# Cara Rodgveller

## Skipped Spawning (Sablefish focus) and influence on management

Skipped spawning generally appears to be a plastic trait in many marine teleost fish, and is more common than we think. Variation in skipped spawning is likely a result of environmental conditions and has been attributed to poor feeding conditions, given that the probability of spawning is a trade-off between mortality, energetic costs associated with reproduction and migration, and maintenance.

With respect to Alaska sablefish, skipped spawning rates varied drastically (from about 21% to 6% in 2011 and 2015, respectively; Rodgveller *et al.*, 2016; Rodgveller, 2018a, 2018b), suggesting the plasticity of skipped spawning. In these papers, this was attributed to a potential shift from a cool PDO phase to a warmer PDO phase, which has been speculated to be beneficial for sablefish (i.e., when we have seen large recruitment events). Sablefish studied in the west coast are believed to be a separate population from Alaska sablefish; therein they found no evidence of skipped spawning, which might be attributed to genetics or latitudinal variation, but could also be due to the limited geographic scope of the study (Guzmán *et al.*, 2017). Given recent high recruitment events, it might be more likely that the younger large cohorts might be more susceptible to skipped spawning, considering that large recruitment events can lead to density-dependent effects, to which can result in reduced growth and the need to partition more energy towards somatic growth instead of reproduction. Further, considering the life-history of Alaska sablefish (long-lived, low natural mortality), it may be more beneficial to skip-spawn as there may be a higher probability of increasing your *lifetime* reproductive potential, if you decide to forego spawning in one year. This is somewhat evidenced by Rodgveller et al. (2018), where they found skipped-spawning decreases with age.

Unlike fish that undergo mass atresia (rapid reabsorption of vitellogenic oocytes; abortive maturation), sablefish display a “resting” type of skipped spawning. For Alaska sablefish, skipped spawning has primarily been identified using histological methods, where it is generally indicated by a thick ovarian wall, blood vessels in lamellae, and thick tunica walls. However, for some other species, skipped spawning can be identified using electronic tags (e.g., Pacific Halibut display spawning vertical migrations and distinct patterns), physiological measures (-estradiol, levels of water-soluble proteins, absence of spawning migrations at a given size, growth annuli, and isotopic signatures).

In terms of the significance to fisheries management and Alaska sablefish in general, the incorporation of skipped-spawning into maturity curves used for management has demonstrated decreases in spawning stock biomass (SSB) and less optimistic stock status. This is not surprising given that maturity is directly used to calculate reproductive potential. In Rodgveller et al. (2016), they classified skipped-spawning fish as immature, resulting in a shift in the age-at-50% maturity to about 9-years. However, I do not think this is an adequate approach to incorporate skipped-spawning into the calculations of reproductive potential, because we are reclassifying the maturity curve as functional maturity. Instead, I believe a potentially fruitful approach would be as follows:

where *SSB* is the spawning stock biomass, *PSS* is the proportion of skipped spawners, which is modelled as a function of age and potentially other covariates. The rest of the equation represents our standard calculations for *SSB*. I believe this approach might be better, because we partition out the females into two groups: 1) skipped spawners, and 2) spawners. Of the individuals that do not skip-spawning, they are either mature or immature, which then forms the rest of our *SSB* calculations. Additionally, we seldom have a large amount of skipped-spawning data and using this approach allows us to define an average skipped-spawning curve, which may be more representative of the population dynamics, rather than annually adjusting the *functional* maturity curve. Nonetheless, failing to incorporate skipped-spawning will result in more optimistic perceptions of stock status.

## Sablefish Reproductive Biology

Big Picture Questions

* What have we learned about skipped spawning in fishes and its influence on management?
* Why does maturity and fecundity vary over time?
* Why are reproductive dynamics important to understand and incorporate in the management process?
* What are some methods we can use to better predict skipped spawning and the probability of being mature? What sorts of data are needed in this context?
* Synthesize the current state of knowledge of reproduction for Alaska sablefish and potential developments for this species.
* How can reference points better consider the reproductive biology of a species?
* What are some ways of accounting for skipped spawning in an assessment context?
* What are some alternative metrics we can use in our assessments?
* Why is it important to account for age-diversity in the SSB for our metrics in stock assessments?
* Is SSB a good measure of egg production?
* What are some core assumptions of SSB? Consequences if SSB is not proportional to egg production?

