm, yet some of the



models show big differences between estimated selectivity at 90 cm and final selectivity. A similar result has been obtained in SS2 models of other species. If we have no biological explanation for such a result, this may be a reason for going to a model in which selectivity is forced to be asymptotic.

There must be some fundamental problems with the data, given that the model does not converge without informative priors.

The age data don't seem to correspond with modes in the length frequencies. On the other hand, the *NoAgeData* model presented yesterday didn't give fits that were very different from other models, suggesting that any conflict between the age data in the size data is minor.

Variability in length at age merits further investigation. When the variability in length at age 12 was freed (in the *FreeGroCV* model), the value estimated by the model was much higher than the outside-the-model estimate. Is this parameter influenced by the fact that  $M$  is constrained to be constant across age? Perhaps it would be better to model variability in length at age as a function of age rather than as a function of length. Variability in length at age for young ages is confounded with temporal variation in growth parameters. Length at age can vary across areas as well as across time.

Different values for maximum age should be explored.

Before the 2005 assessments, the length at age 1.5 was set equal to the average of the first length mode from the most recent five surveys. However, it was sometimes difficult to identify the first length mode.

The mean lengths at age for ages 1-3 (16-21 cm, 28-32 cm, 37-43 cm) are different from the first three modes in the aggregate survey length compositions (16 cm, 32 cm, 46 cm; Figure 12). Does this mean that the age data are unreliable, does it mean that we need to add variability in length at age 1, or does it mean that survey selectivity needs to be allowed to vary between years? Could this be due to spatial differences in mean size at age?

## **Wednesday afternoon session**

The Wednesday afternoon session consisted of a general discussion of modeling issues and an opportunity for workshop participants to make suggestions for this year's Pacific cod stock assessments.

### *General discussion*

The following is a summary of some of the comments made during the general discussion of modeling issues (it should be emphasized that these are comments made by individuals, not consensus conclusions of the workshop).

## Use of age composition and length-at-age data

Inside-the-model estimates of length at age tend to show much higher lengths at the oldest ages than outside-the model estimates because of low survey selectivity at those ages (Figure 13). When the length at age is filtered by selectivity, the inside-the-model parameter estimates also show very good fits (Figure 14).

Tagging data have been used to estimate length at age parameters for BS Pacific cod. The estimated parameter values were  $K = 0.1146$  and  $L_{inf} = 132.52$  cm (Figure 15). Given the similarities of the growth curves obtained from fitting the survey length-age data outside the model and from fitting the tagging data outside the model, and given that these two curves are very different from the growth curve estimated inside the model, the inside-the-model estimates should be viewed with suspicion.

Length at age 1 should be allowed to vary randomly from year to year. On the other hand, if there is no strong confirmation from the length-age data that this value is actually changing, should the model be allowed to change it? If the data corresponding to ages 1-3 were removed from the model, the problem would go away. Another option would be to keep length at age 1 constant, but remove all but 1 of the mean size at age records from the data.

Variability in length at age 1 should be estimated from the distribution of lengths around the first mode rather than from the length-age data (Figure 16). Note, however, that variability in length at age is defined by a linear relationship which needs to fit well across all ages, not just age 1.

Variability in length at age should treat the standard deviation, rather than the CV, as the dependent variable. More generally, all four options available in SS2 for modeling the variability in length at age should be considered.

Given that otolith samples were stratified by length in early years, estimates of variability in length at age based on those samples could be biased.

Focusing on the distribution of age at size would be more informative than the distribution of size at age.

The age composition data should be given a higher weight in the objective function.

Priority should be given to obtaining age compositions from the longline fishery.

## Use of survey and commercial CPUE data

The pre-1982 shelf trawl survey data should be omitted because there are only three years in the time series, making it difficult to estimate catchability and all of the selectivity parameters. On the other hand, these data give us signals regarding the exceptionally large year classes spawned during the late 1970s. Historical biomass estimates can be very useful.

There are problems with the youngest ages in the post-1981 shelf trawl survey data. Either the

youngest ages should be removed from the data or selectivity should be allowed to change. The standard error of the biomass estimates should be increased.

The slope trawl survey data should be omitted. There is not much information there, and this survey assesses only a very tiny portion of the stock.

Survey age compositions weighted by survey estimates of absolute abundance should be plotted to examine consistency of the survey data.

The longline fishery CPUE should be added to the model as an estimate of abundance. The average input sample size should be estimated iteratively. Why the longline fishery only (note that the CPUE time series from the different gear types do not always match—Figure 17)? Given that we do not have a long time series of length compositions to accompany the CPUE from the IPHC survey, the longline fishery is the next best thing. Is the Pacific cod CPUE in the IPHC survey going up because halibut abundance is going down, meaning less hook competition?

### **Use of length composition data**

How should length data be binned? One option would be to set the bin size equal to the resolution of the data. On the other hand, if bin size gets very small, there will likely be lots of zeros in the data, which could cause problems. Another option would be to base bin size on percentiles of the data, but the locations of these will vary between fisheries and surveys.

Use of bootstrapping to develop an input sample size for length composition data should be explored further. Another alternative would be to base input sample size on a nonlinear regression of output (“effective”) sample size against actual sample size.

Because SS2 ignores process error everywhere but in the stock-recruitment relationship, the model is necessarily “wrong” to some extent, and iterating the input sample size may help to compensate for this. On the other hand, the input sample sizes estimated by iteration are sometimes larger than the actual sample size, in which case it is unclear how iterating the input sample sizes is compensating for the model’s exclusion of process error. There are two schools of thought in the statistical literature (pro and con) regarding iteration. Iterative least squares is an example of “pro.” The problem in the “pro” literature is that the examples almost always deal with just a single data source, not the multiple data sources we are dealing with here.

Given that we have many observations of the same thing (cohort strength over time), we should enable us to estimate the observation error variance, assuming that we have the model “right.”

### **Use of prior distributions**

It is unrealistic to believe that the model of this complexity will ever converge satisfactorily with absolutely no informative priors. Rather than removing all informative priors, the goal should be to make sure that any informative priors are “even” and reasonable. Any prior distributions on selectivity parameters will need to be developed with great care.

One approach would be to develop an initial model with no informative priors at all, then experiment with adding informative priors one at a time in various combinations in an attempt to discover the minimum necessary number of informative priors.

The opposite approach would be to start with informative priors on all parameters, then experiment with dropping them one at a time in various combinations.

Creative use of phases can substitute for turning informative priors on and off.

Is it appropriate to use informative priors simply to get the model to converge satisfactorily?

### **Identifying where the problem is**

Once conflicts within the data are resolved, problems with convergence may be unrelated to the use or nonuse of informative priors.

To determine why the model will not converge satisfactorily without informative priors, one approach would be to start with a reduced number of data sets and a simple model, then add data sets and elements of model complexity one at a time. To begin with, a single selectivity pattern should be estimated for all eras, seasons, and gears.

A global average selectivity could be estimated outside the model by making several simplifying assumptions. On the other hand, this may be too simplistic.

### *Suggestions for this year's assessments*

The workshop concluded with an opportunity for participants to make suggestions for this year's assessments. The list of suggestions was as follows (it should be emphasized that these are suggestions made by individuals, not consensus conclusions of the workshop).

#### **Start Year**

1. Start the model in 1982, because that is when the current survey time series starts.
2. Start the model in 1976, do avoid confounding initial age composition with the regime shift and to avoid biasing estimates of reference biomass levels by underestimating the strong 1976 and 1977 year classes.
3. Try alternative models with the starting year set at 1976 and 1982.

#### **Natural mortality**

1. Estimate  $M$  inside the model.
2. Do not estimate  $M$  inside the model. Instead, fix it at a value of about 0.35.
3. Estimate a separate  $M$  for ages 0-2.
4. Do not estimate a separate  $M$  for ages 0-2 unless the resulting estimate of  $M$  for ages 0-2 is higher than the resulting estimate of  $M$  for ages 3 and above.

5. Explore higher  $M$  for old fish.
6. Run 10 (base model with a separate  $M$  estimated for ages 9+) should be explored further.
7. Use data on liver condition to estimate age-dependent  $M$ .
8. Set  $M$  at the value that forces at least one fishery to exhibit asymptotic selectivity (equivalently, force one fishery to exhibit asymptotic selectivity, then profile over  $M$ ).

### **Age and growth**

1. Estimate growth parameters inside the model.
2. Do not estimate growth parameters inside the model.
3. Estimate time-varying growth parameters inside the model.
4. Estimate variability of length at age inside the model.
5. Do not use the age data unless the problems with ageing are resolved. Replace the age data with the corresponding length-frequency data.
6. If the ageing issues are resolved, include the age data as age-conditioned-on-length rather than using mean-length-at-age data.
7. If time-varying survey selectivity is not used, remove ages 1-3 from the survey data.
8. Look at growth data by area.

### **Survey and fishery CPUE**

1. Use the longline CPUE as an index of abundance because it is consistent with the halibut longline survey, but there is no length-frequency data for the halibut survey.
2. Do not use the pre-1982 survey data, because it is a short time series and it causes problems due to bounds or priors used for  $Q$ .
3. Do not use the slope survey, because it covers such a small component of the population.

### **Catchability and selectivity**

1. Ensure that the range on  $Q$  is reasonable (the lower bound should be lower than the value used in the workshop base model).
2. Include time-varying parameters for the left-hand limb of the survey selectivity schedule.
3. Removal of some of the time blocks for selectivity may be appropriate and can reduce the complexity of the model.
4. The 6-parameter double-normal selectivity function should not be used because it has too many parameters, and the interdependence of some of the parameters is problematic. A simpler functional form with no interdependent parameters should be used instead.
5. Seek to add an exponential logistic (or similar) selectivity option to SS2.
6. Use a logistic selectivity curve for one fishery (equivalently, force the selectivity for one fishery to be asymptotic).
7. Run 9 (base model with survey selectivity forced to be asymptotic and  $Q$  fixed at 0.5) should be explored further.

### **Prior distributions**

1. Don't use any informative priors.

2. Consider using a prior on the growth rate  $K$  based on the tagging data (mean = 0.11) and a prior on  $Q$  based on the archival tagging study (median = 0.47).
3. Prior distributions should not be based on data used in the model (no double-counting).

## **Other**

1. Do not use the regime shift methodology in the model. Instead, estimate the initial recruitment, initial recruitment deviates, and initial fishing mortality, but don't fit to the initial catch. This allows the model ample flexibility to estimate the initial age-structure without constraints or redundant parameters. Thought should be given to what years are averaged to generate recruitment for the projections.
2. Use iterative re-weighting to determine appropriate weights for all likelihood components.
3. Use bootstrapping to develop input sample sizes for length composition data, then maybe rescale across the board afterward.
4. To find out what it is that is causing convergence problems, start with a simpler model, fewer data, no priors, then worry about details.
5. The focus of this year's assessments should be to develop base models with which everyone is relatively comfortable. Minor permutations can be considered later.
6. Get really comfortable with the data.
7. Develop a two-sex model.
8. Include AI catches in the BS model.

## Tables

Table 1a.	Pre-workshop BS model runs (base, “growth” runs, “fixed $M$ and $Q$ ” runs)
Table 1b.	Pre-workshop BS model runs (base, “prior” runs)
Table 1c.	Pre-workshop BS model runs (base, “asymptotic” runs, “Tier 1” run)
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Table 2a.	Pre-workshop GOA model runs (base, “growth” runs, “fixed $M$ and $Q$ ” runs)
Table 2b.	Pre-workshop GOA model runs (base, “prior” runs)
Table 2c.	Pre-workshop GOA model runs (base, “asymptotic” runs, “Tier 1” run)
Table 3a.	Tuesday night BS model runs (runs 1-4)
Table 3b.	Tuesday night BS model runs (runs 7-10)

Table 1a--Pre-workshop BS model runs

	Base	Growth runs		Fixed M and Q runs	
		FixedGro	FreeGroCV	Fixed M	Fixed Q
<b>Objective function and its components</b>					
Objective function	2048.30	1781.77	1955.84	2049.02	2051.43
Age composition	62.42	65.18	65.51	62.65	62.28
Size at age	267.31	0.00	210.73	269.06	268.70
Recruitment	27.30	27.31	34.29	26.45	27.47
Priors	133.49	83.04	128.62	131.88	135.28
Pre-82 shelf trawl survey biomass	5.13	0.66	6.40	5.00	3.79
Post-81 shelf trawl survey biomass	44.45	40.30	43.69	44.04	43.79
Slope trawl survey biomass	0.58	0.40	0.50	0.58	0.53
Jan-May trawl fishery sizecomp	260.54	271.14	261.99	261.60	262.23
Jun-Dec trawl fishery sizecomp	386.68	397.12	390.77	387.23	384.32
Longline fishery sizecomp	463.03	499.52	475.40	462.73	465.66
Pot fishery sizecomp	185.69	181.20	173.03	185.80	186.50
Pre-82 shelf trawl survey sizecomp	46.69	39.09	37.90	45.30	44.90
Post-81 shelf trawl survey sizecomp	158.71	170.44	120.51	160.37	159.80
Slope trawl survey sizecomp	6.27	6.36	6.51	6.35	6.20
<b>Life history parameters</b>					
Natural mortality rate	0.344	0.404	0.379	0.370	0.374
Length at age 1	11.128	11.100	10.216	11.071	11.097
Length at age 12	113.604	93.300	102.651	113.250	113.324
Brody growth coefficient	0.036	0.113	0.077	0.037	0.036
CV length at age 1	0.16	0.16	0.16	0.16	0.16
CV length at age 12	0.066	0.066	0.183	0.066	0.066
<b>Recruitment</b>					
Median recruitment (pre-1976 regime)	317,853	488,773	323,020	367,912	405,006
Median recruitment (post-1975 regime)	535,202	984,117	625,684	655,334	747,433
Recruitment standard deviation	0.63	0.63	0.63	0.63	0.63
<b>Catchability</b>					
Pre-1982 shelf trawl survey catchability	0.986	0.817	0.981	0.985	0.966
Post-1981 shelf trawl survey catchability	0.917	0.682	0.738	0.870	0.750
Slope trawl survey catchability	0.011	0.008	0.010	0.010	0.009
<b>Selectivity</b>					
Jan-May trawl fishery sel at 90cm (for)	0.417	0.853	0.470	0.447	0.442
Jan-May trawl fishery sel at 90cm (dom)	0.628	0.981	0.658	0.660	0.608
Jan-May trawl fishery sel at 90cm (new)	0.681	1.000	0.685	0.712	0.641
Jun-Dec trawl fishery sel at 90cm (for)	0.715	1.000	0.770	0.756	0.751
Jun-Dec trawl fishery sel at 90cm (dom)	1.000	1.000	1.000	1.000	0.999
Jun-Dec trawl fishery sel at 90cm (new)	0.982	0.984	0.986	0.993	0.964
Longline fishery sel at 90cm (for)	0.288	0.597	0.331	0.306	0.305
Longline fishery sel at 90cm (dom)	0.512	1.000	0.529	0.540	0.491
Longline fishery sel at 90cm (new)	0.344	0.741	0.333	0.364	0.319
Pot fishery sel at 90cm (dom)	0.525	1.000	0.533	0.553	0.501
Pot fishery sel at 90cm (new)	0.420	0.997	0.400	0.442	0.389
Pre-82 shelf trawl survey sel at 90cm	0.982	0.265	0.961	0.978	0.955
Post-81 shelf trawl survey sel at 90cm	0.266	0.541	0.753	0.285	0.272
Slope trawl survey sel at 90cm	0.440	0.996	0.446	0.494	0.383
Jan-May trawl fishery ending sel (for)	0.018	0.295	0.029	0.023	0.023
Jan-May trawl fishery ending sel (dom)	0.018	0.298	0.039	0.022	0.021
Jan-May trawl fishery ending sel (new)	0.033	0.810	0.059	0.040	0.035
Jun-Dec trawl fishery ending sel (for)	0.021	0.455	0.040	0.026	0.028
Jun-Dec trawl fishery ending sel (dom)	0.045	0.588	0.094	0.054	0.052
Jun-Dec trawl fishery ending sel (new)	0.036	0.637	0.061	0.042	0.038
Longline fishery ending sel (for)	0.009	0.221	0.013	0.011	0.012
Longline fishery ending sel (dom)	0.016	0.314	0.036	0.020	0.018
Longline fishery ending sel (new)	0.013	0.531	0.025	0.016	0.013
Pot fishery ending sel (dom)	0.018	0.347	0.044	0.022	0.020
Pot fishery ending sel (new)	0.039	0.937	0.083	0.049	0.041
Pre-82 shelf trawl survey ending sel	0.969	0.256	0.934	0.962	0.929
Post-81 shelf trawl survey ending sel	0.018	0.468	0.346	0.023	0.023
Slope trawl survey ending sel	0.101	0.872	0.117	0.117	0.092
<b>Biomass</b>					
Pristine biomass (all ages)	2,172,230	1,986,000	1,747,750	2,109,500	2,327,440
Pristine biomass (ages 3+)	2,134,710	1,914,610	1,706,580	2,065,680	2,277,710
Pristine female spawning biomass	880,530	672,065	664,800	831,170	913,160
Initial biomass (all ages)	425,106	360,471	254,974	371,234	382,872
Initial biomass (ages 3+)	392,873	285,945	214,954	333,970	341,753
Initial female spawning biomass	169,325	84,759	85,932	138,565	140,874
2006 biomass (all ages)	945,982	937,359	891,942	948,864	1,155,930
2006 biomass (ages 3+)	921,524	893,391	867,582	920,860	1,124,170
2006 female spawning biomass	342,106	285,442	314,981	334,527	420,115



