ISC/25/ALBWG-02/04

# Evaluation of size data sets and applicability of mixture models in the Japanese pole-and-line fishery[1]

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1. This working paper was submitted to the ISC Albacore Working Group Intercessional Workshop, October 27 – November 2, 2025, held at the National Research Institute of Fisheries Science, Yokohama, Japan.

## Abstract
The Japanese pole-and-line fishery substantially affects North Pacific albacore. However, size selectivity is difficult to estimate because the highly variable and multimodal observed lengths preclude a clear size selectivity function. To address this issue, we applied a mixture model approach that uses visually estimated mean fish weight per set from logbooks. We then compared the derived length composition with port-sampled lengths to evaluate accuracy and utility. The mean-weight mixture model did not reliably identify cohorts (poor fit and unstable classification) and revealed digit preference in logbook entries, with spikes at 4 and 10 kg. The length composition derived from the classified mean weights was inconsistent with the port-sampled lengths. By contrast, comparisons with catch amount indicated that the port-sampled data successfully captured high-catch strata and are representative of the fleet. Resampling lengths in proportion to catch numbers yielded a composition broadly consistent with the raw port samples, thereby confirming the trimodal distribution observed in port sampling. These findings suggest that logbook mean weight does not reflect average catch size per set. Consequently, we do not recommend mean-weight-based mixture models for defining fleets. Because the port-sampled lengths are representative, they should be used with catch-proportional resampling (or weighting) to set effective sample sizes. Therefore, given the strong spatial overlap among cohorts, the conventional area-as-fleet approach warrants re-evaluation.

## Introduction
The Japanese pole-and-line fishery primarily targets skipjack and albacore in the western North Pacific. Although albacore is secondary to skipjack, the pole-and-line sector accounts for 27% in 2024 of the total catch, indicating its substantial influence on the stock (ISC 2023). Size selectivity estimation for this fishery is challenging. Pole-and-line length data exhibit strong interannual and seasonal variability and a multimodal distribution, complicating stock assessment model fitting. To address this, the ISC Albacore Working Group (ALBWG) assumes constant gear selectivity but uses changing availability driven by migration and distribution shifts. This approach has improved model fit, but it still fails to capture the large, highly variable changes in length composition. In contrast, longline analyses have shown that mixture models using visually estimated mean fish weight recorded in logbooks can effectively stratify catches into distinct size groups (Ijima et al. 2023). Although body weight is also reported in pole-and-line logbooks, its accuracy and the feasibility of applying a mixture model have not been evaluated. Therefore, this study applies a mixture-model analysis to pole-and-line logbook data. We then organize and compare mean-weight and length data using the mixture-model results to assess the accuracy of pole-and-line observations and to recommend the optimal use of these data in stock assessment models.

## Material and methods
### Data Sets
This study used two datasets spanning 1994 to 2024, specifically pole-and-line logbooks and port-sampled length data. The total number of samples is summarized in Table 1. The logbooks record the operation date, 1∘×1∘ latitude–longitude coordinates, catch weight, and visually estimated mean fish weight for each set. Although the mean weight is estimated visually rather than measured, the logbooks provide precise locations and near-complete coverage of all operations. Port-sampled lengths were collected at major ports including Kesennuma, Yaizu, and Chiba-Katsuura, and these data also include observer-program records. Each entry recorded the sampling date, the 5∘×5∘ fishing area, and the fork length for each fish. However, this dataset may contain temporal and spatial sampling bias. Specifically, the sampling date refers to measurement rather than operation, and this time lag may introduce artifacts due to albacore movement, as it is a highly migratory species. Furthermore, the spatial coverage of the surveys is difficult to verify.

### Mixture model analysis
We performed a mixture-model analysis with the R package flexmix (Leisch 2004). The two data sources were harmonized to the same resolution of year, month, and 5° × 5° grid cells before analysis. All subsequent analyses used this stratum as the minimum unit.