# Pete Hulson

## Magnusson Stevens Act and Management Objectives

The MSA is the primary legislature governing fisheries and uses the precautionary approach where the Council incorporates forward looking conservation measures that address differing levels of uncertainty. Further, the Council seeks to make decisions based on sound scientific decision and provide management proactively rather than reactively. FMP plans have to conform to the 10 National Standards set forth by the MSA. These are:

1. Prevent overfishing and achieve OY on a continuing basis,
2. Conservation and management based on the best available science,
3. Manage individual stocks as a single unit and coordinate with neighboring stocks if necessary,
4. Conservation measures should not be discriminatory or benefit others inequitably,
5. Conservation and management measures should account for variability in catch and the resource,
6. Conservation and management measures should be as efficient as possible,
7. Conservation and management measures should minimize costs,
8. Conservation and management measures should avoid harm and hardship to communities (economic) and provide opportunities for participation in the fishery,
9. Bycatch should be minimized,
10. Safety of human life should be prioritized.

In terms of management objectives for the council, they are broadly grouped into the following categories:

1. To prevent overfishing (conservative measures of harvest, evaluation of F40 rule, 2 million mt OY cap, adaptive management for dynamic range of OY),
2. Promote sustainable fisheries and communities (conservation measures balance both harvest of socio-economic considerations, equitable allocation of resources, and safety at sea),
3. Preserve food web (development of ecosystem indices, adjust ABC based on ecosystem factors, limit forage fish harvest),
4. Reduce bycatch (formation of bycatch incentive programs, bycatch limits and research on population status of non-targeted species, reduce economic-related discards, seasonal allocations and gear restrictions, account for bycatch mortality in TAC, reduce waste and maximize retention and utilization),
5. Avoid impacts to sea birds and sea lions,
6. Reduce impacts to habitats (area closures, HAPC, EFH designation and mapping),
7. Promote equitable and efficient fishery resource use,
8. Increase Native Consultation,
9. Improve data quality, monitoring, and enforcement.

## Tier System for Stock Assessments

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Tiers | OFL | ABC | a | b | c | HCR (Threshold) | Stock Recruit |
| 1 | FOFL = arithmetic mean of Fmsy | FABC = harmonic mean of Fmsy | Threshold control with = 0.05 using Bmsy | Threshold control with = 0.05 using Bmsy | Threshold control with = 0.05 using Bmsy | Only uses Bmsy reference points | Yes (Age-structured) |
| 2 | FOFL = Fmsy | FABC = Fmsy \* (F40 / F35) | Threshold control with = 0.05 using Bmsy and Fx% | Threshold control with = 0.05 using Bmsy and Fx% | Threshold control with = 0.05 using Bmsy and Fx% | For ABC setting, uses Bmsy and Fx% | Yes (Age-structured) |
| 3 | FOFL = F35 | FABC = F40 | Threshold control with = 0.05 using Bx% | Threshold control with = 0.05 using Bx% | Threshold control with = 0.05 using Bx% | Uses both Bx% and Fx% | No (Age-structured) |
| 4 | FOFL = F35 | FABC = F40 | NA | NA | NA | NA | No (Generally Age-structured) |
| 5 | FOFL = M | FABC = 0.75 \* M | NA | NA | NA | NA | No (Generally index method) |
| 6 | FOFL = Avg Catch (1979 – 1995) | FABC = 0.75 \* Avg Catch (1979 – 1995) | NA | NA | NA | NA | No (Catch only methods) |

## Status Determination

**Overfished Status:** Occurs when stock falls below the minimum stock-size threshold, which is defined as ½ of Bmsy or B40% depending on the tier of the stock. For tiers 4 – 6, since there is not estimate of Bmsy, overfished status is undefined. Thus, to declare overfished status, if the current year SSB is less than ½ of Bmsy, then the stock is overfished. If it is above, it is not overfished. If it is in between ½ of Bmsy and Bmsy, then we need to do stochastic simulations for 10 years, while fishing at the OFL and look at the mean SSB over that 10 year span – if it is below ½ of Bmsy, then the stock is overfished.