Table 1b--Pre-workshop BS model runs

	Base	Prior runs					
		PriorCV30	PriorCV40	PriorWt20	PriorWt40	PriorWt60	PriorWt80
<b>Objective function and its components</b>							
Objective function	2048.30	2198.28	2112.21	1916.76	1955.93	1989.89	2020.42
Age composition	62.42	65.10	65.41	62.55	62.36	62.29	62.31
Size at age	267.31	<b>300.67</b>	286.56	258.49	260.33	262.42	264.79
Recruitment	27.30	24.62	<b>24.44</b>	29.44	28.91	28.35	27.79
Priors	133.49	<b>206.52</b>	<b>150.35</b>	<b>43.12</b>	<b>72.21</b>	<b>96.22</b>	<b>116.44</b>
Pre-82 shelf trawl survey biomass	5.13	<b>6.99</b>	<b>7.12</b>	3.93	4.19	4.49	4.81
Post-81 shelf trawl survey biomass	44.45	42.99	43.97	42.61	43.12	43.62	44.07
Slope trawl survey biomass	0.58	0.61	<b>0.65</b>	0.54	0.53	0.53	0.55
Jan-May trawl fishery sizecomp	260.54	268.34	265.46	254.33	256.29	257.88	259.27
Jun-Dec trawl fishery sizecomp	386.68	398.78	396.63	383.07	383.84	384.67	385.63
Longline fishery sizecomp	463.03	469.37	465.95	455.18	457.57	459.54	461.31
Pot fishery sizecomp	185.69	186.49	184.67	179.97	181.60	183.02	184.34
Pre-82 shelf trawl survey sizecomp	46.69	48.19	45.48	46.22	46.29	46.38	46.50
Post-81 shelf trawl survey sizecomp	158.71	170.68	167.73	155.81	156.31	156.98	157.82
Slope trawl survey sizecomp	6.27	<b>8.95</b>	<b>7.79</b>	<b>1.51</b>	<b>2.40</b>	<b>3.51</b>	<b>4.79</b>
<b>Life history parameters</b>							
Natural mortality rate	0.344	<b>0.427</b>	<b>0.410</b>	0.321	0.326	0.331	0.338
Length at age 1	11.128	10.182	10.445	11.566	11.455	11.347	11.237
Length at age 12	113.604	104.450	106.687	119.757	118.114	116.550	115.035
Brody growth coefficient	0.036	<b>0.070</b>	<b>0.061</b>	<b>0.016</b>	<b>0.021</b>	<b>0.026</b>	<b>0.031</b>
CV length at age 1	0.16	0.16	0.16	0.16	0.16	0.16	0.16
CV length at age 12	0.066	0.066	0.066	0.066	0.066	0.066	0.066
<b>Recruitment</b>							
Median recruitment (pre-1976 regime)	317,853	<b>448,531</b>	<b>409,555</b>	295,973	299,705	305,596	312,035
Median recruitment (post-1975 regime)	535,202	<b>919,697</b>	<b>788,273</b>	<b>481,422</b>	490,215	503,984	519,956
Recruitment standard deviation	0.63	0.63	0.63	0.63	0.63	0.63	0.63
<b>Catchability</b>							
Pre-1982 shelf trawl survey catchability	0.986	0.928	0.968	0.996	0.993	0.991	0.988
Post-1981 shelf trawl survey catchability	0.917	0.856	0.909	0.921	0.921	0.918	0.917
Slope trawl survey catchability	0.011	<b>0.012</b>	<b>0.012</b>	<b>0.013</b>	<b>0.012</b>	0.012	0.011
<b>Selectivity</b>							
Jan-May trawl fishery sel at 90cm (for)	0.417	<b>0.674</b>	<b>0.588</b>	<b>0.361</b>	<b>0.373</b>	0.386	0.401
Jan-May trawl fishery sel at 90cm (dom)	0.628	<b>0.968</b>	<b>0.928</b>	<b>0.523</b>	<b>0.544</b>	0.569	0.597
Jan-May trawl fishery sel at 90cm (new)	0.681	<b>1.000</b>	<b>1.000</b>	<b>0.525</b>	<b>0.557</b>	<b>0.594</b>	0.636
Jun-Dec trawl fishery sel at 90cm (for)	0.715	<b>0.975</b>	<b>0.926</b>	<b>0.615</b>	<b>0.640</b>	0.664	0.689
Jun-Dec trawl fishery sel at 90cm (dom)	1.000	1.000	1.000	0.972	0.982	0.990	0.997
Jun-Dec trawl fishery sel at 90cm (new)	0.982	1.000	1.000	0.889	0.910	0.934	0.960
Longline fishery sel at 90cm (for)	0.288	<b>0.422</b>	<b>0.379</b>	0.260	0.265	0.272	0.280
Longline fishery sel at 90cm (dom)	0.512	<b>0.977</b>	<b>0.914</b>	<b>0.425</b>	<b>0.443</b>	0.463	0.486
Longline fishery sel at 90cm (new)	0.344	<b>0.722</b>	<b>0.646</b>	<b>0.276</b>	<b>0.289</b>	<b>0.304</b>	0.323
Pot fishery sel at 90cm (dom)	0.525	<b>0.997</b>	<b>0.961</b>	<b>0.435</b>	<b>0.453</b>	0.473	0.497
Pot fishery sel at 90cm (new)	0.420	<b>0.978</b>	<b>0.943</b>	<b>0.347</b>	<b>0.360</b>	<b>0.376</b>	0.396
Pre-82 shelf trawl survey sel at 90cm	0.982	0.963	0.969	0.992	0.989	0.986	0.984
Post-81 shelf trawl survey sel at 90cm	0.266	<b>0.641</b>	<b>0.529</b>	<b>0.196</b>	<b>0.210</b>	<b>0.226</b>	0.245
Slope trawl survey sel at 90cm	0.440	<b>1.000</b>	<b>0.999</b>	<b>0.048</b>	<b>0.081</b>	<b>0.144</b>	<b>0.253</b>
Jan-May trawl fishery ending sel (for)	0.018	<b>0.081</b>	<b>0.051</b>	<b>0.009</b>	<b>0.011</b>	<b>0.013</b>	<b>0.016</b>
Jan-May trawl fishery ending sel (dom)	0.018	<b>0.081</b>	<b>0.052</b>	<b>0.011</b>	<b>0.012</b>	<b>0.014</b>	<b>0.016</b>
Jan-May trawl fishery ending sel (new)	0.033	<b>0.283</b>	<b>0.154</b>	<b>0.017</b>	<b>0.020</b>	<b>0.024</b>	<b>0.028</b>
Jun-Dec trawl fishery ending sel (for)	0.021	<b>0.120</b>	<b>0.065</b>	<b>0.010</b>	<b>0.013</b>	<b>0.015</b>	<b>0.018</b>
Jun-Dec trawl fishery ending sel (dom)	0.045	<b>0.211</b>	<b>0.123</b>	<b>0.026</b>	<b>0.030</b>	<b>0.034</b>	<b>0.039</b>
Jun-Dec trawl fishery ending sel (new)	0.036	<b>0.326</b>	<b>0.159</b>	<b>0.016</b>	<b>0.020</b>	<b>0.024</b>	<b>0.029</b>
Longline fishery ending sel (for)	0.009	<b>0.049</b>	<b>0.030</b>	<b>0.004</b>	<b>0.005</b>	<b>0.006</b>	<b>0.008</b>
Longline fishery ending sel (dom)	0.016	<b>0.083</b>	<b>0.055</b>	<b>0.010</b>	<b>0.011</b>	<b>0.012</b>	<b>0.014</b>
Longline fishery ending sel (new)	0.013	<b>0.154</b>	<b>0.084</b>	<b>0.006</b>	<b>0.007</b>	<b>0.008</b>	<b>0.010</b>
Pot fishery ending sel (dom)	0.018	<b>0.098</b>	<b>0.063</b>	<b>0.010</b>	<b>0.011</b>	<b>0.013</b>	<b>0.015</b>
Pot fishery ending sel (new)	0.039	<b>0.342</b>	<b>0.190</b>	<b>0.016</b>	<b>0.020</b>	<b>0.025</b>	<b>0.031</b>
Pre-82 shelf trawl survey ending sel	0.969	0.923	0.943	0.988	0.982	0.977	0.973
Post-81 shelf trawl survey ending sel	0.018	<b>0.232</b>	<b>0.132</b>	<b>0.004</b>	<b>0.006</b>	<b>0.008</b>	<b>0.013</b>
Slope trawl survey ending sel	0.101	<b>0.888</b>	<b>0.851</b>	<b>0.022</b>	<b>0.033</b>	<b>0.046</b>	<b>0.067</b>
<b>Biomass</b>							
Pristine biomass (all ages)	2,172,230	<b>1,731,140</b>	<b>1,730,430</b>	<b>2,500,040</b>	<b>2,420,750</b>	2,337,840	2,252,390
Pristine biomass (ages 3+)	2,134,710	<b>1,676,820</b>	<b>1,682,100</b>	<b>2,464,480</b>	<b>2,384,940</b>	2,301,500	2,215,440
Pristine female spawning biomass	880,530	<b>616,605</b>	<b>636,415</b>	<b>1,048,270</b>	<b>1,008,145</b>	965,555	921,610
Initial biomass (all ages)	425,106	<b>262,154</b>	<b>277,353</b>	<b>530,681</b>	<b>506,515</b>	<b>479,257</b>	450,971
Initial biomass (ages 3+)	392,873	<b>212,992</b>	<b>233,825</b>	<b>502,509</b>	<b>477,485</b>	<b>449,185</b>	419,786
Initial female spawning biomass	169,325	<b>72,345</b>	<b>85,337</b>	<b>227,392</b>	<b>214,086</b>	<b>199,107</b>	183,573
2006 biomass (all ages)	945,982	<b>742,635</b>	<b>722,376</b>	<b>1,164,560</b>	<b>1,108,280</b>	<b>1,052,860</b>	997,270
2006 biomass (ages 3+)	921,524	<b>710,859</b>	<b>693,123</b>	<b>1,139,830</b>	<b>1,083,790</b>	<b>1,028,420</b>	972,803
2006 female spawning biomass	342,106	<b>223,024</b>	<b>221,915</b>	<b>449,719</b>	<b>422,271</b>	<b>394,881</b>	367,381

Table 1c--Pre-workshop BS model runs

	Base	Asymptotic runs				Tier 1 runs
		AsympTFsry	AsympLFsry	AsympPFsry	AsympTSrvy	Ricker
<b>Objective function and its components</b>						
Objective function	2048.30	2065.94	2078.28	2065.50	2084.31	2048.30
Age composition	62.42	67.21	<b>69.88</b>	67.54	<b>68.99</b>	62.42
Size at age	267.31	283.57	285.24	283.71	<b>301.57</b>	267.31
Recruitment	27.30	<b>24.24</b>	<b>24.14</b>	<b>24.23</b>	25.05	27.30
Priors	133.49	<b>106.58</b>	<b>103.54</b>	<b>106.67</b>	<b>100.32</b>	133.49
Pre-82 shelf trawl survey biomass	5.13	<b>7.85</b>	<b>9.01</b>	<b>7.98</b>	4.62	5.13
Post-81 shelf trawl survey biomass	44.45	44.60	45.49	44.85	45.16	44.45
Slope trawl survey biomass	0.58	<b>0.71</b>	<b>0.78</b>	<b>0.72</b>	0.61	0.58
Jan-May trawl fishery sizecomp	260.54	272.20	266.87	264.59	266.23	260.54
Jun-Dec trawl fishery sizecomp	386.68	397.31	399.65	397.55	397.87	386.68
Longline fishery sizecomp	463.03	462.07	472.56	461.90	468.19	463.03
Pot fishery sizecomp	185.69	182.51	183.07	188.63	182.31	185.69
Pre-82 shelf trawl survey sizecomp	46.69	44.47	44.36	44.46	43.87	46.69
Post-81 shelf trawl survey sizecomp	158.71	166.38	167.97	166.50	173.30	158.71
Slope trawl survey sizecomp	6.27	6.24	5.72	6.17	6.22	6.27
<b>Life history parameters</b>						
Natural mortality rate	0.344	<b>0.405</b>	<b>0.411</b>	<b>0.405</b>	<b>0.419</b>	0.344
Length at age 1	11.128	10.482	10.342	10.475	10.106	11.128
Length at age 12	113.604	106.574	105.485	106.521	<b>102.112</b>	113.604
Brody growth coefficient	0.036	<b>0.062</b>	<b>0.067</b>	<b>0.062</b>	<b>0.080</b>	0.036
CV length at age 1	0.16	0.16	0.16	0.16	0.16	0.16
CV length at age 12	0.066	0.066	0.066	0.066	0.066	0.066
<b>Recruitment</b>						
Median recruitment (pre-1976 regime)	317,853	<b>388,561</b>	<b>389,011</b>	<b>388,628</b>	<b>429,631</b>	317,853
Median recruitment (post-1975 regime)	535,202	<b>729,125</b>	<b>741,700</b>	<b>730,073</b>	<b>863,976</b>	535,202
Recruitment standard deviation	0.63	0.63	0.63	0.63	0.63	0.63
<b>Catchability</b>						
Pre-1982 shelf trawl survey catchability	0.986	0.990	0.991	0.991	0.986	0.986
Post-1981 shelf trawl survey catchability	0.917	0.954	0.969	0.956	<b>0.787</b>	0.917
Slope trawl survey catchability	0.011	<b>0.013</b>	<b>0.015</b>	<b>0.013</b>	0.011	0.011
<b>Selectivity</b>						
Jan-May trawl fishery sel at 90cm (for)	0.417	<b>0.559</b>	<b>0.597</b>	<b>0.562</b>	<b>0.659</b>	0.417
Jan-May trawl fishery sel at 90cm (dom)	0.628	<b>0.938</b>	<b>0.981</b>	<b>0.940</b>	<b>0.983</b>	0.628
Jan-May trawl fishery sel at 90cm (new)	0.681	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.681
Jun-Dec trawl fishery sel at 90cm (for)	0.715	<b>0.898</b>	<b>0.931</b>	<b>0.901</b>	<b>0.978</b>	0.715
Jun-Dec trawl fishery sel at 90cm (dom)	1.000	1.000	1.000	1.000	1.000	1.000
Jun-Dec trawl fishery sel at 90cm (new)	0.982	0.998	0.948	0.995	0.993	0.982
Longline fishery sel at 90cm (for)	0.288	<b>0.374</b>	<b>0.395</b>	<b>0.376</b>	<b>0.438</b>	0.288
Longline fishery sel at 90cm (dom)	0.512	<b>0.954</b>	<b>1.000</b>	<b>0.958</b>	<b>1.000</b>	0.512
Longline fishery sel at 90cm (new)	0.344	<b>0.733</b>	<b>1.000</b>	<b>0.772</b>	<b>0.770</b>	0.344
Pot fishery sel at 90cm (dom)	0.525	<b>0.991</b>	<b>1.000</b>	<b>0.993</b>	<b>1.000</b>	0.525
Pot fishery sel at 90cm (new)	0.420	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	0.420
Pre-82 shelf trawl survey sel at 90cm	0.982	0.977	0.977	0.977	0.964	0.982
Post-81 shelf trawl survey sel at 90cm	0.266	<b>0.552</b>	<b>0.643</b>	<b>0.563</b>	<b>0.999</b>	0.266
Slope trawl survey sel at 90cm	0.440	<b>0.992</b>	<b>0.997</b>	<b>0.993</b>	<b>0.994</b>	0.440
Jan-May trawl fishery ending sel (for)	0.018	<b>0.045</b>	<b>0.053</b>	<b>0.046</b>	<b>0.082</b>	0.018
Jan-May trawl fishery ending sel (dom)	0.018	<b>0.052</b>	<b>0.067</b>	<b>0.053</b>	<b>0.095</b>	0.018
Jan-May trawl fishery ending sel (new)	0.033	<b>0.999</b>	<b>0.548</b>	<b>0.202</b>	<b>0.300</b>	0.033
Jun-Dec trawl fishery ending sel (for)	0.021	<b>0.053</b>	<b>0.062</b>	<b>0.053</b>	<b>0.100</b>	0.021
Jun-Dec trawl fishery ending sel (dom)	0.045	<b>0.113</b>	<b>0.142</b>	<b>0.114</b>	<b>0.195</b>	0.045
Jun-Dec trawl fishery ending sel (new)	0.036	<b>0.178</b>	<b>0.382</b>	<b>0.170</b>	<b>0.240</b>	0.036
Longline fishery ending sel (for)	0.009	<b>0.026</b>	<b>0.031</b>	<b>0.026</b>	<b>0.053</b>	0.009
Longline fishery ending sel (dom)	0.016	<b>0.056</b>	<b>0.072</b>	<b>0.057</b>	<b>0.101</b>	0.016
Longline fishery ending sel (new)	0.013	<b>0.118</b>	<b>0.999</b>	<b>0.110</b>	<b>0.174</b>	0.013
Pot fishery ending sel (dom)	0.018	<b>0.064</b>	<b>0.083</b>	<b>0.065</b>	<b>0.117</b>	0.018
Pot fishery ending sel (new)	0.039	<b>0.242</b>	<b>0.618</b>	<b>0.999</b>	<b>0.364</b>	0.039
Pre-82 shelf trawl survey ending sel	0.969	0.960	0.959	0.960	0.936	0.969
Post-81 shelf trawl survey ending sel	0.018	<b>0.140</b>	<b>0.195</b>	<b>0.134</b>	<b>0.999</b>	0.018
Slope trawl survey ending sel	0.101	<b>0.799</b>	<b>0.873</b>	<b>0.802</b>	<b>0.836</b>	0.101
<b>Biomass</b>						
Pristine biomass (all ages)	2,172,230	<b>1,670,230</b>	<b>1,612,190</b>	<b>1,666,170</b>	<b>1,696,650</b>	2,172,230
Pristine biomass (ages 3+)	2,134,710	<b>1,624,870</b>	<b>1,566,650</b>	<b>1,620,790</b>	<b>1,644,410</b>	2,134,710
Pristine female spawning biomass	880,530	<b>618,050</b>	<b>589,915</b>	<b>616,100</b>	<b>603,225</b>	880,530
Initial biomass (all ages)	425,106	<b>275,644</b>	<b>260,112</b>	<b>274,439</b>	<b>258,542</b>	425,106
Initial biomass (ages 3+)	392,873	<b>234,639</b>	<b>218,941</b>	<b>233,451</b>	<b>211,747</b>	392,873
Initial female spawning biomass	169,325	<b>86,978</b>	<b>79,339</b>	<b>86,425</b>	<b>72,100</b>	169,325
2006 biomass (all ages)	945,982	<b>675,876</b>	<b>644,989</b>	<b>673,665</b>	<b>750,148</b>	945,151
2006 biomass (ages 3+)	921,524	<b>648,388</b>	<b>617,497</b>	<b>646,144</b>	<b>719,755</b>	921,524
2006 female spawning biomass	342,106	<b>204,232</b>	<b>187,794</b>	<b>202,683</b>	<b>226,089</b>	342,106