We used the visually estimated mean fish weight as the response variable for the logbook analysis and analyzed the data by quarter. The number of mixture classes was fixed at K = 1–4, and grouping factors were year, month, and 5°×5° grid. Because the response value is a mean, we used the number of fish as weights in the likelihood, calculated as catch amount ÷ mean weight. The weighted log-likelihood for this model is:

$$\log(L) = \sum_{g=1}^{G} \sum_{n=1}^{N_g} w_n \log\left(\sum_{k=1}^{K} \pi_k f(x_{g,n}|\sigma_k)\right), \quad (1)$$

where, $G$ is number of observation groups and the number of observations in group $g$ is $N_g$. $w_n$ is non-negative weight for each observation, $\pi_k$ is mixing proportion, $x_{g,n}$ is observation, and $\sigma_k$ is the standard deviation of log-normal distribution for $k$th mixture class. To enable comparison with the port sampling length frequency data, the classified mean weights were converted to fork length with uncertainty:

$$\log(W) = -10.249343 + 2.877937 \times \log(L) + e, e \sim N(0, \sigma^2), \quad (2)$$

where $W$ is whole weight, $L$ is fork length and $\sigma^2$ is the variance of error $e = 0.01845374$. The resulting fork lengths were then subjected to catch-weighted resampling.

For the length analysis, we used data resampled proportional to the number of fish caught within each year, month, and 5∘×5 ∘ grid. This resampling was performed to account for potential random-sampling failures arising from spatial bias. We used the same latent-class setting (K=1–4) and grouping factors as those in the logbook analysis. We modified the log-likelihood function (Equation 1) by dropping the weight variable. For comparison, both dependent variables were summarized by the latent classes obtained above, and histograms were plotted. In this specific comparison, the number of latent classes was fixed at K = 2.

## Results and Discussion

The mixture model with mean weight as the response variable did not separate data for Q1–Q2 (Figure 1). In Q3–Q4, two clusters were suggested, but sharp modes at 4 kg and 10 kg indicate heaping or reporting bias at those weights. Length compositions converted from the two mean-weight clusters showed little agreement with the raw length data, except for Cluster 1 in Q2 (Figure 2). This contrasts with longline fishery results and points to a substantial error in at least one of the datasets.

If the problem were in the length data, a plausible cause would be spatiotemporal sampling bias. We therefore tested coverage by aggregating catch weight from hauls with length measurements within mixture-model strata (5°×5° grid, month, year; Figure 3). Except for 1988–2001 in Q3–Q4, port sampling primarily targeted high-catch strata, suggesting the length data are broadly representative of the spatiotemporal catch pattern. We then performed resampling of port sampling data weighted by catch numbers. For Q1–Q2, the resampled length compositions were generally consistent with the raw data. In Q3–Q4, the 80-cm mode was reduced (Figure 4). Furthermore, even after resampling, the characteristic trimodal length structure persisted, including under a leave-one-port-out sensitivity analysis (Figure 5). These results indicate that mean body weight reported in pole-and-line logbooks is unlikely to reflect operation-level average fish size. Accordingly, the trimodal catch length distribution derived from port sampling is considered reliable.

We analyzed port-sampled lengths with a mixture model but could not resolve the mixture, despite clear evidence of mixed structure (Figure 6). This likely reflects high variability in the migration and distribution of albacore <90 cm and suggests that the current resolution (year, month, 5°×5° grid) is insufficient. Although 1°×1° coordinates are unavailable for the length data, replacing month with measurement week could improve temporal resolution and classification. While clear size-structure patterns exist, their variability and the large spatial overlap among size groups indicate that current boundary settings should be reconsidered.

## Conclusion

- Visually estimated mean fish weight in pole-and-line logbooks is less accurate than in longline logbook data; applying a mixture-model analysis to these weights is not recommended.
- In Q1–Q2, port sampling was concentrated in high-catch strata, indicating length data that are broadly representative of the spatiotemporal catch pattern.

- In Q3–Q4, after catch-number resampling, the length data likewise appear broadly representative of the underlying catch distribution.
- The size (length) data are generally of good quality, but catch-proportional weighting/resampling is needed to compute effective sample size.
- The mixture model applied to the size data did not separate cohorts, likely due to insufficient spatiotemporal resolution.
- Given the substantial spatial overlap among cohorts, the conventional Area-as-Fleet approach for defining fishing units may not be strictly necessary.