Once declared overfished, a rebuilding plan must be put in place with levels of FOFL and Fmsy that will rebuild the stock in a reasonable time frame.

**Approaching Overfished Status**: MSA requires us to determine whether a stock is approaching overfishing. This is done by projecting the current year SSB forward by two years and fishing at maxFABC so see if we fall below ½ of Bmsy. If we do, we are approaching an overfished status, vice versa. If we are in between ½ of Bmsy and Bmsy, we need to do stochastic simulations where the first two years are fished at maxFABC and the last 10 are fished at FOFL. If we fall below ½ of Bmsy in year 12, then we are approaching an overfished condition, and amendments need to be made.

## Harvest Specifications

Definitions:

1. Maximum Sustainable Yield – the largest long term catch that can be taken from a stock or complex under the current prevailing environmental and fishery characteristics,
2. Optimum Yield – the amount of fish that provides the greatest benefit to the nation, is prescribed according to MSY with adjustments due to uncertainty, and provides a rebuilding plan to which allows us to reattain MSY if the stock is overfished. For the BSAI, the system wide OY is equal to 1.4 million mt – 2 million mt, while in the GOA, the OY is 116,000 mt – 800,000 mt.

Generally, harvest specifications follow a hierarchy. This hierarchy is as follows: 1) OFL = Maximum Fishing Mortality Threshold, 2) ABC, 3) ACL, which is generally equal to ABC, 4) TAC, which can be adjusted down from the ABC due to uncertainty, and 5) MSST (minimum stock size threshold), below which we are not allowed to fish (i.e., below ½ of B35% for Tier 3 stocks).

With respect to setting TACs, the general process is usually as follows: 1) determine maximum permissible ABC from Plan Team and SSC, 2) determinate an acceptable level of TAC based on current scientific information and socio-ecological considerations, and 3) make sure the sum of TACs fall within the BSAI OY range.

## NPFMC Management Measures

1. OY set at 1.4 million mt to 2 million mt, which may not be exceeded,
2. Area closures to reduce bycatch of salmon, crab, herring, crab, etc,
3. Area closures and transit closures to protect stellar sea lion foraging areas and walrus transit areas,
4. Area closures to protect unique habitats (Bowers Ridge, Alaska Seamounts),
5. Prohibited Species Catch limits and caps, wherein exceeding these limits can lead to area and fishery closures (Chinook, Herring, Crab),
6. EFH designations to understand the life-stages at which certain species are most vulnerable (although not really extensively used in management),
7. Use of prevailing ecosystem information and uncertainty in the management process to reduce ABC to set TACs,
8. Input controls to limit vessel tonnage, horsepower, and size,
9. No directed commercial fishery allowed on forage species

## AI Pacific Cod

### Biology and Life-History

Pacific cod generally occur at depths from the shoreline to about 500m. Eggs are demersal, and the larval duration is about 90 days. The survival of eggs and hatching success have been found to be dependent on temperature – recruitment is also highly influenced by temperature. Eggs move quickly to the surface upon hatching and larval stages have fairly good swimming abilities. Larval drift can be great, where larval stages have been found to be transported by currents from the Kenai and Kodiak to Unimak. Larvae tend to exhibit shoreward movement (i.e., inshore) but this relationship can vary.

Juvenile Pacific cod tend to settle near the seafloor and can also be dependent on nursery habitats (as inferred from Atlantic cod). Habitat use of juveniles are generally in shallower waters from coastal-demersal to shelf-pelagic (0 – 80m). Habitat distribution of juveniles is hypothesized to be as a result of density-dependence, temperatures, and prevalence of demersal predators.