Table 1d--Pre-workshop BS model runs

	Base	Other runs					
		IteratedN	DecSizAgeN	2xSurveySE	NoAgeData	NoSlope	StartYr1982
<b>Objective function and its components</b>							
Objective function	2048.30	<b>3553.07</b>	<b>1775.07</b>	2005.62	2101.59	2036.16	<b>1753.88</b>
Age composition	62.42	<b>28.68</b>	56.21	64.21	<b>0.00</b>	62.24	62.51
Size at age	267.31	<b>266.63</b>	<b>68.39</b>	263.61	264.43	266.77	264.02
Recruitment	27.30	<b>33.73</b>	24.97	27.50	26.81	27.51	<b>11.83</b>
Priors	133.49	<b>166.10</b>	<b>90.48</b>	132.63	137.10	129.17	129.52
Pre-82 shelf trawl survey biomass	5.13	<b>6.78</b>	3.65	<b>2.88</b>	<b>5.79</b>	4.95	<b>0.00</b>
Post-81 shelf trawl survey biomass	44.45	<b>52.88</b>	<b>36.85</b>	<b>18.12</b>	45.14	44.32	41.60
Slope trawl survey biomass	0.58	<b>0.69</b>	<b>0.52</b>	<b>0.20</b>	<b>0.68</b>	<b>0.00</b>	0.59
Jan-May trawl fishery sizecomp	260.54	<b>393.60</b>	269.08	260.89	260.10	260.43	<b>219.97</b>
Jun-Dec trawl fishery sizecomp	386.68	<b>873.77</b>	395.34	387.11	387.76	386.32	<b>268.06</b>
Longline fishery sizecomp	463.03	<b>1039.19</b>	467.10	454.12	462.71	463.51	<b>403.71</b>
Pot fishery sizecomp	185.69	<b>469.58</b>	181.71	185.85	186.64	185.67	185.69
Pre-82 shelf trawl survey sizecomp	46.69	<b>23.15</b>	<b>41.89</b>	43.76	46.59	46.78	<b>0.00</b>
Post-81 shelf trawl survey sizecomp	158.71	<b>186.92</b>	<b>132.52</b>	158.38	<b>271.58</b>	158.50	160.23
Slope trawl survey sizecomp	6.27	<b>11.40</b>	6.35	6.36	6.27	<b>0.00</b>	6.16
<b>Life history parameters</b>							
Natural mortality rate	0.344	0.321	<b>0.443</b>	0.337	0.344	0.342	0.310
Length at age 1	11.128	11.197	<b>9.382</b>	11.201	11.268	11.154	11.233
Length at age 12	113.604	114.342	<b>100.201</b>	114.678	115.027	114.005	114.444
Brody growth coefficient	0.036	0.033	<b>0.107</b>	0.032	<b>0.031</b>	0.034	0.032
CV length at age 1	0.16	0.16	0.16	0.16	0.16	0.16	0.16
CV length at age 12	0.066	0.066	0.066	0.066	0.066	0.066	0.066
<b>Recruitment</b>							
Median recruitment (pre-1976 regime)	317,853	<b>258,746</b>	<b>459,440</b>	299,080	317,742	316,332	<b>437,637</b>
Median recruitment (post-1975 regime)	535,202	<b>422,608</b>	<b>989,940</b>	502,625	531,469	531,469	<b>467,007</b>
Recruitment standard deviation	0.63	0.63	0.63	0.63	0.63	0.63	0.63
<b>Catchability</b>							
Pre-1982 shelf trawl survey catchability	0.986	0.990	0.976	0.969	0.988	0.986	<b>n/a</b>
Post-1981 shelf trawl survey catchability	0.917	0.972	0.834	0.963	0.949	0.912	0.988
Slope trawl survey catchability	0.011	<b>0.014</b>	0.010	<b>0.012</b>	0.011	0.011	0.011
<b>Selectivity</b>							
Jan-May trawl fishery sel at 90cm (for)	0.417	0.390	<b>0.733</b>	0.378	0.417	0.413	0.415
Jan-May trawl fishery sel at 90cm (dom)	0.628	0.597	<b>0.978</b>	0.628	0.628	0.617	0.591
Jan-May trawl fishery sel at 90cm (new)	0.681	0.669	<b>1.000</b>	<b>0.751</b>	0.698	0.666	0.651
Jun-Dec trawl fishery sel at 90cm (for)	0.715	0.660	<b>1.000</b>	0.667	0.710	0.708	0.772
Jun-Dec trawl fishery sel at 90cm (dom)	1.000	0.997	1.000	0.999	1.000	0.999	0.993
Jun-Dec trawl fishery sel at 90cm (new)	0.982	0.973	0.998	1.000	0.990	0.975	0.966
Longline fishery sel at 90cm (for)	0.288	0.279	<b>0.495</b>	0.267	0.286	0.285	0.288
Longline fishery sel at 90cm (dom)	0.512	0.494	<b>1.000</b>	0.521	0.511	0.501	0.478
Longline fishery sel at 90cm (new)	0.344	0.347	<b>0.682</b>	<b>0.390</b>	0.359	0.335	0.326
Pot fishery sel at 90cm (dom)	0.525	0.507	<b>1.000</b>	0.538	0.523	0.514	0.491
Pot fishery sel at 90cm (new)	0.420	0.429	<b>0.989</b>	<b>0.478</b>	0.438	0.409	0.400
Pre-82 shelf trawl survey sel at 90cm	0.982	0.990	0.944	<b>0.404</b>	0.984	0.982	<b>n/a</b>
Post-81 shelf trawl survey sel at 90cm	0.266	0.258	<b>0.500</b>	0.283	0.265	0.257	0.258
Slope trawl survey sel at 90cm	0.440	<b>0.055</b>	<b>0.994</b>	<b>0.559</b>	<b>0.492</b>	<b>0.978</b>	<b>0.388</b>
Jan-May trawl fishery ending sel (for)	0.018	<b>0.015</b>	<b>0.138</b>	<b>0.017</b>	0.017	0.018	<b>0.010</b>
Jan-May trawl fishery ending sel (dom)	0.018	<b>0.014</b>	<b>0.159</b>	<b>0.015</b>	0.017	0.017	<b>0.013</b>
Jan-May trawl fishery ending sel (new)	0.033	<b>0.028</b>	<b>0.417</b>	0.034	0.031	0.032	<b>0.025</b>
Jun-Dec trawl fishery ending sel (for)	0.021	<b>0.016</b>	<b>0.194</b>	0.020	0.020	0.021	<b>0.014</b>
Jun-Dec trawl fishery ending sel (dom)	0.045	<b>0.032</b>	<b>0.321</b>	<b>0.037</b>	0.043	0.043	<b>0.034</b>
Jun-Dec trawl fishery ending sel (new)	0.036	<b>0.027</b>	<b>0.345</b>	0.036	0.034	0.034	<b>0.028</b>
Longline fishery ending sel (for)	0.009	<b>0.007</b>	<b>0.100</b>	<b>0.008</b>	0.008	0.009	<b>0.004</b>
Longline fishery ending sel (dom)	0.016	<b>0.012</b>	<b>0.172</b>	<b>0.013</b>	0.015	0.015	<b>0.012</b>
Longline fishery ending sel (new)	0.013	<b>0.010</b>	<b>0.288</b>	0.013	0.012	0.012	<b>0.009</b>
Pot fishery ending sel (dom)	0.018	<b>0.013</b>	<b>0.196</b>	<b>0.015</b>	0.017	0.017	<b>0.013</b>
Pot fishery ending sel (new)	0.039	<b>0.029</b>	<b>0.542</b>	0.040	0.037	0.036	<b>0.028</b>
Pre-82 shelf trawl survey ending sel	0.969	0.981	0.907	<b>0.374</b>	0.973	0.969	<b>n/a</b>
Post-81 shelf trawl survey ending sel	0.018	<b>0.014</b>	<b>0.302</b>	<b>0.012</b>	<b>0.013</b>	0.017	<b>0.011</b>
Slope trawl survey ending sel	0.101	<b>0.025</b>	<b>0.847</b>	<b>0.124</b>	0.109	<b>0.900</b>	<b>0.085</b>
<b>Biomass</b>							
Pristine biomass (all ages)	2,172,230	2,126,520	<b>1,709,000</b>	2,195,810	2,170,900	2,207,740	<b>2,599,450</b>
Pristine biomass (ages 3+)	2,134,710	2,095,720	<b>1,648,890</b>	2,160,070	2,133,400	2,170,320	<b>2,564,700</b>
Pristine female spawning biomass	880,530	883,120	<b>591,870</b>	898,870	882,365	897,840	<b>1,090,475</b>
Initial biomass (all ages)	425,106	435,488	<b>234,715</b>	435,779	432,034	434,152	<b>1,969,300</b>
Initial biomass (ages 3+)	392,873	406,755	<b>181,740</b>	403,431	400,317	402,172	<b>1,948,840</b>
Initial female spawning biomass	169,325	177,583	<b>60,801</b>	173,788	173,839	174,129	<b>733,325</b>
2006 biomass (all ages)	945,982	926,285	<b>776,980</b>	885,229	918,125	971,414	933,446
2006 biomass (ages 3+)	921,524	907,595	<b>739,436</b>	861,590	890,481	946,926	912,733
2006 female spawning biomass	342,106	345,420	<b>236,940</b>	312,799	327,036	354,015	347,029

Table 2a--Pre-workshop GOA model runs

	Base	Growth runs		Fixed M and Q runs	
		FixedGro	FreeGroCV	Fixed M	Fixed Q
<b>Objective function and its components</b>					
Objective function	857.51	799.33	854.90	878.12	863.70
Age composition	5.18	<b>5.77</b>	<b>5.81</b>	<b>6.85</b>	<b>5.76</b>
Size at age	52.21	<b>0.00</b>	47.37	<b>60.11</b>	54.44
Recruitment	20.51	21.90	<b>23.16</b>	<b>24.02</b>	20.03
Priors	96.77	101.06	96.02	90.42	97.86
Trawl survey biomass	4.64	4.33	4.58	<b>8.77</b>	<b>5.32</b>
Jan-May trawl fishery sizecomp	72.88	71.83	72.71	69.79	73.54
Jun-Dec trawl fishery sizecomp	172.09	171.18	172.07	170.56	172.96
Longline fishery sizecomp	205.08	200.16	205.08	204.79	205.53
Pot fishery sizecomp	113.48	113.62	113.43	115.10	113.53
Trawl survey sizecomp	114.67	109.47	114.67	<b>127.72</b>	114.74
<b>Life history parameters</b>					
Natural mortality rate	0.512	0.532	0.511	<b>0.370</b>	0.539
Length at age 1	13.510	13.800	13.357	13.102	13.367
Length at age 12	92.348	93.000	90.346	88.389	91.354
Brody growth coefficient	0.096	<b>0.108</b>	0.105	<b>0.124</b>	0.102
CV length at age 1	0.14	0.14	0.14	0.14	0.14
CV length at age 12	0.062	0.062	<b>0.084</b>	0.062	0.062
<b>Recruitment</b>					
Median recruitment (pre-1976 regime)	735,327	<b>815,418</b>	726,335	<b>239,066</b>	<b>1,083,322</b>
Median recruitment (post-1975 regime)	853,243	924,677	841,970	<b>274,800</b>	<b>1,237,743</b>
Recruitment standard deviation	0.22	0.22	0.22	0.22	0.22
<b>Catchability</b>					
Trawl survey catchability	0.980	0.978	0.980	0.992	<b>0.750</b>
<b>Selectivity</b>					
Jan-May trawl fishery sel at 90cm (dom)	1.000	1.000	1.000	1.000	1.000
Jan-May trawl fishery sel at 90cm (new)	1.000	1.000	1.000	1.000	1.000
Jun-Dec trawl fishery sel at 90cm (for)	0.679	0.702	0.713	<b>0.386</b>	<b>0.781</b>
Jun-Dec trawl fishery sel at 90cm (dom)	0.689	0.641	0.704	<b>0.521</b>	0.673
Jun-Dec trawl fishery sel at 90cm (new)	1.000	0.970	1.000	1.000	0.975
Longline fishery sel at 90cm (for)	0.711	0.724	0.742	<b>0.452</b>	<b>0.807</b>
Longline fishery sel at 90cm (dom)	0.998	0.996	0.999	0.962	0.999
Longline fishery sel at 90cm (new)	1.000	0.999	0.999	0.999	0.999
Pot fishery sel at 90cm (dom)	0.280	0.276	0.291	0.258	0.288
Pot fishery sel at 90cm (new)	0.940	<b>0.716</b>	0.930	0.968	<b>0.797</b>
Trawl survey sel at 90cm	0.594	<b>0.286</b>	<b>0.889</b>	<b>0.873</b>	<b>0.709</b>
Jan-May trawl fishery ending sel (dom)	0.707	<b>0.841</b>	<b>0.797</b>	<b>0.794</b>	<b>0.893</b>
Jan-May trawl fishery ending sel (new)	0.900	0.886	0.901	0.910	0.890
Jun-Dec trawl fishery ending sel (for)	0.242	<b>0.282</b>	<b>0.273</b>	<b>0.127</b>	<b>0.356</b>
Jun-Dec trawl fishery ending sel (dom)	0.152	0.150	0.162	<b>0.130</b>	0.163
Jun-Dec trawl fishery ending sel (new)	0.730	<b>0.425</b>	0.702	<b>0.804</b>	<b>0.447</b>
Longline fishery ending sel (for)	0.108	<b>0.141</b>	<b>0.123</b>	<b>0.078</b>	<b>0.166</b>
Longline fishery ending sel (dom)	0.682	<b>0.758</b>	<b>0.773</b>	0.662	<b>0.838</b>
Longline fishery ending sel (new)	0.914	0.890	0.909	0.936	0.893
Pot fishery ending sel (dom)	0.216	0.232	0.235	<b>0.900</b>	<b>0.900</b>
Pot fishery ending sel (new)	0.793	<b>0.620</b>	0.767	<b>0.235</b>	<b>0.243</b>
Trawl survey ending sel	0.453	<b>0.264</b>	<b>0.761</b>	<b>0.896</b>	<b>0.654</b>
<b>Biomass</b>					
Pristine biomass (all ages)	746,642	780,122	732,977	<b>629,541</b>	<b>916,921</b>
Pristine biomass (ages 3+)	678,848	702,399	666,342	<b>601,833</b>	<b>823,119</b>
Pristine female spawning biomass	240,397	250,760	234,584	243,250	<b>281,909</b>
Initial biomass (all ages)	549,553	<b>606,561</b>	540,608	<b>439,606</b>	<b>711,042</b>
Initial biomass (ages 3+)	505,925	554,287	498,578	<b>422,656</b>	<b>648,357</b>
Initial female spawning biomass	167,493	183,886	164,873	165,453	<b>206,753</b>
2006 biomass (all ages)	538,083	570,446	533,549	<b>389,475</b>	<b>705,043</b>
2006 biomass (ages 3+)	474,245	497,942	470,813	<b>363,125</b>	<b>616,791</b>
2006 female spawning biomass	157,270	169,812	155,991	<b>133,872</b>	<b>203,818</b>