## References


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**Table 1.** Number of samples for length frequency data used in this study.

| Year | Chiba-katsuura | Kesennuma | Yaizu | Wagu | Nakiri | Ishinomaki | Kii-katsuura | Observer | Nakaminato | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|
| 1994 | 0 | 0 | 1186 | 0 | 0 | 0 | 0 | 0 | 868 | 216 |
| 1995 | 0 | 0 | 1000 | 0 | 0 | 0 | 0 | 0 | 0 | 187 |
| 1996 | 0 | 0 | 13826 | 0 | 0 | 0 | 0 | 0 | 30 | 469 |
| 1997 | 0 | 0 | 33822 | 0 | 0 | 0 | 0 | 0 | 477 | 220 |
| 1998 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 130 |
| 1999 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 | 929 |
| 2000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1086 |
| 2001 | 0 | 0 | 0 | 0 | 0 | 101 | 0 | 0 | 352 | 2064 |
| 2002 | 0 | 1228 | 23762 | 0 | 0 | 112 | 567 | 4165 | 0 | 3030 |
| 2003 | 0 | 6630 | 22000 | 0 | 0 | 0 | 825 | 5064 | 0 | 393 |
| 2004 | 0 | 280 | 8928 | 0 | 0 | 0 | 1749 | 1208 | 0 | 1262 |
| 2005 | 0 | 0 | 6764 | 61 | 1 | 336 | 0 | 3189 | 0 | 673 |
| 2006 | 1158 | 640 | 1703 | 0 | 0 | 104 | 54 | 0 | 0 | 1078 |
| 2007 | 0 | 1578 | 3202 | 0 | 0 | 419 | 0 | 0 | 0 | 2075 |
| 2008 | 0 | 1518 | 2848 | 0 | 0 | 0 | 0 | 0 | 0 | 461 |
| 2009 | 0 | 2421 | 6563 | 0 | 0 | 0 | 0 | 0 | 0 | 1193 |
| 2010 | 0 | 160 | 5843 | 0 | 0 | 0 | 0 | 0 | 0 | 1056 |
| 2011 | 1758 | 8 | 1951 | 0 | 0 | 0 | 0 | 0 | 0 | 612 |
| 2012 | 2192 | 0 | 1968 | 0 | 0 | 0 | 0 | 0 | 0 | 880 |
| 2013 | 1435 | 2484 | 1850 | 0 | 0 | 0 | 0 | 0 | 0 | 1134 |
| 2014 | 0 | 1715 | 4670 | 0 | 0 | 78 | 0 | 0 | 0 | 1116 |
| 2015 | 0 | 1985 | 800 | 0 | 0 | 500 | 206 | 0 | 0 | 806 |
| 2016 | 0 | 2020 | 3915 | 0 | 0 | 0 | 0 | 0 | 0 | 974 |
| 2017 | 0 | 2239 | 5648 | 0 | 0 | 0 | 0 | 0 | 0 | 693 |
| 2018 | 0 | 3437 | 2302 | 0 | 0 | 0 | 0 | 0 | 0 | 470 |
| 2019 | 0 | 181 | 2750 | 0 | 0 | 0 | 0 | 0 | 0 | 35 |
| 2020 | 0 | 5001 | 2924 | 0 | 0 | 0 | 0 | 0 | 0 | 93 |
| 2021 | 0 | 261 | 2498 | 0 | 0 | 0 | 0 | 0 | 0 | 85 |
| 2022 | 0 | 0 | 991 | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| 2023 | 0 | 4111 | 1102 | 0 | 0 | 0 | 0 | 0 | 0 | 106 |
| 2024 | 0 | 1816 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