Although juveniles have some flexibility in being somewhat pelagic to demersal, adults are strongly associated with the seafloor and diel vertical migration has been observed. Adults tend to form large spawning aggregations and are annual spawners. Furthermore, they undertake spawning migrations as well as feeding migrations (has been observed to travel about 100nmi to 500nmi).

### Stock Structure

Pacific cod are wide ranging and are found from California to Norton Sound, as well as from the Gulf of Anadyr to the Yellow Sea. Their distribution is generally limited from 34N to 65N. In the BSAI region, they are widely distributed across the EBS, although in recent years, there has been evidence of a northward movement into the NBS. Tagging studies have found that they migrate both within and between the EBS, AI, and GOA, suggesting a lot of potential for stock mixing. In general, Pacific cod are likely to perform natal homing during the spawning months (Jan – Apr) but migrate around to feed outside of that duration.

Genetics also indicate that the EBS and AI are discrete spawning stocks. Using SNPs, a high assignment success was found in assigning the origin of spawning populations (Gulf of Alaska, Hecate Strait, Kodiak Island, and Prince William Sound populations). Some studies have also found that the ZP3 locus have distinct sets of haplotypes (spawning populations from Kodiak vs. Prince William Sound). There seems to be some differentiation there between the Bering Sea group and other groups in the Gulf of Alaska, Hecate Strait, and Prince William Sound. There might be some selection processes on these northern (Bering Sea) populations wherein local adaptation is driving differences in haplotype frequencies.

### Fishery Characteristics

The fishery is a multi-gear fishery that is composed predominately of trawl, pot, and hook-and-line gear. The catches among these gears fluctuate quite a bit and the selectivities are likely different, which may suggest the need for time-varying selectivity. Nonetheless, most the catch results from longline gear, followed by trawl gear, and pot gear (pot gear seems to be the least). The fishery during the feeding season tends to be longline gear, while trawl nets are typically used during the spawning season. Given the migratory patterns there and the different gears used, some thought needs to put into how selectivity should be structured in this respect.

### 2020 AI Pacific Cod

#### SSC and Plan Team Comments

1. SSC suggests exploring averaging multiple surveys (not sure if there is data for that) as well as using a VAST model for the purpose of apportionment, but not updates were made and no VAST models were explored due to a lack of a survey,
2. The SSC appreciates the efforts in the exploration of age-structured methods and recommends further explorations. They also recommend fitting the maturity curve inside the assessment as well as using *M­*-prior methods from Jason Cope to explore the estimate of natural mortality used in the assessment. Neither of these were done in this current assessment cycle. The age-structured model was not updated due to a lack of survey data, although I believe an effort should have been made to look at an alternative estimator for *M*.

#### Assessment Structure

The 2020 AI Pacific Cod stock assessment is defined as a Tier 5 stock. As such, the FOFL is defined as *M* (0.34) while the FABC is defined as 0.75*M* (0.255), and the resulting catch advice would be the biomass estimated, multiplied by these quantities. Thus, the 2019 AI Pacific Cod assessment uses a simple random effects model, wherein the index of the NMFS Bottom Trawl Survey in the AI region is used (triennial early on and biennial in recent periods):

where is the observed index of abundance (trawl survey biomass), are lognormally distributed deviates constrained by the variance observed from the trawl survey, and are treated as random effects and represent the true unobserved trawl survey biomass, which follows a random walk process:

where are deviations from a random walk, which are constrained by a process error variance term (. In the assessment, only one process error variance term is estimated as a fixed-effect, and are estimated as latent unobserved random effects. Essentially, this model smooths over the observed survey biomass using a state-space random walk model.

Considering that this is a tier 5 stock, an estimate of *M* is needed to provide management advice, which is multiplied with to provide an estimate of catch advice (either *M* or 0.75*M*). This value was updated several times in accordance with natural mortality assessments from the EBS Pacific cod assessment, but this practice is no longer done given concerns with the EBS *M* estimate not necessarily being equal to that of the AI. Thus, I believe the authors here have continued their use of Jensen’s age-at-maturity estimator for *M*, which is currently specified at 0.34.

