Appendix A: Proposed size structured stock assessment model framework for Alaska weathervane scallops

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Purpose

This analysis details development of a size structured population dynamics model for Alaska weathervane scallops. Specifically, models were developed for surveyed areas including Kodiak Shelikof district (KSH), Kodiak Northeast district (KNE), West Kayak Island subsection (WKI), East Kayak Island subsection (EKI), Yakutat district combined (YAK).

Data

Retained Catch

Scallop landings are typically discussed in terms of round (i.e., whole animal) weight and meat weight, with the latter being used as the unit of measure for fishery management. Prior to 2009/10 meat weight data were only available from fish ticket data, which may contain some errors associated with ADF&G statistical area and/or district designations (personal communication Ryan Burt ADF&G). Since 2009/10, meat weight data have been tracked by the observer program using daily meat production logs. Although meat weight is used for management, round weight at size is less variable, and thus can presumably be applied to all years and seasons with less risk of misspecification when season-specific meat weight at size data are unavailable. Pre-2009, round weight data was recorded by vessel captains in fishing logs, by multiplying the number the estimated number of bushels by the average bushel weight, which differed by vessel. From 2009/10 number of bushels have been counted by observers during observed hauls and by captains during unobserved hauls. Bushel weights are measured by observers and averaged over the course of the season by district.

Round weight was available from 1990/91 - 2024/25 for KSH, KNE, and YAK, and from 1997/98 - 2024/25 for WKI and EKI. Catch data are available for Kayak Island subsections from 1995/96, but were not parsed by subsection, and were not used here. For all areas, retained catch was assigned a CV of 0.05 prior to 2009/10, and 0.03 for years after 2009/10.

Discard Catch

Discarded scallops ($\hat{D}$) were estimated from observer bycatch by haul data as

$$\hat{D} = A(\frac{1}{n}\sum_{i=1}^{n}\frac{d_i}{a_i}) \tag{1}$$

where d_i is the discarded round weight and a_i is the dredge hours corresponding to the sampled dredge in tow i, n is the number of observed tows in the fishery, and A is the total fishery dredge hours. Discard estimates were available for all years 1996/97 - 2024/25 in which there was a fishery. Standard errors and CV for discards were estimated directly as

$$\sigma_D = \sqrt{A^2(\frac{1}{n}\mathrm{Var}(\frac{d_i}{a_i}))} \tag{2}$$

Handling mortality on discards is assumed to be 0.2. The proportion of handling mortality used here is a conservative, legacy value used by ADF&G borrowed from Atlantic sea scallops (*Placopecten magellanicus*) (NEFSC 2007). Unpublished data on Alaska weathervane scallops suggest actual handling mortality could be lower (unpublished data, Goldman ADF&G), though a recent study of estimated that dredge fishery handling mortality was 21% (Rudders et al. 2022).

Fishery CPUE

Fishery catch per unit effort (CPUE) is the only source of index data before the ADF&G dredge survey began in 2016. CPUE standardization was derived from at-sea observer data from the 1996/97 - 2024/25 seasons. CPUE was defined as the total round weight of the catch per dredge-hour. Prior to analysis, fishery log-book data were filtered so that data representative of core fishing effort only included hauls that employed 13 or 15 ft dredges and adequate dredge performance. Zero catches were removed since they are typically rare and indicate poor gear performance. Hauls were also limited to the inner 95% of CPUE and depth to isolate core fishing effort.

CPUE standardization models were fit using general additive models (GAM) as implemented in the R package *mgcv* (Wood 2004). All models assumed a Gamma error distribution with log-link. Null models by district included only year (of season opening) as an explanatory variable

$$\ln(CPUE_i) = Year_{y,i} \tag{3}$$

The full scope of models evaluated included vessel, depth, dredge width, month and bed. Bed was not included for WKI District, since it only contains a single bed. Depth was fit as a thin plate regression spline, with smoothness determined by generalized cross-validation (Wood 2004). All other variables were fit as factors. The effects of variable addition were evaluated by forward and backward stepwise selection. The addition of a new variable was considered significant if CAIC (Anderson et al., 1998) decreased by at least two per degree of freedom lost and deviance explained (R^2) increased by at least 0.01. The best model forms by district are listed in Table 1. The marginal effects of selected covariates are in Figures 1 - 5.