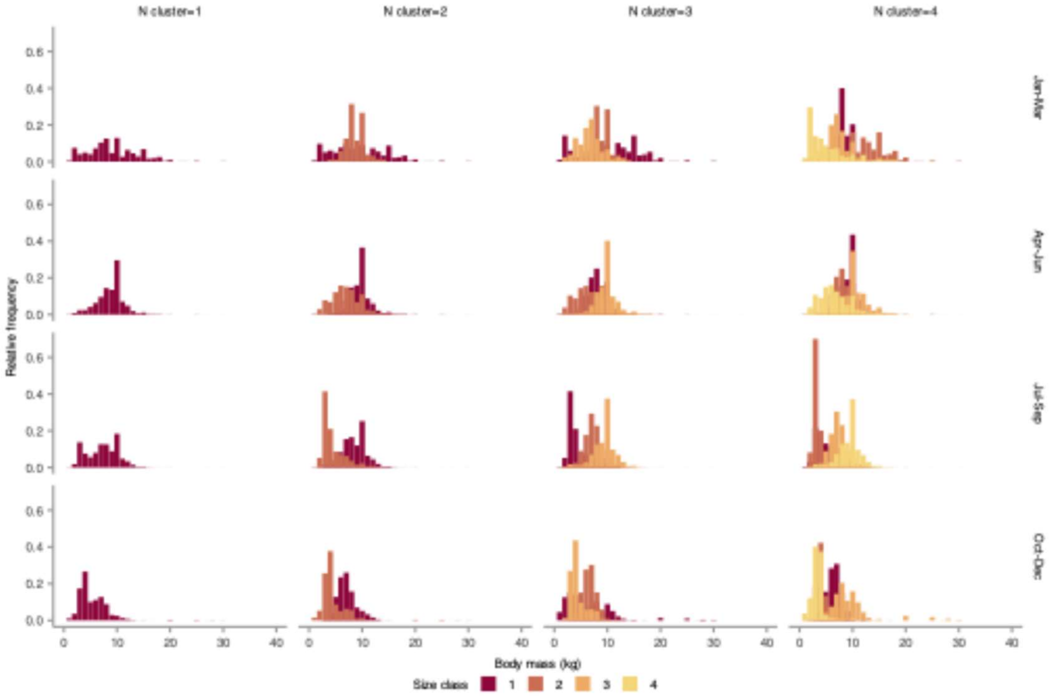


**Figure 1.** Mixture-model classification using visually estimated mean fish weight as the response variable. Models with k=1–4 latent classes were fitted, and the data were grouped by year, month, and a 5°×5° grid.

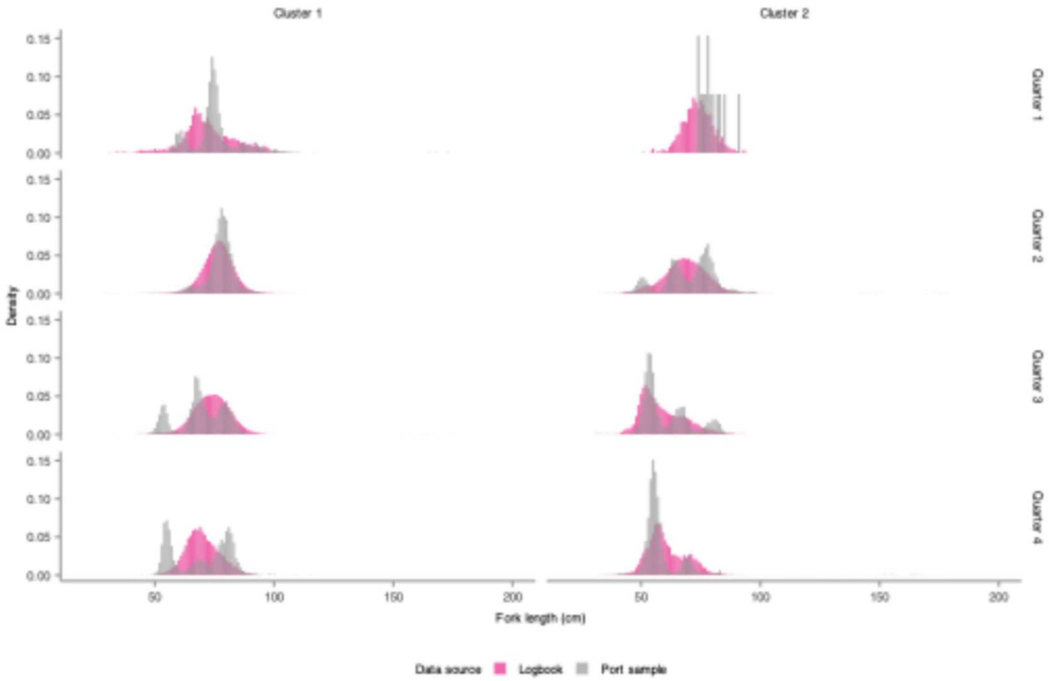


**Figure 2**. Comparison of mixture model results based on visually estimated mean fish weight with port-sampling data. The mixture model results show length compositions converted from mean-weight classifications and weighted by catch numbers. The port-sampling length composition was summarized using the same grouping factors as the mixture model: year, month, and a 5°×5° grid.