The assessment estimates fairly wide confidence intervals for 2020, which they attributed to a lack of survey data since 2018 (i.e., no survey data in 2019 and 2020 because of COVID).

#### Harvest Apportionment

For AI Pacific Cod, there are several issues that need to be addressed with respect to apportionment of harvest. These include: 1) apportionment of harvest from the state, and 2) apportionment of harvest given Stellar Sea Lion protection measures.

Prior to 2014, apportionment of BSAI Pacific Cod for the state was done by multiplying 3% of the TAC from the assessment. Following 2014, when the AI Pacific Cod stock was managed separately from EBS, apportionment to the state was done by multiplying about 27% - 39% of the AI Pacific Cod to the state. The percentage increases by 4% if the catch reaches 90% of the guideline harvest level from the state in the previous year, but may not exceed 39% (6804 t).

Prior to 2014, there was a regulation that prevented the harvest of Pacific Cod in Area 543 (in the AI region). However, there was an amendment in 2015, that now puts a harvest limit in Area 543, instead of fully restricting fishing. There, an apportionment of the TAC is made by:

where is the harvest limit in area 543 and is calculated by subtracting the TAC by the guideline harvest level from the state, and then multiplying the proportion of biomass in area 543 relative to the total biomass of the assessed stock (). This can be calculated several ways including: 1) using the average survey raw proportions, 2) the most recent survey raw proportions, 3) using the average survey estimate from Area 543 and dividing that by the average survey estimate from the entire area, and 4) using the most recent survey estimate from 543 and dividing that by the survey estimate in the most recent year. The last approach is what was used in this assessment.

### 2021 AI Pacific Cod

#### SSC and Plan Team Comments

1. SSC suggests exploring averaging multiple surveys as well as using a VAST model for the purpose of apportionment, but not updates were made and no VAST models again this year,
2. The SSC appreciates the efforts in the exploration of age-structured methods and recommends further explorations. They also recommend fitting the maturity curve inside the assessment but this was not done due to potential confounding with ageing error – which I do not think is a great excuse – fitting the maturity curve in the assessment would allow for the propagation of ageing error in the maturity curve,
3. Several growth models were investigated and it was eventually decided based on AIC and parsimony that the von Bertalanffy growth model would fit the best,
4. The SSC requested the author to look into the use of Jason Cope’s method for determining *M*. This was done in this assessment cycle and the estimate came out to 0.36, although a point estimate of 0.4 was used in the assessment model this cycle,
5. The Plan Team wanted the author to bring forward both model runs of maturity (observer and Stark 2007). The teams recommended the observer data because it has more samples and is more representative than the Stark (2007) estimates, but wanted histology verification,
6. The authors requested guidance on data-weighting from the SSC, but no data-weighting exercises were really attempted this assessment cycle (survey ages weighted by hauls, and fishery was set to standardize at a mean of 20 for ISS),
7. Results from 3 age-structured assessments were brought forward this cycle, and the SSC recommended not bringing forward one of the models that dropped fishery length data. These assessments differed in 1) the estimate of M (0.34 vs. 0.4) and 2) the maturity curves used.
8. Despite the *M­-*prior methods suggesting a point estimate of 0.36, the SSC and authors recommended a value of 0.4, to balance the tradeoff in the likelihood profile indicated by the fishery and survey (0.3 vs. 0.8). The estimate of 0.4 follows the general mode of *M* used in this assessment in previous years. However, there is no firm justification as to why the value of 0.4 was really chosen.

#### Assessment Structure

##### Data

The 2021 assessment brings forward 3 age-structured assessment models and 1 tier 5 assessment model (rolled over from 2020). For the tier 5 model, it uses what was described in the 2020 AI Pacific Cod assessment model – BTS biomass estimates using a random-walk smoother.