The standardized CPUE index was extracted from the models as the year coefficient (β_i) with the first level set to zero and scaled to canonical coefficients (β_i') as

$$\beta_i' = \frac{\beta_i}{\bar{\beta}} \tag{4}$$

where

$$\bar{\beta} = \sqrt[n_i]{\prod_{i=1}^{n_j} \beta_i} \tag{5}$$

and n_j is the number of levels in the year variable. Nominal CPUE was scaled by the same method for comparison (Figure 6).

Fishery Shell Height Composition

Size composition of scallops is shell height measured from the umbo to outer shell margin. Scallops with shell heights between 41 - 160+ mm shell height were included in the model in 10 mm size bins. Shell height is measured for 40 retained and 40 discarded scallops during every observer sampled tow. Shell height distribution observed over the entire season is estimated by weighting the shell height composition of a given tow by the round weight catch of retained and discarded scallops of that tow, relative to all tows in the season. Input effective sample sizes (N_{obs}) were computed as

$$N_{obs} = \min(100, N_{meas}) \tag{6}$$

where N_{meas} was the total number of scallops measured.

ADF&G Survey Data

Survey Biomass

Observed ADF&G dredge survey biomass was estimated for sampled beds in KSH, KNE, WKI, EKI, and YAK by methods described in Burt et al., (2021). Round biomass was used as opposed to meat weight biomass, since meat weight at size is known to vary between surveys, likely due to fluctuation in survey and reproductive timing (Hennen and Hart 2012). Observed district biomass computed as the sum of bed biomass estimates. Biomass of beds that were not surveyed in a given year that other beds in the district were, were filled in with predicted values of a weighted linear model in the form of

$$\ln(B_{t,j}) = Year_t + Bed_{b,j} + \epsilon \tag{7}$$

with weights equal to the inverse of the coefficient of variation (CV) on $B_{t,j}$. Since the EK1 bed spans the boundary between the E and YAK districts, EK1 was modeled with the YAK District. Samples that included only the EKI portion of EK1 in 2016 were removed from analysis. The beds KSH2 and KSH3 (Kodiak Shelikof district), and KNE4 (Kodiak Northeast district) were also removed from analysis since they were only surveyed once, and contribute only a marginal proportion of biomass in each district. Biomass estimates by bed and district from 2016 - 2025 are listed in Table 2.

Survey Shell Height Composition

Survey shell height composition data were estimated using the same method as fishery data. Survey composition was given larger input weights than fishery data as

$$N_{obs} = \min(500, N_{meas}) \tag{8}$$

Analytic Approach

Software

This analysis uses GMACS version 2.20.34a (GitHub Repository).

Model Dimensions

Basic model dimensions were as follows:

- Start year: 1990/91 KSH, KNE, YAK; 1997/98 WKI, EKI;
- End year: 2024/25;
- Single sex (i.e., males + females combined);
- 10 mm size classes from 51 - 160+ mm shell height;
- Two fleets: Directed Fishery, ADF&G survey.

Annual Structure

The modeled 'scallop year' runs from May 1 to April 30 and includes five seasons:

1. May 1: Dredge survey;
2. May 1 - May 30: Natural mortality;
3. June 1: Estimate SSB;
4. June 1 - Fishery Midpoint: Fishery;
5. Fishery Midpoint - April 30: Natural Mortality, Growth, Recruitment.

Model Processes

Numbers at shell height (N) of scallops were updated each season (s) by

$$N_{t,s+1,j} = \sum_i N_{t,s,i} e^{-Z_{t,s,i}} X_{i,j} + R_{t,s,j} \tag{9}$$

where $Z_{t,s,i}$ is the total mortality of size i, in season s of year t, X_{i_j} is growth from size i to j and $R_{t,s,j}$ is recruitment at that size and time step.

Initial Conditions

Models started in a non-equilibrium state. N matrices were populated by estimating an initial recruitment (R_{init}) and N-at-size deviations with 101 - 110 mm as the reference size class. A likelihood penalty on N-at-size deviations ($N_{dev,i}$) was defined as

$$LL^{N_{dev}} = \sum N_{dev,i}^2 \tag{10}$$

Weight at Shell Height

Round weight (w) was related to shell height using ADF&G dredge survey data as

$$w_i = \alpha SH_i^{\beta} \tag{11}$$

where α and β are allometric growth parameters. Weight at size was specific to each district (Figure 7).