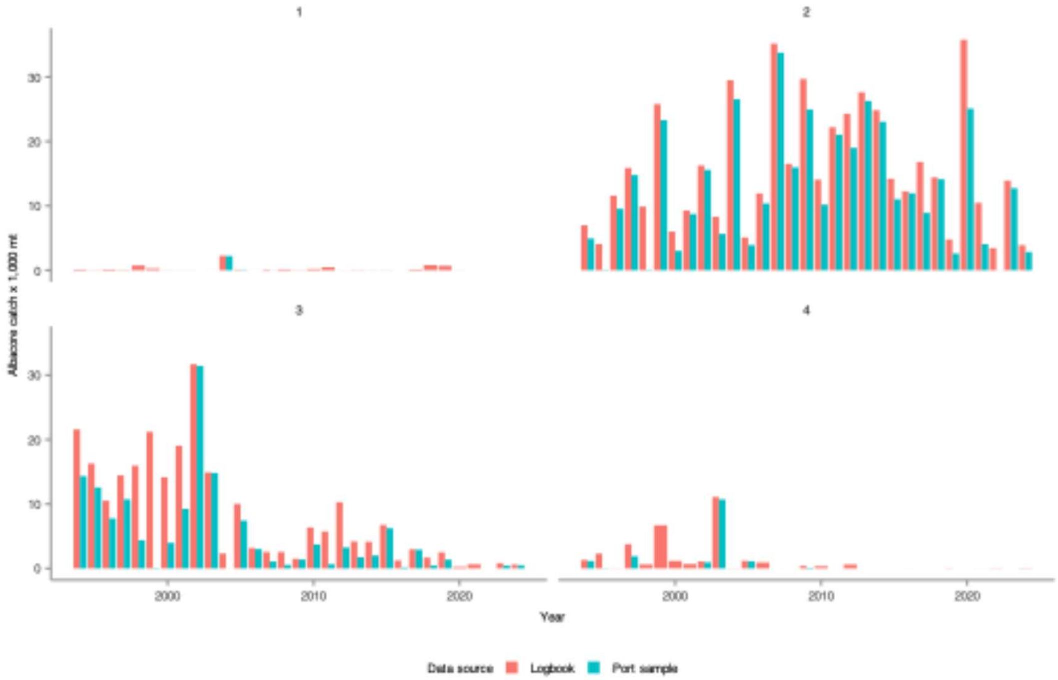


Figure 3. Catch-based coverage of the length data. The figure compares total catch with the catch aggregated over year, month, and 5°×5° grid cells where length measurements were available.

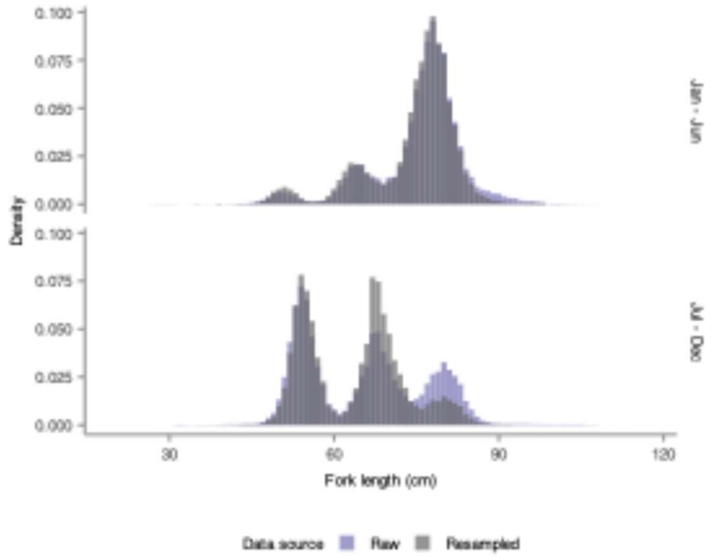


Figure 4. Comparison of two datasets derived from the same port sampling. One uses raw length data, and the other uses catch-number-weighted resampled lengths. Because catches were extremely low in Q1 and Q4, Q1 was pooled with Q2 and Q4 with Q3.