The age-structured assessment model uses the following datasets:

1. Fishery catch (1991 – 2021; more during spawning season (winter), larger fish)
2. Fishery size compositions (1991 – 2021)
3. Biomass index from BTS survey (biennial and triennial, most recent = 2018; more during summer months, smaller fish),
4. Age composition from BTS survey (biennial and triennial, most recent = 2018)

In the age-structured assessment model, there are a decent number of age-composition samples available for use in modelling (500 – 1000 samples per survey year). Length-composition data are not used for the survey because age-data are available. The survey biomass index is a design-based index that is expanded to the strata and summed. The NMFS LL survey is also conducted in this same region, which I believe to be biennial. I believe that the author should make efforts to incorporate these data into the age-structured model and investigate the quality and quantity of length and age-composition data from the LL survey.

For fishery data, gears and statistical areas from AI are combined and modelled together. Catch data are simply summed. For length composition data, most of these data come from longline and trawl fisheries. The assessment document indicates that length compositions are combined by weighting by the relative catch in each statistical area. Depending on how well each gear, season, and area overlap, this might not be an appropriate approach, and the length frequency data should instead be weighted by relative catch across seasons, gears, and areas given that there appears to be differences in the sizes of fish caught depending on these characteristics (larger fish during winter months, which tend to be trawl gears). However, given that most of the fishing takes place in the winter months, season weighting might not be necessary. Nonetheless, I think gear \* area might be an appropriate relative weighting scheme for these data.

##### Model Structure

The model used is an age-structured model with a single-sex and a 1:1 sex-ratio (10 ages, 10+ is the plus group). The survey and fishery both assume logistic age-based selectivity. A growth function following von Bertalanffy dynamics is estimated outside the assessment, which is used to construct an age-length matrix as well as compute weight-at-age. An ageing error matrix is used in the assessment as well. Recruitment and fishing mortality parameters are time-varying, while all other parameters are constant. Survey catchability and selectivity are estimated within the assessment, while maturity is estimated outside of the assessment. Natural mortality is fixed inside the assessment (either as 0.34 or 0.4) and fishery length frequencies are weighted by the relative catch in each statistical area.

Data-weighting methods were attempted to weight survey age-composition and length frequencies but led to unreasonably high likelihood weights – this resulted in decreased survey catchability and biomass estimates, which do not seem to make a whole lot of sense. You would expect decreased survey catchability to increase biomass estimates. Nonetheless, they ended up weighting the samples using the number of hauls in each year for survey age compositions. Different weighting values resulted in expected changes in fits to data sources. Increasing weights to length-frequencies led to better fits to these data, but poorer fits to survey indices. However, this tended to result in poor convergence criteria. Thus, they ended up weighting the length frequency data as the number of lengths sampled to retain annual sampling variability, but weighted so that the mean of the weights were 20, so as not to overwhelm the model by forcing fits to length data.

A new maturity curve was also implemented in this model, because the old maturity curves was based off the EBS and had limited samples. The new maturity curve was similar but had a slightly lower age-at-50% maturity (4 years old). The maturity curve was estimated outside the assessment using length-based maturity, and was then converted to age-based.

Length-at-age and associated age-length keys were also constructed using a von Bertalanffy growth model, instead of more highly parameterized and flexible models as they all performed similarly. The age-length transition matrix was constructed by simulating values conditioned on the mean length-at-age and its associated CV/variance. Length-at-age was then converted to weight-at-age using an allometric relationship.

With respect to natural mortality, a value of 0.34 was used based on age-based maturity estimators of *M* initially. The estimate of natural mortality differ quite a bit from the GOA and the BSAI stocks (0.47 vs. 0.3ish). Likelihood profiles of *M* showed strong data conflicts – fishery length data indicated a value of 0.3 would be best, while survey ages, biomass, and the recruitment penalty suggested a value of 0.8 which is very unreasonable (but this could also be due to large fish moving out of the surveyed area – i.e., not seeing any large fish there which would result in *M* being estimated fairly high, while the fishery sees large fish, which is why you see that data conflict there; the conflict could also be due to the seasonal and spawning migrations as well as the fishery and survey operating in different times). Following this, a value of *M* = 0.4 was used instead to compromise between these data conflicts, which also matched some of the modes of *M* used in this assessment. 0.4 was considered a good starting point given estimates of 0.47 from GOA and 0.348 from the EBS assessment. The *M*-prior methods from Jason Cope suggested a value of 0.36. Given all of the above, *M* was set at 0.4 in this assessment.