Table 2b--Pre-workshop GOA model runs

	Base	Prior runs					
		PriorCV30	PriorCV40	PriorWt20	PriorWt40	PriorWt60	PriorWt80
<b>Objective function and its components</b>							
Objective function	857.51	<b>992.75</b>	907.60	<b>759.40</b>	789.85	815.13	837.45
Age composition	5.18	<b>6.42</b>	<b>5.88</b>	<b>3.46</b>	<b>4.06</b>	<b>4.59</b>	4.97
Size at age	52.21	56.00	54.19	<b>44.29</b>	47.17	49.45	51.22
Recruitment	20.51	<b>23.27</b>	21.66	18.69	19.23	19.68	20.09
Priors	96.77	<b>198.93</b>	<b>133.77</b>	<b>34.39</b>	<b>54.91</b>	<b>70.71</b>	<b>83.34</b>
Trawl survey biomass	4.64	<b>5.52</b>	4.87	4.26	4.34	4.41	4.59
Jan-May trawl fishery sizecomp	72.88	76.18	74.06	71.89	71.54	71.67	72.20
Jun-Dec trawl fishery sizecomp	172.09	180.43	175.01	168.90	169.21	169.98	170.95
Longline fishery sizecomp	205.08	210.99	206.79	196.75	199.72	202.07	203.99
Pot fishery sizecomp	113.48	116.92	114.68	109.53	109.96	110.78	112.64
Trawl survey sizecomp	114.67	118.10	116.67	107.25	109.71	111.80	113.46
<b>Life history parameters</b>							
Natural mortality rate	0.512	0.487	0.496	<b>0.590</b>	0.554	0.536	0.523
Length at age 1	13.510	13.287	13.420	14.467	14.054	13.791	13.619
Length at age 12	92.348	90.077	91.067	100.947	96.872	94.526	93.103
Brody growth coefficient	0.096	<b>0.111</b>	0.105	<b>0.049</b>	<b>0.070</b>	<b>0.083</b>	0.092
CV length at age 1	0.14	0.14	0.14	0.14	0.14	0.14	0.14
CV length at age 12	0.062	0.062	0.062	0.062	0.062	0.062	0.062
<b>Recruitment</b>							
Median recruitment (pre-1976 regime)	735,327	<b>597,537</b>	<b>644,301</b>	<b>1,397,590</b>	<b>1,053,680</b>	<b>896,821</b>	803,712
Median recruitment (post-1975 regime)	853,243	<b>717,049</b>	<b>757,668</b>	<b>1,639,989</b>	<b>1,223,468</b>	<b>1,038,097</b>	930,056
Recruitment standard deviation	0.22	0.22	0.22	0.22	0.22	0.22	0.22
<b>Catchability</b>							
Trawl survey catchability	0.980	0.909	0.947	0.990	0.986	0.985	0.984
<b>Selectivity</b>							
Jan-May trawl fishery sel at 90cm (dom)	1.000	1.000	1.000	0.998	1.000	1.000	1.000
Jan-May trawl fishery sel at 90cm (new)	1.000	1.000	1.000	<b>0.654</b>	<b>0.841</b>	0.998	1.000
Jun-Dec trawl fishery sel at 90cm (for)	0.679	<b>0.993</b>	<b>0.849</b>	<b>0.568</b>	<b>0.581</b>	0.613	0.652
Jun-Dec trawl fishery sel at 90cm (dom)	0.689	<b>1.000</b>	<b>0.903</b>	<b>0.307</b>	<b>0.394</b>	<b>0.504</b>	<b>0.616</b>
Jun-Dec trawl fishery sel at 90cm (new)	1.000	1.000	1.000	<b>0.317</b>	<b>0.485</b>	<b>0.720</b>	0.953
Longline fishery sel at 90cm (for)	0.711	<b>0.790</b>	0.744	<b>0.638</b>	0.658	0.685	0.707
Longline fishery sel at 90cm (dom)	0.998	1.000	1.000	<b>0.776</b>	<b>0.868</b>	0.947	0.992
Longline fishery sel at 90cm (new)	1.000	1.000	1.000	<b>0.586</b>	<b>0.710</b>	0.972	0.999
Pot fishery sel at 90cm (dom)	0.280	<b>0.364</b>	<b>0.318</b>	<b>0.139</b>	<b>0.179</b>	<b>0.225</b>	0.265
Pot fishery sel at 90cm (new)	0.940	0.977	0.972	<b>0.279</b>	<b>0.388</b>	<b>0.545</b>	0.885
Trawl survey sel at 90cm	0.594	<b>0.958</b>	<b>0.885</b>	<b>0.118</b>	<b>0.209</b>	<b>0.348</b>	<b>0.510</b>
Jan-May trawl fishery ending sel (dom)	0.707	<b>0.916</b>	<b>0.902</b>	<b>0.152</b>	<b>0.244</b>	<b>0.386</b>	<b>0.570</b>
Jan-May trawl fishery ending sel (new)	0.900	0.904	0.905	<b>0.119</b>	<b>0.225</b>	<b>0.537</b>	0.884
Jun-Dec trawl fishery ending sel (for)	0.242	<b>0.846</b>	<b>0.419</b>	<b>0.079</b>	<b>0.123</b>	<b>0.170</b>	<b>0.213</b>
Jun-Dec trawl fishery ending sel (dom)	0.152	<b>0.833</b>	<b>0.314</b>	<b>0.066</b>	<b>0.081</b>	<b>0.101</b>	<b>0.128</b>
Jun-Dec trawl fishery ending sel (new)	0.730	<b>0.890</b>	<b>0.873</b>	<b>0.044</b>	<b>0.062</b>	<b>0.122</b>	<b>0.340</b>
Longline fishery ending sel (for)	0.108	<b>0.281</b>	<b>0.166</b>	<b>0.030</b>	<b>0.046</b>	<b>0.068</b>	<b>0.092</b>
Longline fishery ending sel (dom)	0.682	<b>0.918</b>	<b>0.893</b>	<b>0.159</b>	<b>0.254</b>	<b>0.393</b>	<b>0.562</b>
Longline fishery ending sel (new)	0.914	0.918	0.923	<b>0.150</b>	<b>0.290</b>	<b>0.448</b>	0.878
Pot fishery ending sel (dom)	0.216	<b>0.250</b>	0.230	<b>0.081</b>	<b>0.126</b>	<b>0.172</b>	0.206
Pot fishery ending sel (new)	0.793	<b>0.910</b>	<b>0.900</b>	<b>0.151</b>	<b>0.315</b>	<b>0.472</b>	<b>0.623</b>
Trawl survey ending sel	0.453	<b>0.902</b>	<b>0.782</b>	<b>0.028</b>	<b>0.097</b>	<b>0.220</b>	<b>0.368</b>
<b>Biomass</b>							
Pristine biomass (all ages)	746,642	728,259	730,344	<b>925,545</b>	<b>843,158</b>	794,086	762,256
Pristine biomass (ages 3+)	678,848	668,757	668,282	<b>806,955</b>	<b>750,824</b>	714,003	689,424
Pristine female spawning biomass	240,397	241,595	239,848	<b>267,819</b>	257,097	248,002	241,685
Initial biomass (all ages)	549,553	496,503	519,877	<b>676,269</b>	<b>625,897</b>	591,479	566,661
Initial biomass (ages 3+)	505,925	459,341	480,566	<b>602,034</b>	<b>566,984</b>	539,918	519,586
Initial female spawning biomass	167,493	154,812	161,373	<b>184,245</b>	180,241	174,667	169,981
2006 biomass (all ages)	538,083	506,912	516,000	<b>719,175</b>	<b>635,414</b>	587,601	556,694
2006 biomass (ages 3+)	474,245	452,188	458,231	<b>604,901</b>	<b>547,186</b>	511,516	487,821
2006 female spawning biomass	157,270	154,979	154,671	<b>189,543</b>	<b>176,336</b>	166,634	159,993

Table 2c--Pre-workshop GOA model runs

	Base	Asymptotic runs				Tier 1 runs
		AsympTFsry	AsympLFsry	AsympPFsry	AsympTSry	Ricker
<b>Objective function and its components</b>						
Objective function	857.51	857.52	857.50	857.59	858.33	857.00
Age composition	5.18	5.19	5.19	5.21	5.37	5.04
Size at age	52.21	52.22	52.26	52.34	52.65	52.33
Recruitment	20.51	20.51	20.51	20.51	20.71	20.16
Priors	96.77	96.74	96.68	96.50	94.73	96.93
Trawl survey biomass	4.64	4.64	4.64	4.65	4.44	4.21
Jan-May trawl fishery sizecomp	72.88	72.89	72.89	72.91	73.13	72.83
Jun-Dec trawl fishery sizecomp	172.09	172.09	172.08	172.05	171.93	171.83
Longline fishery sizecomp	205.08	205.09	205.10	205.17	205.75	205.01
Pot fishery sizecomp	113.48	113.47	113.46	113.51	112.88	113.54
Trawl survey sizecomp	114.67	114.68	114.70	114.75	116.74	115.11
<b>Life history parameters</b>						
Natural mortality rate	0.512	0.512	0.512	0.512	0.506	0.512
Length at age 1	13.510	13.508	13.505	13.498	13.456	13.498
Length at age 12	92.348	92.339	92.320	92.271	91.811	92.286
Brody growth coefficient	0.096	0.097	0.097	0.097	0.100	0.097
CV length at age 1	0.14	0.14	0.14	0.14	0.14	0.14
CV length at age 12	0.062	0.062	0.062	0.062	0.062	0.062
<b>Recruitment</b>						
Median recruitment (pre-1976 regime)	735,327	734,888	734,002	732,016	695,566	759,360
Median recruitment (post-1975 regime)	853,243	852,731	851,624	849,158	811,630	869,697
Recruitment standard deviation	0.22	0.22	0.22	0.22	0.22	0.22
<b>Catchability</b>						
Trawl survey catchability	0.980	0.980	0.980	0.980	0.977	0.981
<b>Selectivity</b>						
Jan-May trawl fishery sel at 90cm (dom)	1.000	1.000	1.000	1.000	1.000	1.000
Jan-May trawl fishery sel at 90cm (new)	1.000	1.000	1.000	1.000	1.000	1.000
Jun-Dec trawl fishery sel at 90cm (for)	0.679	0.679	0.679	0.680	0.688	0.660
Jun-Dec trawl fishery sel at 90cm (dom)	0.689	0.690	0.691	0.694	0.714	0.685
Jun-Dec trawl fishery sel at 90cm (new)	1.000	1.000	1.000	1.000	1.000	1.000
Longline fishery sel at 90cm (for)	0.711	0.712	0.712	0.713	0.723	0.697
Longline fishery sel at 90cm (dom)	0.998	0.998	0.998	0.999	1.000	0.997
Longline fishery sel at 90cm (new)	1.000	1.000	1.000	1.000	1.000	1.000
Pot fishery sel at 90cm (dom)	0.280	0.280	0.281	0.283	0.299	<b>0.398</b>
Pot fishery sel at 90cm (new)	0.940	0.942	0.944	1.000	0.967	0.991
Trawl survey sel at 90cm	0.594	0.596	0.599	0.608	<b>1.000</b>	<b>0.720</b>
Jan-May trawl fishery ending sel (dom)	0.707	0.710	0.715	0.729	<b>0.836</b>	0.692
Jan-May trawl fishery ending sel (new)	0.900	<b>0.999</b>	0.901	0.904	0.909	0.900
Jun-Dec trawl fishery ending sel (for)	0.242	0.242	0.243	0.244	0.254	0.234
Jun-Dec trawl fishery ending sel (dom)	0.152	0.152	0.153	0.154	<b>0.168</b>	0.150
Jun-Dec trawl fishery ending sel (new)	0.730	0.736	0.742	0.763	0.799	0.736
Longline fishery ending sel (for)	0.108	0.108	0.109	0.110	0.117	0.105
Longline fishery ending sel (dom)	0.682	0.684	0.688	0.700	<b>0.800</b>	0.668
Longline fishery ending sel (new)	0.914	0.915	0.999	0.920	0.927	0.915
Pot fishery ending sel (dom)	0.216	0.217	0.217	0.219	0.236	<b>0.900</b>
Pot fishery ending sel (new)	0.793	0.800	0.806	<b>0.999</b>	<b>0.878</b>	<b>0.214</b>
Trawl survey ending sel	0.453	0.455	0.457	0.468	<b>0.999</b>	<b>0.799</b>
<b>Biomass</b>						
Pristine biomass (all ages)	746,642	746,480	746,208	745,369	736,227	762,237
Pristine biomass (ages 3+)	678,848	678,722	678,524	677,864	671,157	693,115
Pristine female spawning biomass	240,397	240,364	240,320	240,136	238,785	245,505
Initial biomass (all ages)	549,553	549,452	549,331	548,897	533,529	579,086
Initial biomass (ages 3+)	505,925	505,845	505,766	505,434	492,154	534,189
Initial female spawning biomass	167,493	167,477	167,475	167,412	164,010	177,438
2006 biomass (all ages)	538,083	537,933	537,658	536,919	527,691	500,677
2006 biomass (ages 3+)	474,245	474,129	473,924	473,355	466,431	441,246
2006 female spawning biomass	157,270	157,237	157,182	157,010	155,311	146,993

Table 3a--Tuesday night BS model runs

	Base	Run 1	Run 2	Run 3	Run 4
<b>Objective function and its components</b>					
Objective function	2048.30	2048.30	2256.16	2601.83	2087.58
Age composition	62.42	62.42	64.53	98.34	69.84
Size at age	267.31	267.31	299.42	334.57	281.89
Recruitment	27.30	27.30	16.19	39.25	24.40
Priors	133.49	133.49	0.00	0.00	0.00
CPUE	0.00	0.00	0.00	75.17	67.06
Pre-82 shelf trawl survey biomass	5.13	5.13	3.80	0.13	3.79
Post-81 shelf trawl survey biomass	44.45	44.45	38.13	56.07	37.36
Slope trawl survey biomass	0.58	0.58	0.58	6.55	0.79
Jan-May trawl fishery sizecomp	260.54	260.54	288.04	309.21	305.97
Jun-Dec trawl fishery sizecomp	386.68	386.68	392.19	420.20	413.52
Longline fishery sizecomp	463.03	463.03	519.20	671.95	471.76
Pot fishery sizecomp	185.69	185.69	413.47	251.89	191.39
Pre-82 shelf trawl survey sizecomp	46.69	46.69	43.09	124.36	42.16
Post-81 shelf trawl survey sizecomp	158.71	158.71	176.16	204.85	174.57
Slope trawl survey sizecomp	6.27	6.27	1.34	8.79	3.05
<b>Life history parameters</b>					
Natural mortality rate (young)	0.344	0.344	0.328	0.483	0.426
Natural mortality rate (old)	0.344	0.344	0.696	0.483	0.426
Length at age 1	11.128	11.128	11.218	9.860	10.629
Length at age 12	113.604	113.604	108.123	94.824	108.445
Brody growth coefficient	0.036	0.036	0.042	0.114	0.054
CV length at age 1	0.16	0.16	0.16	0.16	0.16
CV length at age 12	0.066	0.066	0.066	0.066	0.066
<b>Recruitment</b>					
Median recruitment (pre-1976 regime)	317,853	317,851	19,155	92	3,062,783,561
Median recruitment (post-1975 regime)	535,202	535,202	2,101,370	1,429,735	782,696
Recruitment standard deviation	0.63	0.63	0.63	0.63	0.63
<b>Catchability</b>					
Pre-1982 shelf trawl survey catchability	0.986	0.986	0.976	0.464	1.560
Post-1981 shelf trawl survey catchability	0.917	0.917	1.138	0.442	0.966
Slope trawl survey catchability	0.011	0.011	0.011	0.020	0.012
<b>Selectivity</b>					
Jan-May trawl fishery sel at 90cm (for)	0.417	0.417	1.000	0.795	0.965
Jan-May trawl fishery sel at 90cm (dom)	0.628	0.628	0.996	1.000	0.000
Jan-May trawl fishery sel at 90cm (new)	0.681	0.681	1.000	1.000	0.912
Jun-Dec trawl fishery sel at 90cm (for)	0.715	0.715	0.987	0.979	0.980
Jun-Dec trawl fishery sel at 90cm (dom)	1.000	1.000	0.898	1.000	0.000
Jun-Dec trawl fishery sel at 90cm (new)	0.982	0.982	0.753	0.964	0.436
Longline fishery sel at 90cm (for)	0.288	0.288	0.746	1.000	0.676
Longline fishery sel at 90cm (dom)	0.512	0.512	1.000	0.970	0.000
Longline fishery sel at 90cm (new)	0.344	0.344	1.000	0.489	0.978
Pot fishery sel at 90cm (dom)	0.525	0.525	0.804	1.000	0.000
Pot fishery sel at 90cm (new)	0.420	0.420	1.000	1.000	1.000
Pre-82 shelf trawl survey sel at 90cm	0.982	0.982	1.000	0.302	1.000
Post-81 shelf trawl survey sel at 90cm	0.266	0.266	1.000	1.000	0.978
Slope trawl survey sel at 90cm	0.440	0.440	0.418	0.003	0.978
Jan-May trawl fishery ending sel (for)	0.018	0.018	0.166	0.000	0.007
Jan-May trawl fishery ending sel (dom)	0.018	0.018	0.000	1.000	0.000
Jan-May trawl fishery ending sel (new)	0.033	0.033	1.000	0.000	0.139
Jun-Dec trawl fishery ending sel (for)	0.021	0.021	0.244	0.270	0.000
Jun-Dec trawl fishery ending sel (dom)	0.045	0.045	1.000	0.874	1.000
Jun-Dec trawl fishery ending sel (new)	0.036	0.036	1.000	0.179	0.000
Longline fishery ending sel (for)	0.009	0.009	0.000	0.259	0.011
Longline fishery ending sel (dom)	0.016	0.016	1.000	0.920	0.087
Longline fishery ending sel (new)	0.013	0.013	1.000	0.000	0.030
Pot fishery ending sel (dom)	0.018	0.018	0.000	0.000	0.063
Pot fishery ending sel (new)	0.039	0.039	1.000	1.000	1.000
Pre-82 shelf trawl survey ending sel	0.969	0.969	1.000	0.000	1.000
Post-81 shelf trawl survey ending sel	0.018	0.018	1.000	1.000	0.215
Slope trawl survey ending sel	0.101	0.101	0.000	0.000	1.000
<b>Biomass</b>					
Pristine biomass (all ages)	2,172,230	2,172,230	1,934,490	1,669,090	1,539,570
Pristine biomass (ages 3+)	2,134,710	2,134,710	1,786,570	1,587,100	1,492,480
Pristine female spawning biomass	880,530	794,620	458,849	513,385	558,795
Initial biomass (all ages)	425,106	425,106	246,874	732,424	235,023
Initial biomass (ages 3+)	392,873	392,873	164,508	576,892	199,622
Initial female spawning biomass	169,325	159,524	35,500	196,758	75,542
2006 biomass (all ages)	945,982	945,982	1,002,430	1,095,430	658,317
2006 biomass (ages 3+)	921,524	921,524	912,171	1,035,750	625,640
2006 female spawning biomass	342,106	288,941	210,277	302,095	181,960