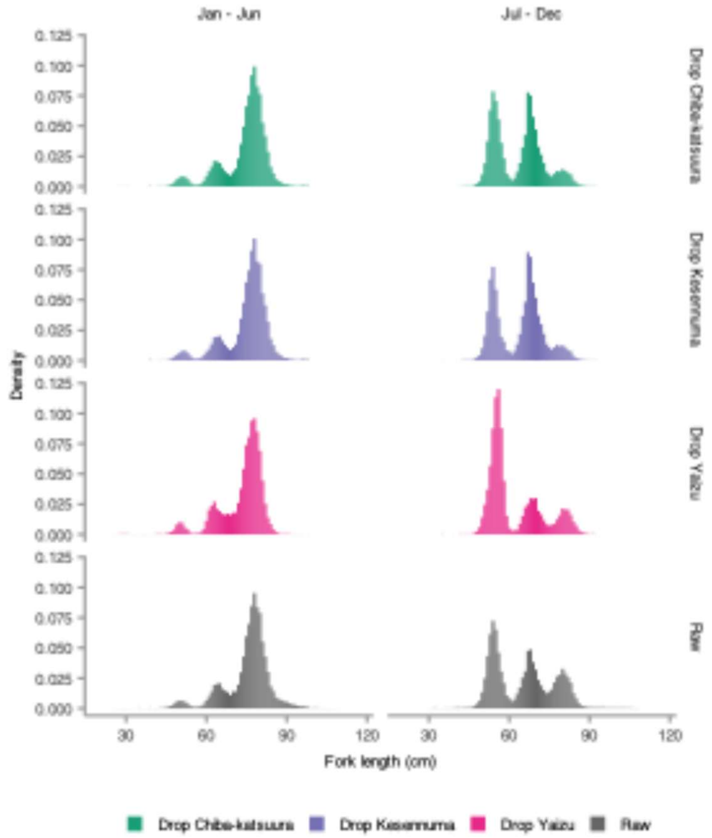


**Figure 5.** Sensitivity analysis of the resampled port-sampled length data. The figure shows results obtained after excluding, in turn, each of the three ports with the largest sample sizes (Chiba-Katsuura, Kesennuma, and Yaizu).

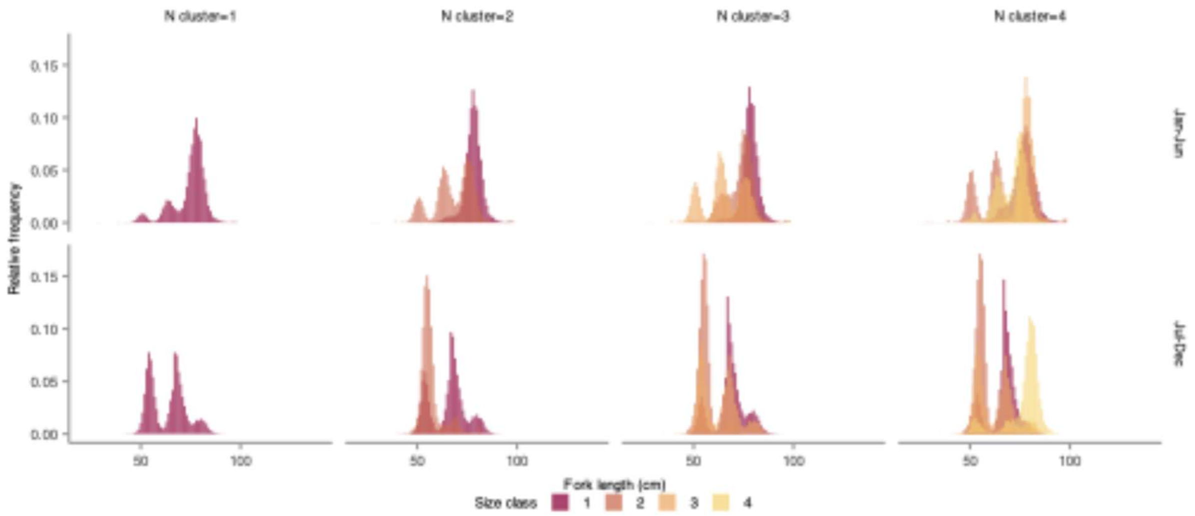


**Figure 6.** Mixture-model analysis results using resampled port-sampled length data as the response variable. No additional weighting was applied because the data were already resampled in proportion to catch numbers.