Catchability estimates were estimated inside the model for the survey, but the fishery was set at 1 based on *a priori* knowledge and studies of cod availability to surveys (fairly high). Catchability estimates changed when *M* was fixed at different values (lower catchability for higher *M*), and it might be worthwhile to attempt to estimate this value as opposed to fixing it, given the large difference in catchability when *M* is fixed at a higher value. Selectivity for both the fishery and survey were estimated as logistic age-based. One could make an argument for a more flexible selectivity form for the fishery given the combined fleet structure, although I realize its informed by primarily length-composition data. However, it might be worthwhile to look at length-based selectivity given the reliance on length-data here, although it may not work as expected given that Pacific cod can demonstrate dramatic fluctuations in size-at-age throughout the season and annually. The justification of similar selectivities between the survey and fishery is that the length distributions match up fairly well at those initial ages. Furthermore, looking at the data, dome-shaped selectivity does not appear to be warranted – likely because they do not reside in untrawlable habitats and larger cod do not appear to leave the region entirely.

Regarding the use of diagnostics, they examine goodness of fits statistics and residuals for the biomass index and composition data. They also use likelihood profiles for *M* to examine potential data conflicts and also use retrospective diagnostics. However, given the model instability to data-weighting, I think an additional jitter analysis should be conducted to see how much results change with incremental changes in initial values. Additionally, while a profile of *M* was conducted, I think a profile of *q* for the survey would also be appropriate to understand the values governing this parameter and whether composition data conflict with this estimate. A conflict in *q* could be also be due to mis-specified selectivity (which does not seem to be an issue based on fits). In due to fixing *M* at 0.4, which may lead to some inconsistencies if 0.4 is not reasonable as determined by the model and could general, fits to these individual data sources appeared adequate. However, retrospective analysis indicated that SSB was consistently positive biased (Mohn’s rho = 0.15). They use Hurtado-Ferro’s paper to justify that the retrospective inconsistencies were not significant – constitutes best available science at that time.

To conclude, the authors recommend this stock to use tier 5 designations for harvest specifications, but for the SSC to consider upgrading the assessment to tier 3 designation.

##### Recommendations on Model Structure

Given that the survey and fishery operate at very distinct times, I think the estimate of *M* might be different in terms of the likelihood profiles between these different data sources because the survey isn’t seeing as many old fish, while the fishery explicitly targets old fish. Furthermore, the difference in survey and fishery timing might resulting in some confounding in the estimate of *M* because of the seasonal migrations of feeding and spawning (i.e., large Pacific Cod move out of the area to feed), suggesting the potential need to construct a spatial model to examine potential movement rates, and better reconcile the estimates of *M*. However, looking at the likelihood profiles, it seems like the survey data suggest that the profile for *M* is really flat beyond 0.3, and the likelihoods do seem to dip at 0.3. I think 0.3ish is a good estimate, but definitely would be interesting to look at some of the spatial structuring in this respect to see if the descending limb of the likelihood profiles for these datasets bound back up.

Spatial structure aside, the fishery also appears to operate at very distinct times. In particular, the trawl fishery seems to primarily operate during the months of Feb – Mar, while the longline and pot fisheries operate year-round. Considering these seasonal movements, I think that the pot gear and hook-and-line gear should be combined into its own fleet, while modelling the trawl fishery as its separate fleet and following *pulse-*fishing dynamics potentially. This would be a fruitful avenue to explore. This is potentially supported by some of the bimodal length frequencies that are observed in these data and some mis-fits to fishery data (long shoulders could be because of combining data from gears with distinct selectivities).

# Dan Goethel (Stock Structure)

## Pacific Cod Stock Structure

## Stock Identification Methods