**Table 3b--Tuesday night BS model runs**

	Base	Run 7	Run 8	Run 9	Run 10
<b>Objective function and its components</b>					
Objective function	2048.30	<b>2567.17</b>	<b>2339.14</b>	2103.68	2020.65
Age composition	62.42	62.72	<b>69.26</b>	<b>72.03</b>	64.43
Size at age	267.31	<b>359.78</b>	292.64	<b>307.46</b>	274.60
Recruitment	27.30	<b>16.77</b>	<b>34.86</b>	23.69	<b>15.13</b>
Priors	133.49	<b>0.00</b>	<b>0.00</b>	<b>107.22</b>	<b>100.63</b>
CPUE	0.00	0.00	0.00	0.00	0.00
Pre-82 shelf trawl survey biomass	5.13	<b>2.11</b>	<b>3.95</b>	<b>1.85</b>	<b>9.08</b>
Post-81 shelf trawl survey biomass	44.45	48.76	45.99	47.39	46.49
Slope trawl survey biomass	0.58	<b>0.34</b>	<b>0.15</b>	<b>0.47</b>	<b>0.69</b>
Jan-May trawl fishery sizecomp	260.54	276.91	280.09	265.95	259.22
Jun-Dec trawl fishery sizecomp	386.68	408.35	403.63	393.03	396.75
Longline fishery sizecomp	463.03	<b>909.75</b>	507.47	476.13	457.21
Pot fishery sizecomp	185.69	<b>249.98</b>	<b>427.23</b>	184.72	181.41
Pre-82 shelf trawl survey sizecomp	46.69	42.75	42.28	42.74	44.33
Post-81 shelf trawl survey sizecomp	158.71	<b>187.22</b>	<b>177.44</b>	174.06	164.13
Slope trawl survey sizecomp	6.27	<b>1.74</b>	<b>54.14</b>	<b>6.94</b>	6.55
<b>Life history parameters</b>					
Natural mortality rate (young)	0.344	<b>0.642</b>	0.358	<b>0.470</b>	<b>0.382</b>
Natural mortality rate (old)	0.344	<b>0.642</b>	0.358	<b>0.470</b>	<b>1.022</b>
Length at age 1	11.128	<b>9.981</b>	10.306	<b>9.990</b>	10.656
Length at age 12	113.604	<b>99.676</b>	104.082	<b>101.035</b>	107.322
Brody growth coefficient	0.036	<b>0.082</b>	<b>0.072</b>	<b>0.084</b>	<b>0.058</b>
CV length at age 1	0.16	0.16	0.16	0.16	0.16
CV length at age 12	0.066	0.066	0.066	0.066	0.066
<b>Recruitment</b>					
Median recruitment (pre-1976 regime)	317,853	250	31	<b>802,019</b>	309,778
Median recruitment (post-1975 regime)	535,202	<b>5,025,322</b>	<b>445,789</b>	<b>1,632,952</b>	<b>798,348</b>
Recruitment standard deviation	0.63	0.63	0.63	0.63	0.63
<b>Catchability</b>					
Pre-1982 shelf trawl survey catchability	0.986	<b>0.713</b>	<b>2.622</b>	<b>0.725</b>	0.991
Post-1981 shelf trawl survey catchability	0.917	<b>0.748</b>	<b>1.331</b>	<b>0.500</b>	0.879
Slope trawl survey catchability	0.011	<b>0.007</b>	0.011	<b>0.007</b>	0.011
<b>Selectivity</b>					
Jan-May trawl fishery sel at 90cm (for)	0.417	<b>1.000</b>	<b>0.896</b>	<b>0.644</b>	<b>0.692</b>
Jan-May trawl fishery sel at 90cm (dom)	0.628	<b>0.853</b>	<b>1.000</b>	<b>0.895</b>	<b>1.000</b>
Jan-May trawl fishery sel at 90cm (new)	0.681	<b>1.000</b>	<b>1.000</b>	<b>0.947</b>	<b>1.000</b>
Jun-Dec trawl fishery sel at 90cm (for)	0.715	<b>0.788</b>	<b>1.000</b>	<b>0.976</b>	<b>1.000</b>
Jun-Dec trawl fishery sel at 90cm (dom)	1.000	<b>0.764</b>	<b>0.874</b>	1.000	1.000
Jun-Dec trawl fishery sel at 90cm (new)	0.982	<b>0.795</b>	<b>0.778</b>	1.000	1.000
Longline fishery sel at 90cm (for)	0.288	<b>1.000</b>	<b>0.575</b>	<b>0.442</b>	<b>0.447</b>
Longline fishery sel at 90cm (dom)	0.512	<b>0.752</b>	<b>1.000</b>	<b>0.883</b>	<b>1.000</b>
Longline fishery sel at 90cm (new)	0.344	<b>1.000</b>	<b>1.000</b>	<b>0.517</b>	<b>0.621</b>
Pot fishery sel at 90cm (dom)	0.525	<b>1.000</b>	<b>0.768</b>	<b>0.943</b>	<b>1.000</b>
Pot fishery sel at 90cm (new)	0.420	<b>1.000</b>	<b>1.000</b>	<b>0.636</b>	<b>0.848</b>
Pre-82 shelf trawl survey sel at 90cm	0.982	1.000	1.000	<b>0.059</b>	0.956
Post-81 shelf trawl survey sel at 90cm	0.266	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>0.541</b>
Slope trawl survey sel at 90cm	0.440	<b>1.000</b>	<b>1.000</b>	<b>0.932</b>	<b>0.994</b>
Jan-May trawl fishery ending sel (for)	0.018	<b>0.516</b>	<b>0.000</b>	<b>0.102</b>	<b>0.170</b>
Jan-May trawl fishery ending sel (dom)	0.018	<b>0.000</b>	<b>1.000</b>	<b>0.095</b>	<b>0.448</b>
Jan-May trawl fishery ending sel (new)	0.033	<b>1.000</b>	<b>1.000</b>	<b>0.193</b>	<b>0.696</b>
Jun-Dec trawl fishery ending sel (for)	0.021	<b>0.000</b>	<b>1.000</b>	<b>0.136</b>	<b>0.301</b>
Jun-Dec trawl fishery ending sel (dom)	0.045	<b>0.000</b>	<b>1.000</b>	<b>0.203</b>	<b>0.922</b>
Jun-Dec trawl fishery ending sel (new)	0.036	<b>0.000</b>	<b>1.000</b>	<b>0.176</b>	<b>0.606</b>
Longline fishery ending sel (for)	0.009	<b>1.000</b>	<b>0.000</b>	<b>0.069</b>	<b>0.111</b>
Longline fishery ending sel (dom)	0.016	<b>0.000</b>	<b>1.000</b>	<b>0.105</b>	<b>0.483</b>
Longline fishery ending sel (new)	0.013	<b>1.000</b>	<b>1.000</b>	<b>0.118</b>	<b>0.451</b>
Pot fishery ending sel (dom)	0.018	<b>1.000</b>	<b>0.000</b>	<b>0.113</b>	<b>0.616</b>
Pot fishery ending sel (new)	0.039	<b>1.000</b>	<b>1.000</b>	<b>0.346</b>	<b>0.739</b>
Pre-82 shelf trawl survey ending sel	0.969	<b>0.000</b>	1.000	<b>0.001</b>	0.921
Post-81 shelf trawl survey ending sel	0.018	<b>1.000</b>	<b>1.000</b>	<b>1.000</b>	<b>0.362</b>
Slope trawl survey ending sel	0.101	<b>1.000</b>	<b>1.000</b>	<b>0.504</b>	<b>0.861</b>
<b>Biomass</b>					
Pristine biomass (all ages)	2,172,230	2,144,630	<b>1,484,810</b>	2,171,040	<b>1,622,850</b>
Pristine biomass (ages 3+)	2,134,710	1,936,120	<b>1,454,760</b>	2,080,390	<b>1,570,920</b>
Pristine female spawning biomass	880,530	<b>515,085</b>	<b>576,170</b>	<b>713,480</b>	<b>549,880</b>
Initial biomass (all ages)	425,106	<b>382,155</b>	<b>143,170</b>	<b>378,451</b>	<b>187,296</b>
Initial biomass (ages 3+)	392,873	<b>212,841</b>	<b>124,357</b>	<b>286,166</b>	<b>148,124</b>
Initial female spawning biomass	169,325	<b>46,130</b>	<b>44,609</b>	<b>87,893</b>	<b>43,827</b>
2006 biomass (all ages)	945,982	<b>1,159,570</b>	<b>455,305</b>	<b>1,159,870</b>	<b>729,074</b>
2006 biomass (ages 3+)	921,524	<b>1,029,870</b>	<b>437,781</b>	<b>1,109,480</b>	<b>700,280</b>
2006 female spawning biomass	342,106	<b>262,385</b>	<b>133,972</b>	363,649	<b>224,369</b>



## Figures

- Figure 1. Cumulative monthly Pacific cod catch by month and gear based on NMFS official statistics, 1991-2006 (BS).
- Figure 2. Mean proportion of male Pacific cod by size category and overall based on all observer data (combined gears; BS).
- Figure 3. Mean relative change in weight given selected lengths of 60-65 cm (bottom panel) and the available sample sizes of length-weight data by month (top panel) for the BS.
- Figure 4. An example output showing bootstrap samples of Pacific cod catch-weighted length frequency data for pot gear (BS).
- Figure 5. Example of new double-normal selectivity pattern.
- Figure 6. Prior distribution of selectivities at length implied by prior distributions on selectivity parameters as specified in the base models.
- Figure 7a. Time series of female spawning biomass, with 95% confidence intervals, as estimated by the BS base model.
- Figure 7b. Time series of female spawning biomass, with 95% confidence intervals, as estimated by the GOA base model.
- Figure 8a. Time series of age 0 fish, with 95% confidence intervals, as estimated by the BS base model.
- Figure 8b. Time series of age 0 fish, with 95% confidence intervals, as estimated by the GOA base model.
- Figure 9a. Fishery and survey selectivity curves estimated by the BS base model.
- Figure 9b. Fishery and survey selectivity curves estimated by the GOA base model.
- Figure 10a. Profile of objective function values across a factorial grid of  $M$  and  $Q$  values for the BS model.
- Figure 10b. Profile of objective function values across a factorial grid of  $M$  and  $Q$  values for the GOA model.
- Figure 11. Comparison of Pacific cod CPUE in the IPHC survey and the longline fishery (BS).
- Figure 12. BS shelf trawl survey length compositions (up to 50 cm) aggregated over time.
- Figure 13. Fitting growth curves to BS trawl survey data without accounting for effects of selectivity.
- Figure 14. Fitting growth curves to BS trawl survey data with effects of selectivity taken into account.
- Figure 15. Length at age as estimated outside the model from tagging data (BS). Two curves were fit based on days at liberty (DAL).
- Figure 16. Comparing aggregate survey numbers at length to a normal distribution with mean = 17 cm and CV = 16% (BS).
- Figure 17. Comparison of commercial fishery CPUE time series by gear type (BS).

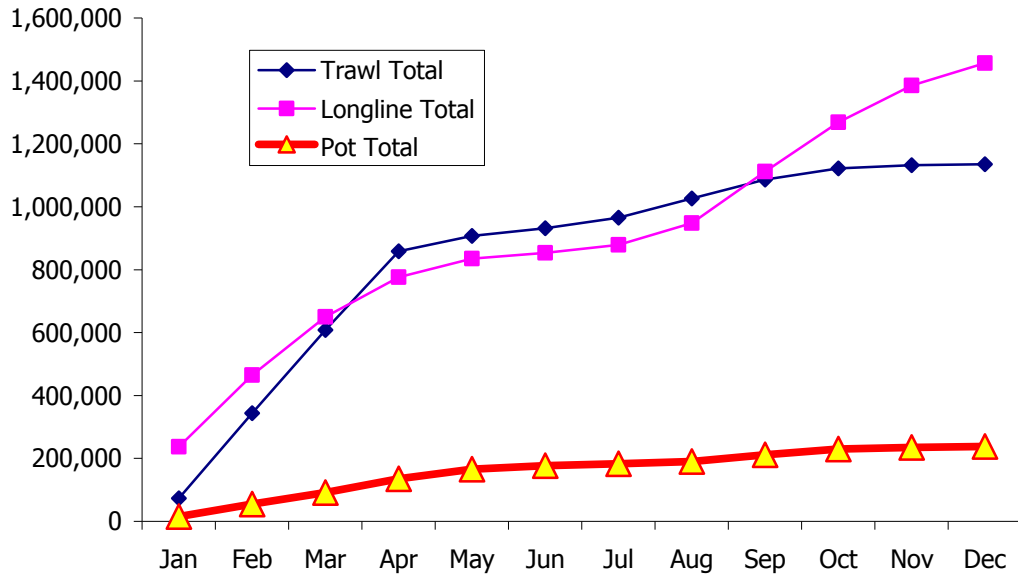


Figure 1. Cumulative monthly Pacific cod catch by month and gear based on NMFS official catch statistics, 1991-2006 (BS).

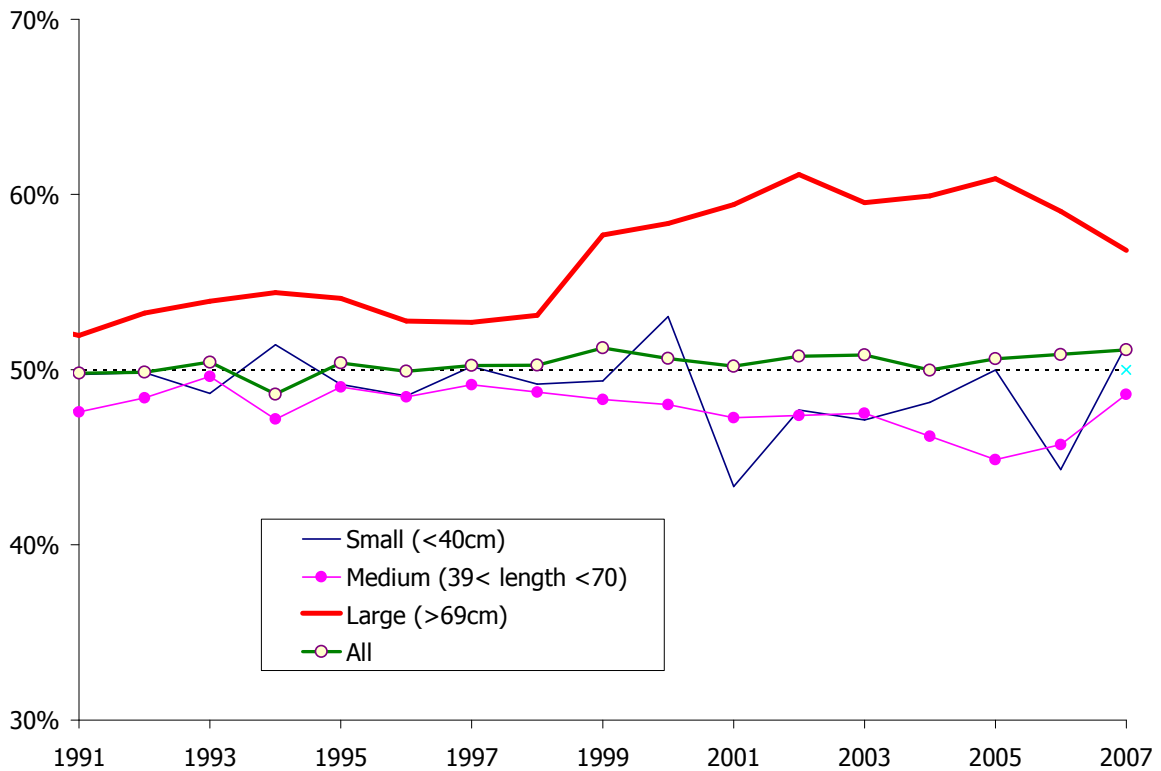


Figure 2. Mean proportion of male Pacific cod by size category and overall based on all observer data (combined gears; BS).

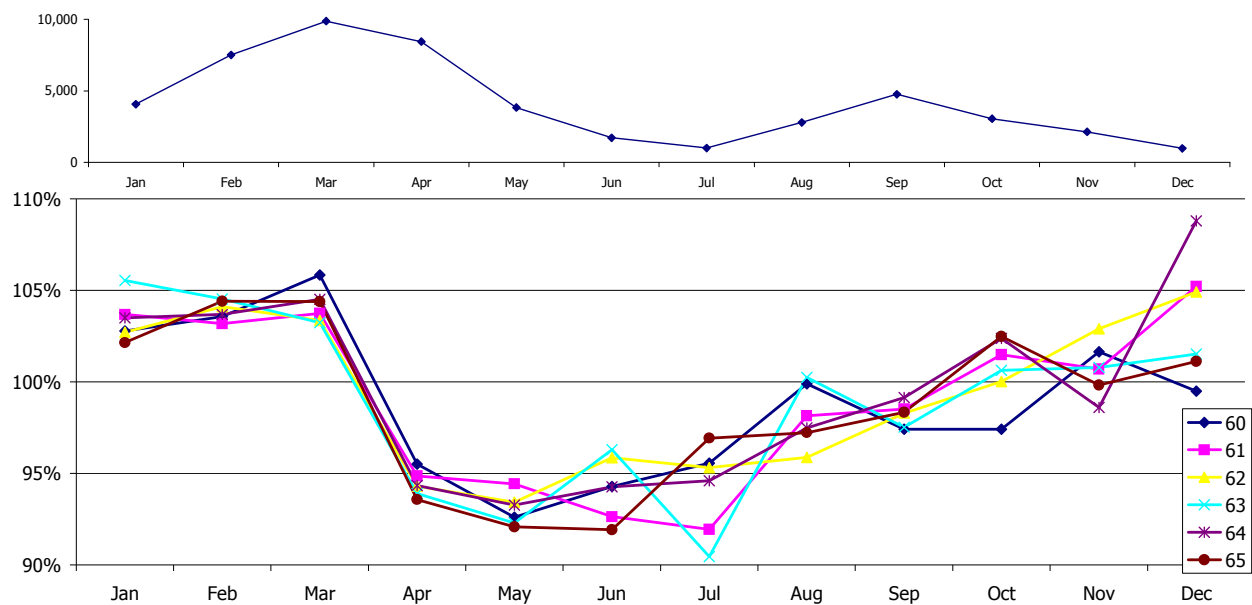


Figure 3. Mean relative change in weight given selected lengths of 60-65 cm (bottom panel) and the available sample sizes of length-weight data by month (top panel) for the BS.

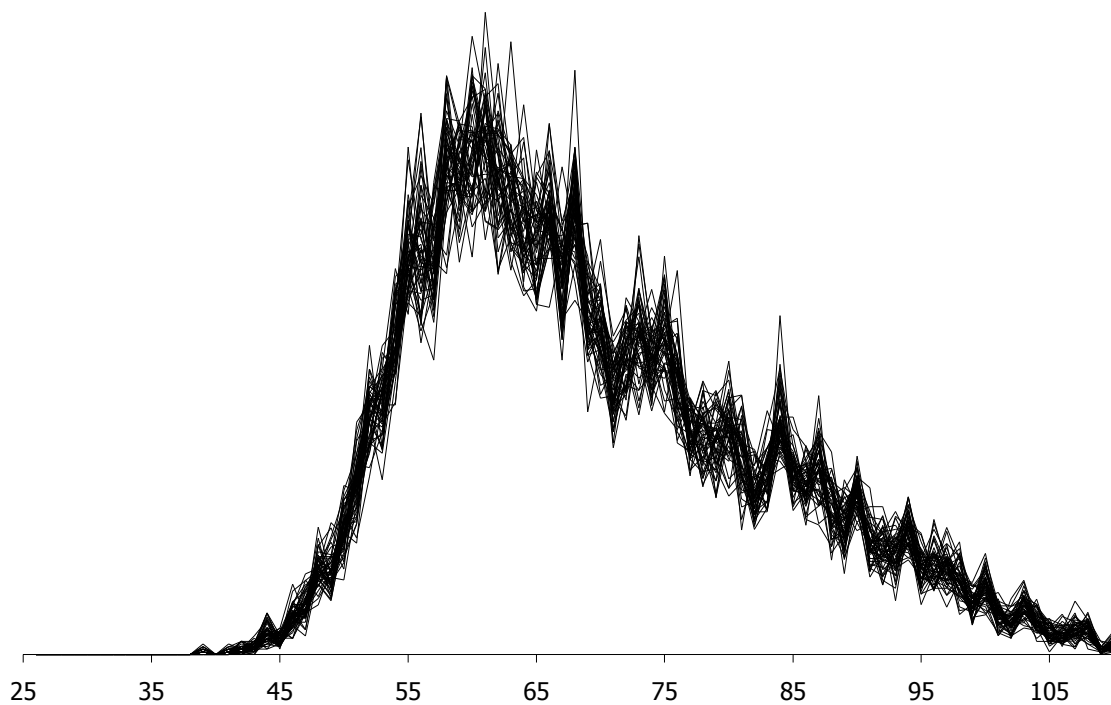


Figure 4. An example output showing bootstrap samples of Pacific cod catch-weighted length frequency data for pot gear (BS).

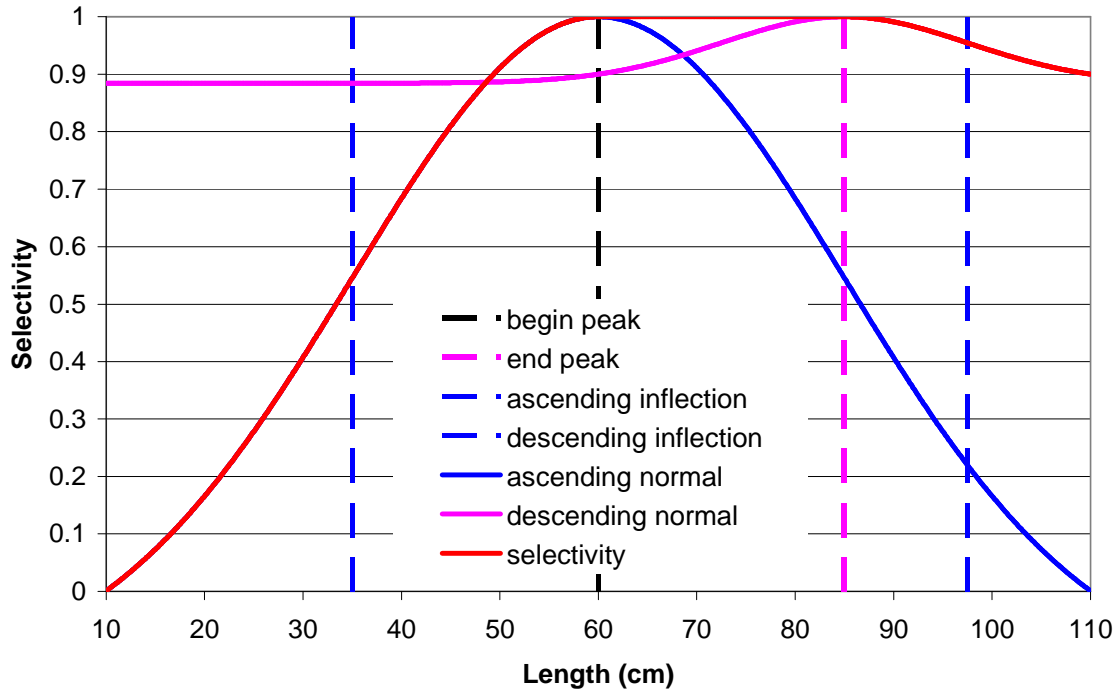


Figure 5. Example of new double-normal selectivity pattern. Selectivity (red curve) overlays the left-hand limb of an underlying, linearly rescaled normal distribution (blue curve) and the right-hand limb of another underlying, linearly rescaled normal distribution (magenta curve).

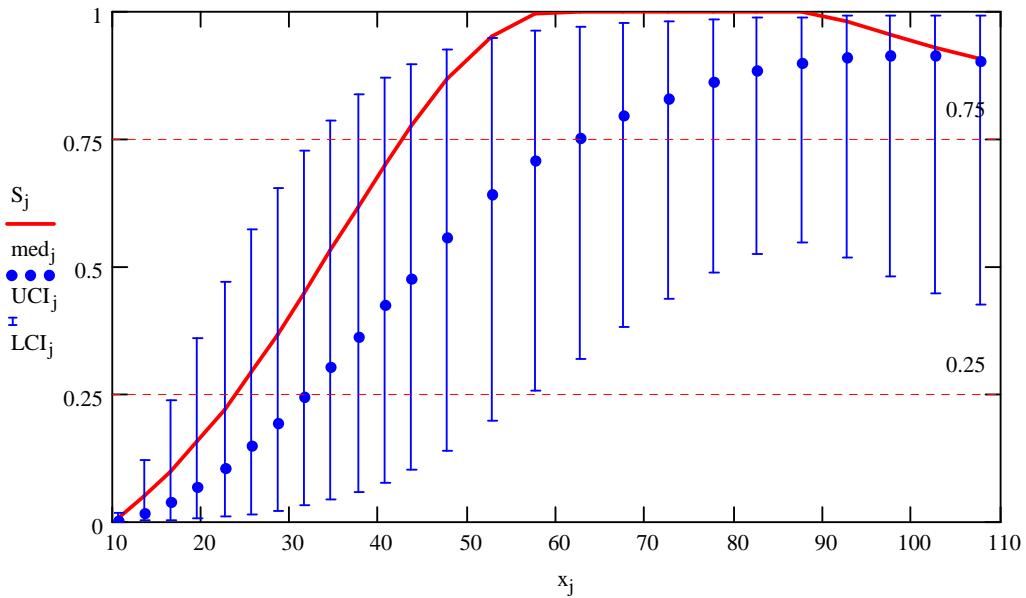


Figure 6. Prior distribution of selectivities at length implied by prior distributions on selectivity parameters as specified in the base models. Blue dots = median, blue error bars = inter-quartile region, red curve = selectivity with parameters set equal to means of their respective priors.

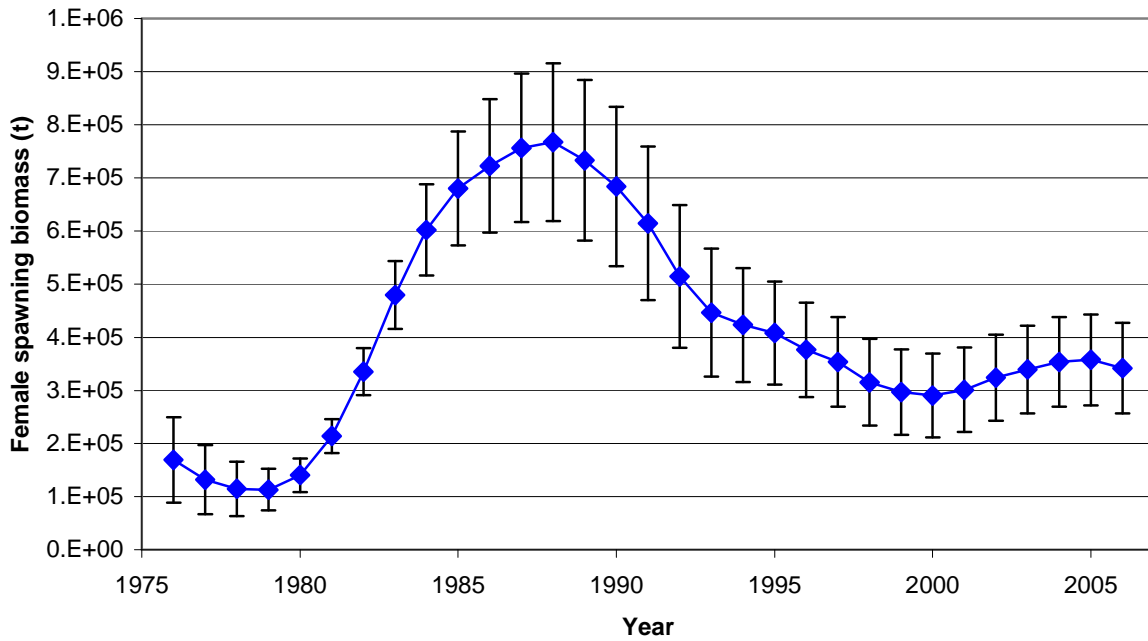


Figure 7a. Time series of female spawning biomass, with 95% confidence intervals, as estimated by the BS base model.

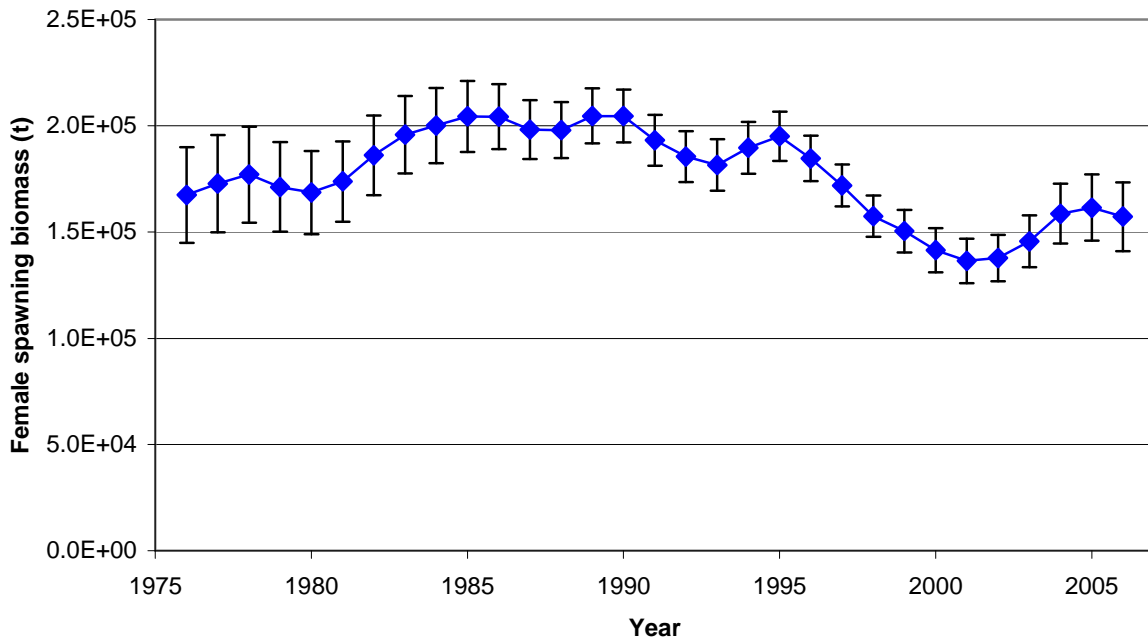


Figure 7b. Time series of female spawning biomass, with 95% confidence intervals, as estimated by the GOA base model.

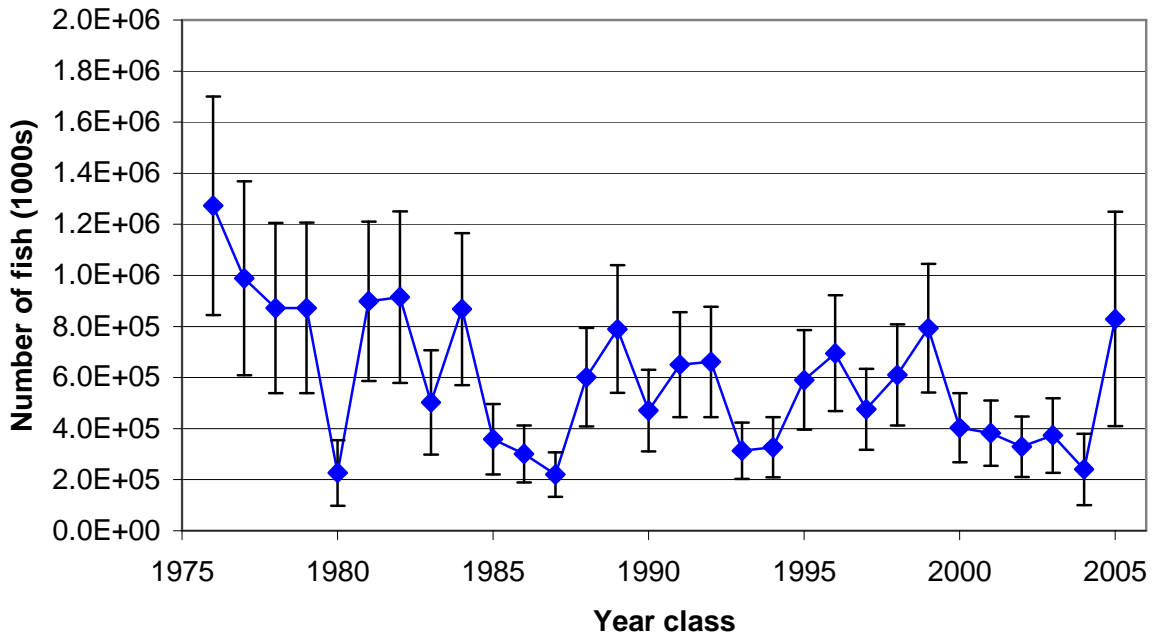


Figure 8a. Time series of age 0 fish, with 95% confidence intervals, as estimated by the BS base model.

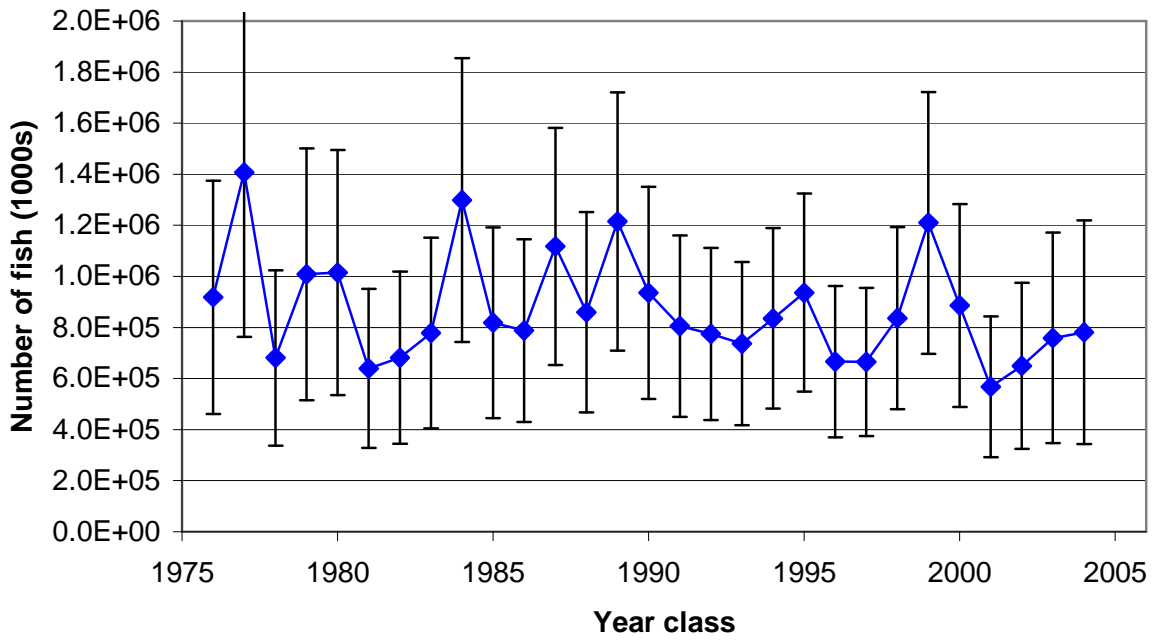


Figure 8b. Time series of age 0 fish, with 95% confidence intervals, as estimated by the GOA base model.

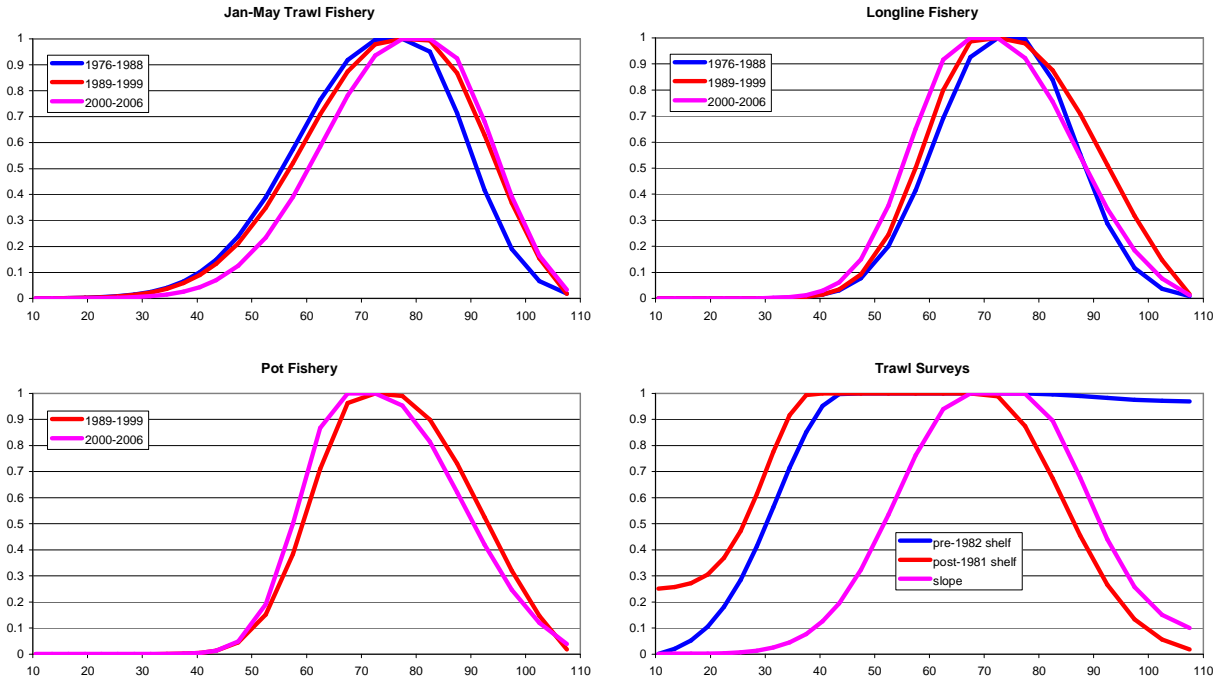


Figure 9a. Fishery and survey selectivity curves estimated by the BS base model.

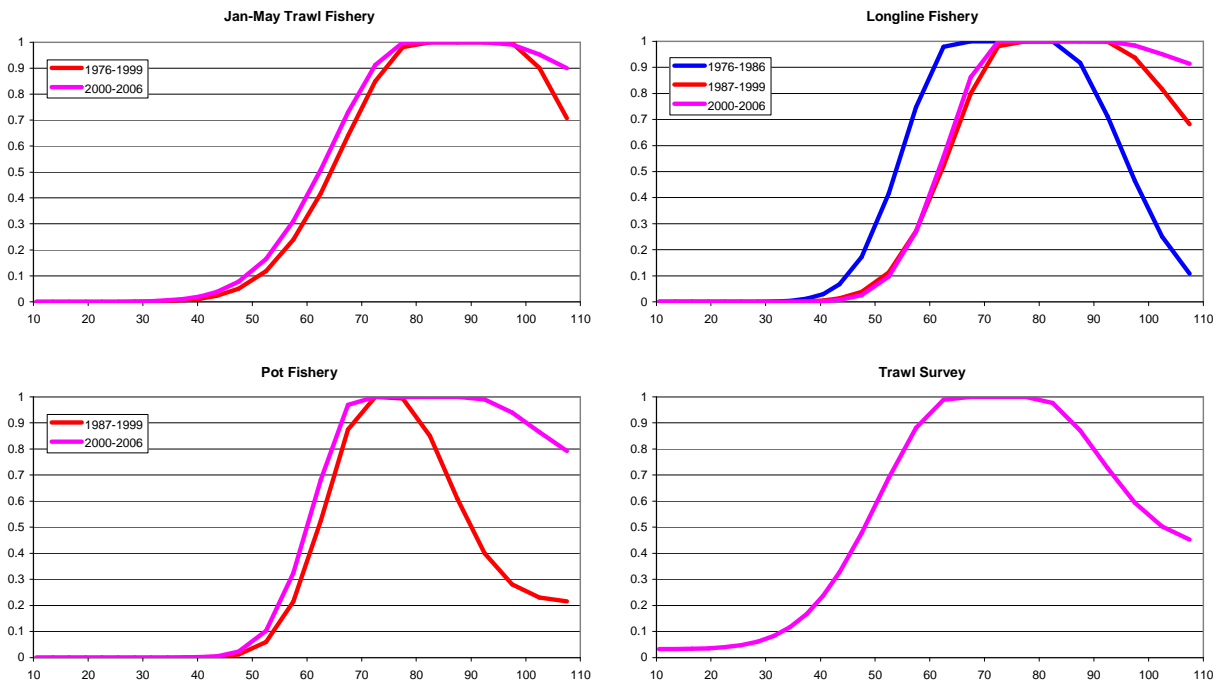


Figure 9b. Fishery and survey selectivity curves estimated by the GOA base model.

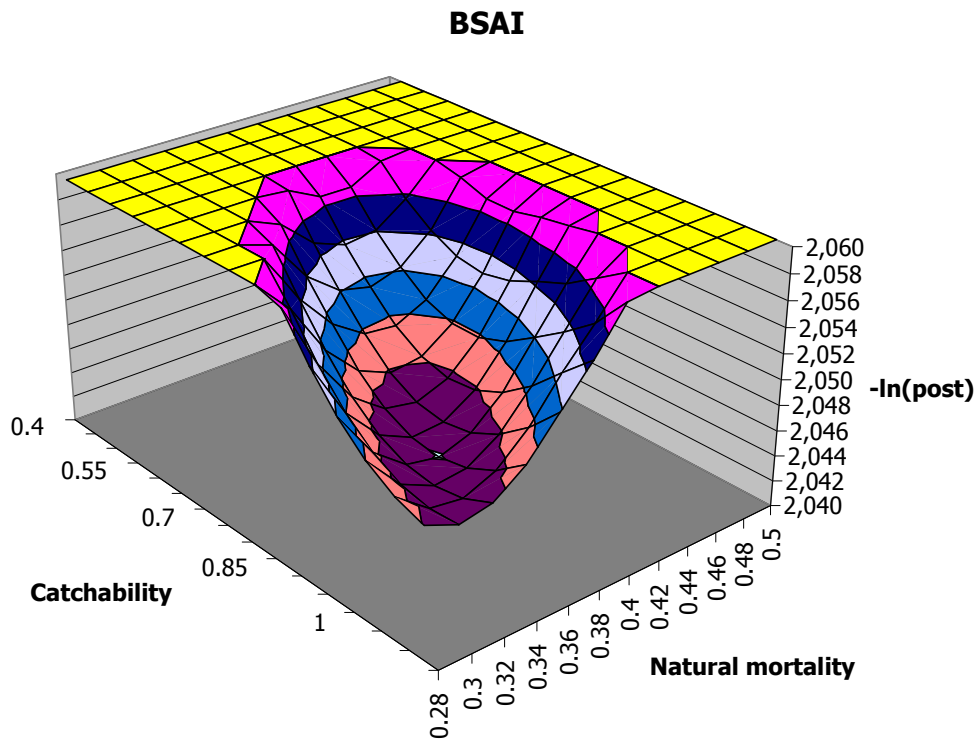


Figure 10a. Profile of objective function values across a factorial grid of  $M$  and  $Q$  values for the BS model.

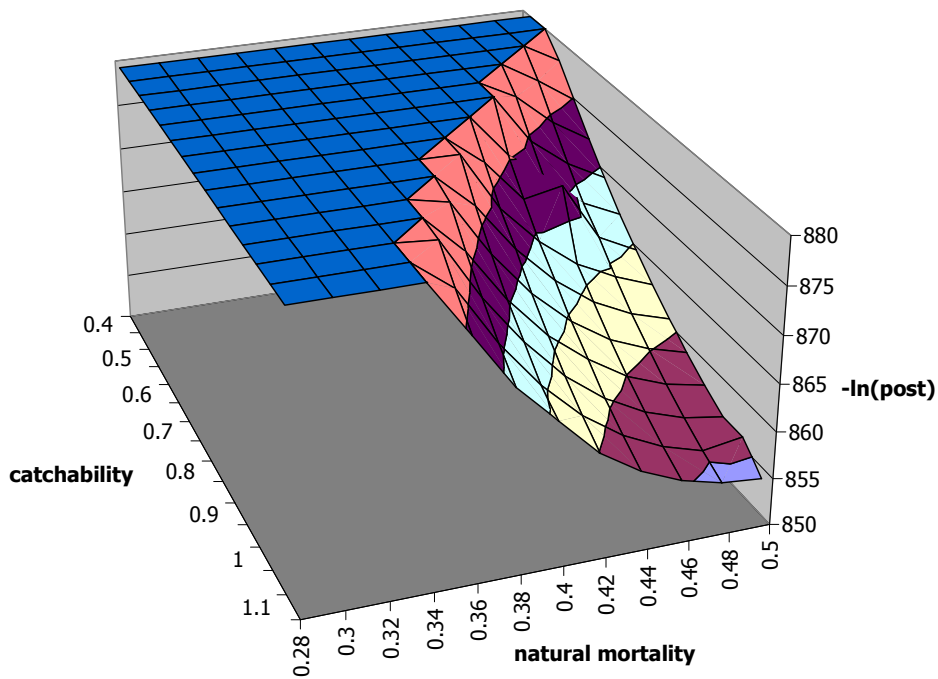


Figure 10b. Profile of objective function values across a factorial grid of  $M$  and  $Q$  values for the GOA model.



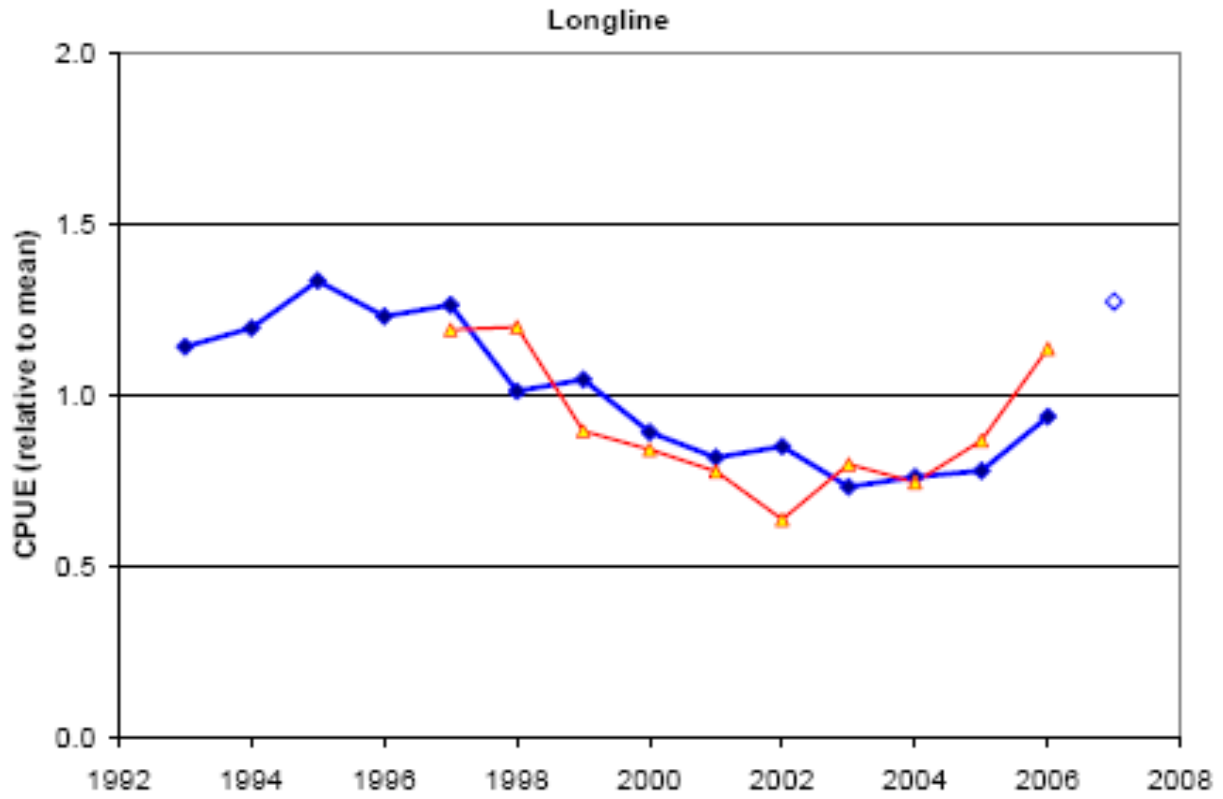


Figure 11. Comparison of Pacific cod CPUE in the IPHC survey and the longline fishery (BS).

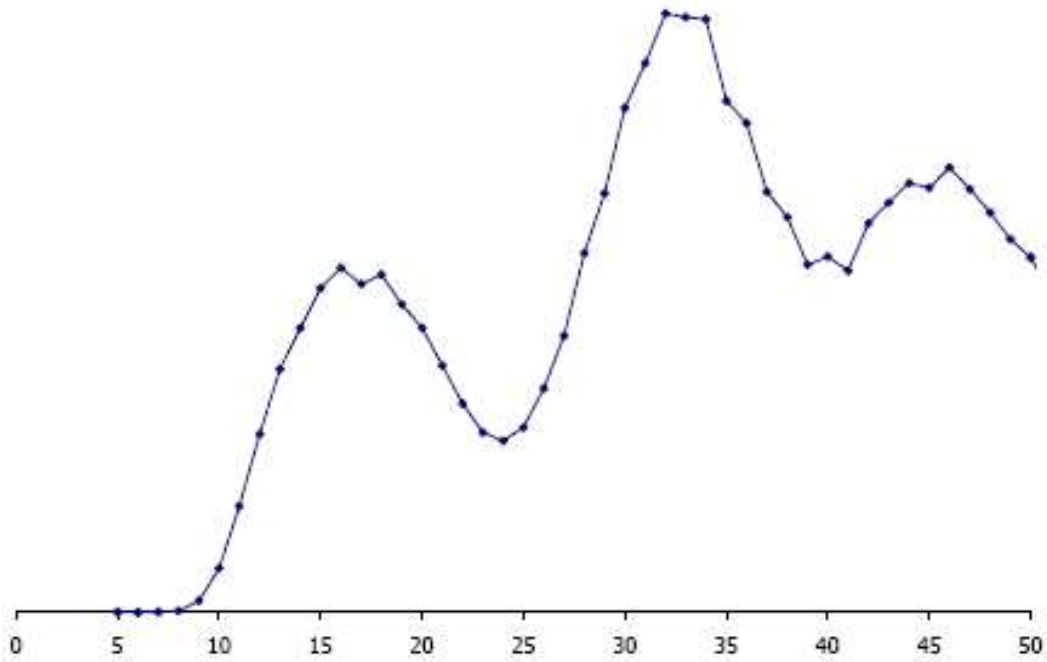


Figure 12. BS shelf trawl survey length compositions (up to 50 cm) aggregated over time.

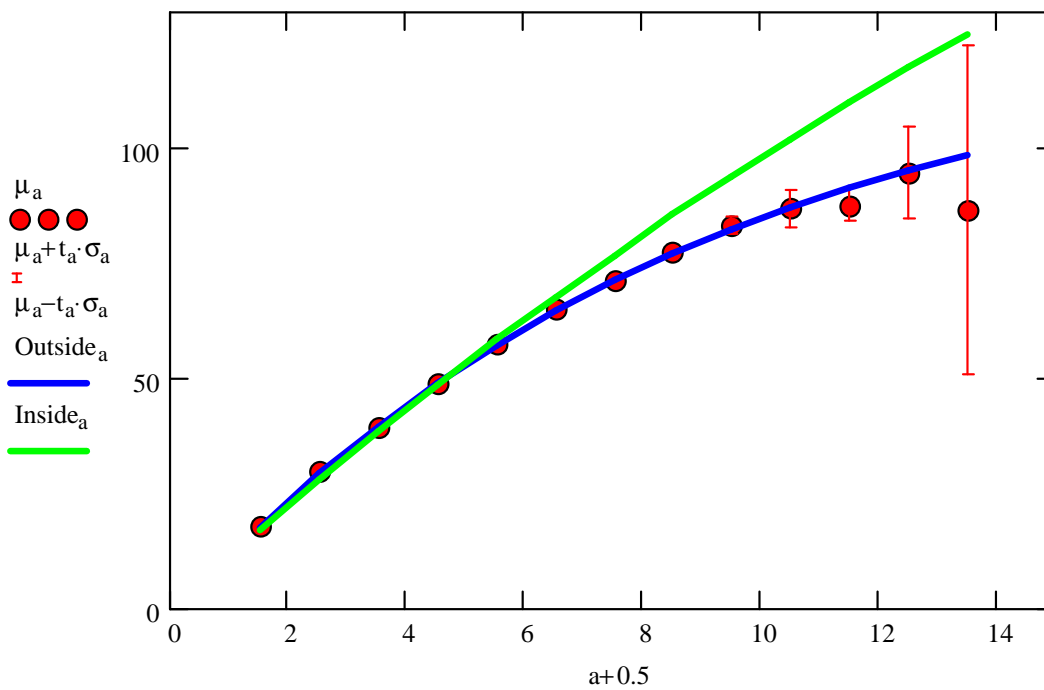


Figure 13. Fitting growth curves to BS trawl survey data without accounting for effects of selectivity. Red dots = mean lengths at age from data (with 95% confidence intervals), blue = growth curve estimated outside the model, green = growth curve estimated inside the model.

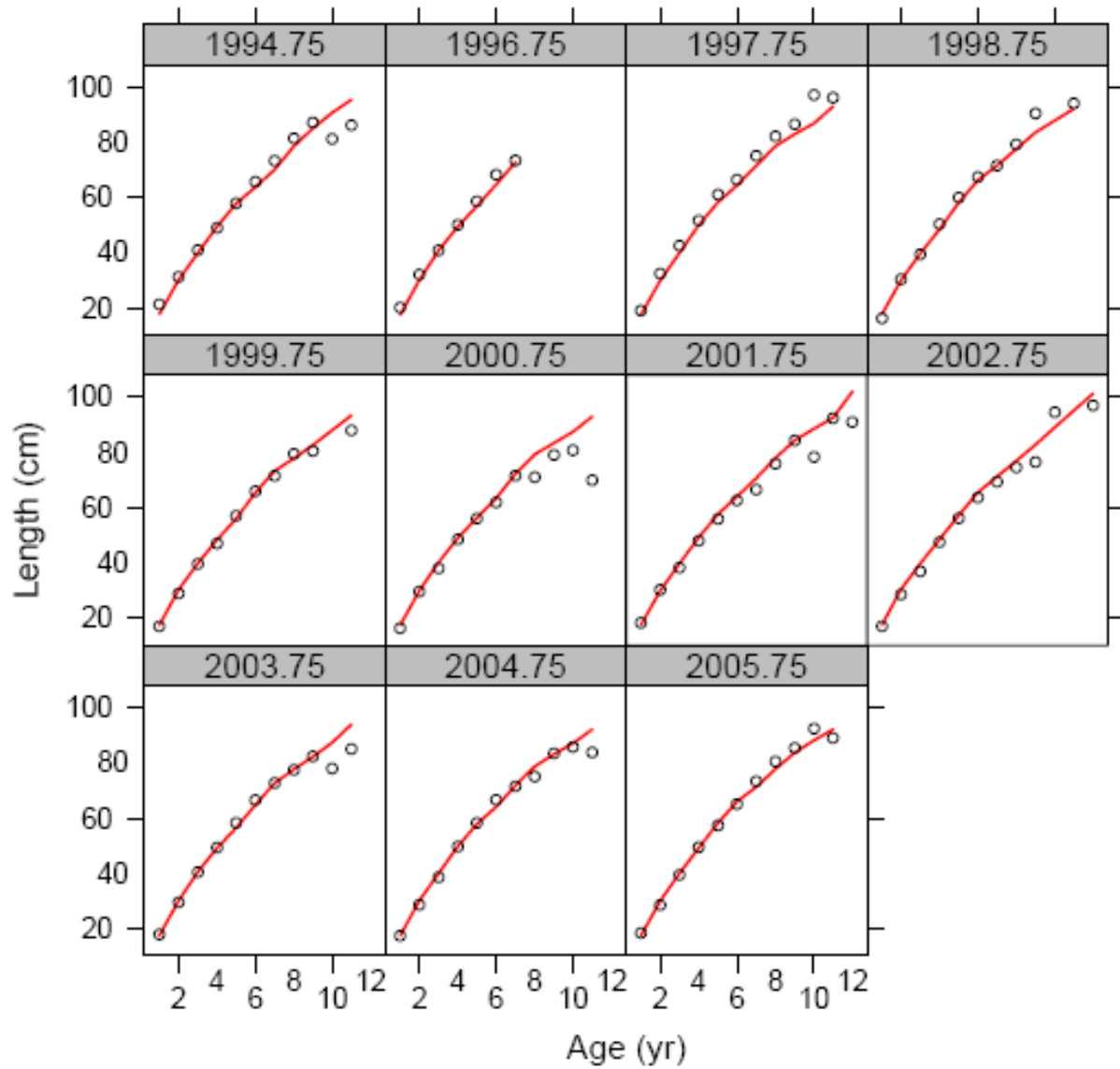


Figure 14. Fitting growth curves to BS trawl survey data with effects of selectivity taken into account.

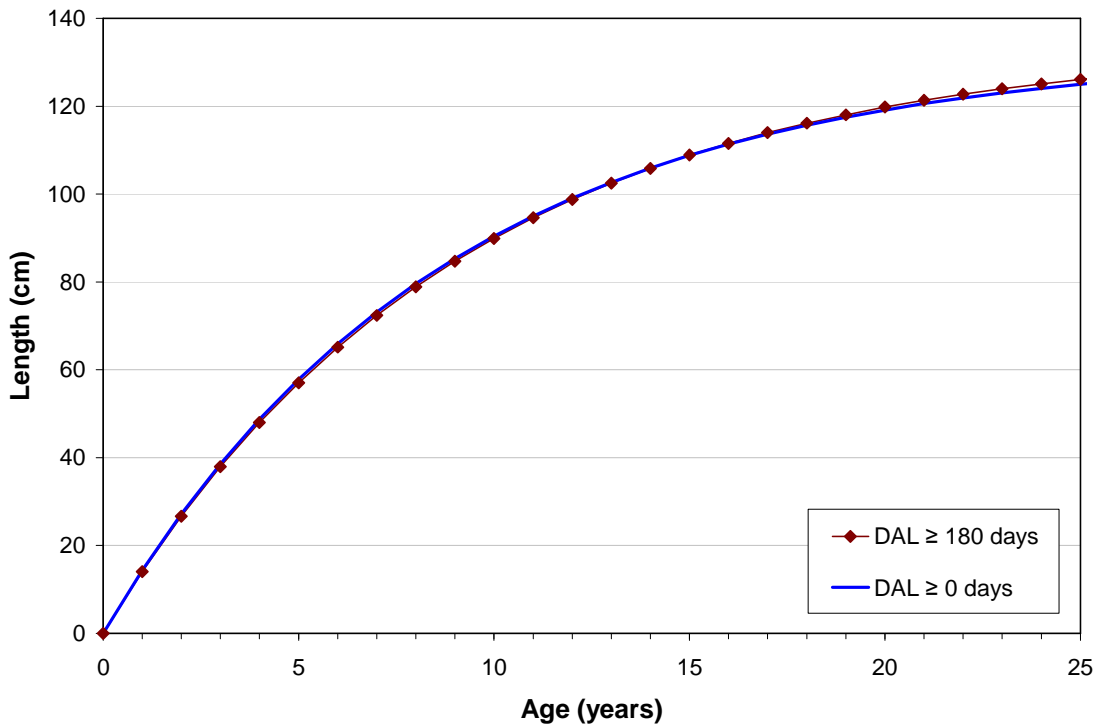


Figure 15. Length at age as estimated outside the model from tagging data (BS). Two curves were fit based on days at liberty (DAL).

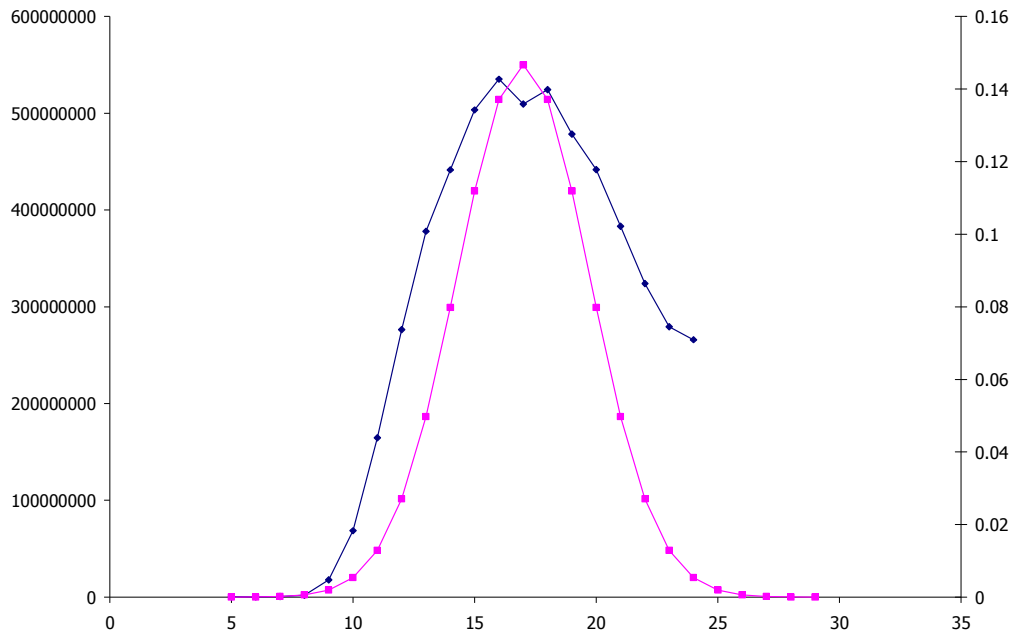


Figure 16. Comparing aggregate survey numbers at length to a normal distribution with mean = 17 cm and CV = 16% (BS).

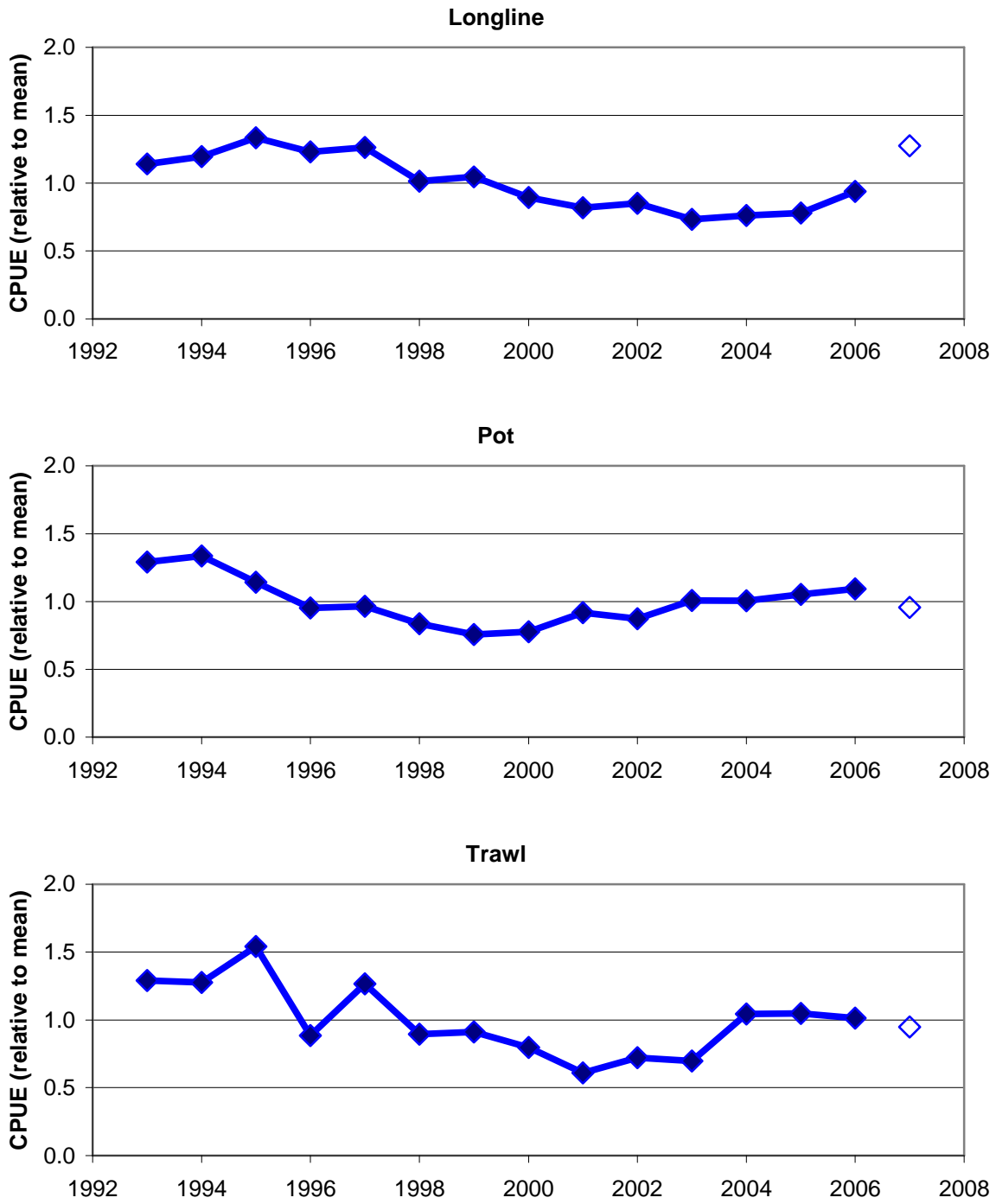


Figure 17. Comparison of commercial fishery CPUE time series by gear type (BS).

## **Appendix A: Workshop Announcement**

### **Announcement**

- What:** Workshop on technical issues involved in the assessments of the Pacific cod stocks in the Bering Sea, Aleutian Islands, and Gulf of Alaska
- Why:** To review recent progress in these assessments and discuss possible improvements
- When:** 9:00 a.m. – 5:00 p.m., April 24-25, 2007
- Where:** Alaska Fisheries Science Center, 7600 Sand Point Way NE., Seattle, WA (Bldg. 4)
- Who:** Authors of the Pacific cod assessments, other scientists involved in Pacific cod research, and anyone interested in the technical issues associated with these assessments.

### **Background**

For many years, the assessments of the Pacific cod stocks in the Bering Sea (BS) and Gulf of Alaska (GOA) have been based on length-structured or age-and-length-structured models (the assessment of the Aleutian Islands (AI) stock has been based on a simple extrapolation of the Bering Sea assessment, derived from the ratio of survey biomasses between the BS and AI). The models attempt to fit a mathematical description of the respective stock's dynamics to data obtained from the AFSC bottom trawl surveys and the commercial fisheries. The stocks in both the BS and GOA are currently estimated to be above the respective biomass levels associated with maximum sustainable yield. However, the estimated strengths of the last several year classes in both areas have been below average, meaning that the stocks in both areas are projected to decline. Furthermore, there is a significant amount of uncertainty surrounding the model estimates of biomass, in part because the values of the trawl survey catchability coefficients in the two areas have been difficult to estimate.

Although all BSAI and GOA groundfish stock assessments are reviewed annually by the AFSC, the Plan Teams, and the Scientific and Statistical Committee, the circumstances surrounding the Pacific cod assessments have led the AFSC to seek additional review this year by offering a workshop on some of the technical issues associated with these assessments. The workshop will involve presentations by the authors of the Pacific cod assessments and other AFSC scientists. Presentations may include, but will not necessarily be limited to, implications of alternative model configurations and different data sets from fisheries, surveys, and tagging studies. The structure of the workshop will be informal, and time will be provided for discussion by all participants. However, it should be understood that the workshop is intended to be technical rather than educational in nature. The objective of the workshop is to ensure that the assessments developed in 2007 provide the best possible inputs for the 2008 harvest specifications, so emphasis will be placed on analyses that can be conducted during this year's assessment cycle. Suggestions for improving the Pacific cod stock assessments are welcome.

For further information, contact: Grant Thompson (541-737-9318, [grant.thompson@noaa.gov](mailto:grant.thompson@noaa.gov))

## Appendix B: Workshop Agenda

**Pacific Cod Technical Workshop**  
Alaska Fisheries Science Center, April 24-25, 2007

### Agenda

#### Tuesday, April 24

- 9:00-9:15 a.m. Pat Livingston: Welcome, introductions, workshop format  
9:15-9:40 a.m. Dave Somerton and Dan Nichol: Survey catchability/availability  
9:40-10:05 a.m. Bing Shi: Estimation of movement and survival rates from tagging data  
10:05-10:30 a.m. Kerim Aydin: Can ecosystem models provide a prior distribution for  $M$ ?
- 10:30-10:45 a.m. *Break*
- 10:45-11:10 a.m. Olav Ormseth: Reproductive potential and egg quality: area and maternal effects  
11:10-11:35 a.m. Doug Kinzey: Multispecies Aleutian Islands assessment model  
11:35-12:00 noon Delsa Anderl: Ageing issues and progress
- 12:00-1:00 p.m. *Lunch*
- 1:00-1:30 p.m. Jim Ianelli: Discussion of fishery and catch sampling issues
- 1:30-3:15 p.m. Grant Thompson: Modeling issues and progress  
This will include an exploration of the following SSC suggestions:
- Estimation of growth inside the model versus outside
  - Model sensitivity to weights assigned to the priors and data components
  - Models that: 1) fix  $Q$  and estimate  $M$ , and 2) fix  $M$  and estimate  $Q$
  - Exploration of model fits across a matrix of  $M$  and  $Q$  values
  - Use of a logistic functional form for survey selectivity and estimability of the descending portions of the survey and fishery selectivity schedules
- 3:15-3:30 p.m. *Break*
- 3:30-5:00 p.m. General discussion and suggestions for evening model runs

#### Wednesday, April 25

- 09:00-9:30 a.m. Discussion on feasibility of a dedicated Pcod longline survey  
9:30-10:30 a.m. Grant Thompson: Results from Tuesday night's model runs
- 10:30-10:45 a.m. *Break*
- 10:45-12:30 a.m. General discussion and suggestions for this year's assessments
- 12:30-1:30 p.m. *Lunch*
- 1:30-5:00 p.m. Continue as necessary

## Appendix C: Workshop Participants

<b>Name</b>	<b>Affiliation</b>
Anderl, Delsa	Alaska Fisheries Science Center
Aydin, Kerim	Alaska Fisheries Science Center
Barbeaux, Steve	Alaska Fisheries Science Center
Bruce, John	Jubilee Fisheries
Butzner, Lisa	North Pacific Longline Association
Casey, Tom	
Clark, Bill	International Pacific Halibut Commission
Connors, Liz	Alaska Fisheries Science Center
DeMaster, Doug	Alaska Fisheries Science Center
Dorn, Martin	Alaska Fisheries Science Center
Down, Kenny	Alaska Frontier Co.
Ferrero, Rich	Alaska Fisheries Science Center
Fraser, Dave	Adak Fisheries
Fraser, Ian	Marine Resources Consultants
Hare, Steven	International Pacific Halibut Commission
Hollowed, Anne	Alaska Fisheries Science Center
Ianelli, Jim	Alaska Fisheries Science Center
Iverson, Don	Jubilee Fisheries
Johnston, Chris	Alaska Fisheries Science Center
Kimura, Dan	Alaska Fisheries Science Center
Kinzey, Doug	University of Washington
Leaman, Bruce	International Pacific Halibut Commission
Livingston, Pat	Alaska Fisheries Science Center
Maunder, Mark	Quantitative Resource Assessment
Neidetcher, Sandi	Alaska Fisheries Science Center
Nelson, Russ	Alaska Fisheries Science Center
Nichol, Dan	Alaska Fisheries Science Center
Norris, James	Marine Resources Consultants
Ormseth, Olav	Alaska Fisheries Science Center
Perry, Mike	BlueNorth Fisheries
Petersen, Mike	NPF
Quinn, Terry	University of Alaska Fairbanks
Reed, Glenn	Pacific Seafood Processors Association
Shi, YunBing	University of Washington
Sleipness, Russ	Jubilee Fisheries
Smith, Thorn	North Pacific Longline Association
Somerton, Dave	Alaska Fisheries Science Center
Stram, Diana	North Pacific Fishery Management Council
Tagart, Jack	Tagart Consulting (for Freezer Longline Coalition)
Thompson, Grant	Alaska Fisheries Science Center
Tsou, Teresa	Washington Dept. of Fish and Wildlife
Tweit, Bill	Washington Dept. of Fish and Wildlife
Vining, Ivan	Alaska Department of Fish and Game
Wells, Doug	Kanaga Island Fish