Maturity

Gonad condition has been qualitatively assessed as part of the ADF&G dredge survey as being "immature", "empty", "initial recovery", "filling", or "full" (Burt et al., 2021). Scallops with gonads in the initial recovery, filling, and full condition were considered mature. Size at maturity was estimated using a binomial regression by district as

$$\text{logit}(p_i) = \beta_0 + \beta_1 SH_i + \epsilon_i \tag{12}$$

where β_0 and β_1 are linear intercept and slope on the logit scale. A maturity ogive was input to GMACS based on the midpoint of each shell height class (Figure 8). It is important to note that maturity only determines the proportion of scallops contributing to spawning stock biomass and does not inform growth or recruitment in this model.

Natural Mortality

Natural mortality was $M = 0.13 \text{ yr}^{-1}$ and was time and size invariant. This mortality value was the median rate estimated by Kruse and Funk (1995) using maximum age (Kaiser 1986; Hennick 1973), growth analysis (Alverson and Carney 1975), and catch curve analysis (Robson and Chapman 1961).

Growth

Growth transition matrices were estimated assuming von Bertalanffy growth with individual variation in asymptotic shell height L_∞ (σ_{L_∞}). Growth parameters L_∞, K (growth rate), and σ_{L_∞} were estimated outside of GMACS using growth increment (shell height, SH) data within a linear mixed-effect model in the form of

$$SH_{L+1} = mSH_L + (b + \beta_j) + \epsilon \tag{13}$$

where β_j is a $\mathcal{N}(0, \sigma^2)$ random intercept by individual scallop. Growth parameters were calculated as

$$L_\infty = \frac{b}{1 - m} \tag{14}$$

$$K = -\ln(m) \tag{15}$$

$$\sigma_{L_\infty} = \frac{\text{Var}(\beta)}{(1 - m)^2} \tag{16}$$

and σ_{L_∞} was transformed to a lognormal scale by $\sqrt{\ln(1 + \sigma_{L_\infty}/L_\infty)^2}$. The growth transition matrix was computed as

$$X_{i,j} = \int_{l_i^-}^{l_i^+} \int_{l_j^-}^{l_j^+} \int_0^\infty F(l_{1i}, l_{2i}, L_\infty, \theta') dL_\infty dl_{2i} dl_{1i} \tag{17}$$

where l_{1i} is the initial shell height within size class i, l_{2j} is the shell height after one period of growth in resulting size class j, F is the product of the probability distributions for growth variation and individuals within the initial size-class, and θ' is a vector of parameters that define the probability distribution functions (Cronin-Fine and Punt 2020). Growth occurred for all individuals once annually, regardless of shell height. Size transition matrices and observed growth increment data are shown in Figure 9.

Selectivity and Retention

Selectivity (S^c) and retention (S^r) at size i were a logistic function of shell height,

$$S_i = \frac{1}{1 + e^{(-\frac{l_i - \theta_{50}}{\sigma_\theta})}} \tag{18}$$

where θ_{50} and σ_θ were estimated parameters representing the size at 50% selectivity (or retention) and slope (or 'width') of the logistic curve, respectively. Separate selectivity curves were estimated for the fishery and ADF&G dredge survey and both processes were time invariant. Selectivity of the plus group size class (165+ mm SH) was forced to 1. No retention occurred during the dredge survey, thus there were six selectivity and retention parameters in total.

Recruitment

Recruitment after the initial year was estimated as

$$R_{t,i} = \bar{R} e^{\epsilon_t} \Omega_i \tag{19}$$

where Ω_i is a normalized gamma function $\Gamma(l \mid \alpha, \beta)$ that describes the size distribution of recruits to the first four size classes. Annual recruitment deviations (ϵ_t) are $\mathcal{N}(0, \sigma\epsilon)$ on a log scale, with $\sigma\epsilon = 0.5$. A smoothness penalty was specified for recruitment deviations as

$$LL^{Rpen} = \sum_t \frac{\epsilon_t^2}{2\sigma_\epsilon^2} + \ln\sigma_\epsilon + \frac{\ln 2\pi}{2} \tag{20}$$

Likelihood Components

Catch

Retained catch biomass was estimated as

$$C_{t,i}^{pre} = w_i N_{t,i} e^{-M\gamma} \frac{F_t S_i^c S_i^r (1 - e^{Z_{t,i}})}{Z_{t,i}} \tag{21}$$

where w_i is the weight (t) at shell height i, $N_{t,i}$ is the number of scallops at shell height i, in year t at the time of the fishery, $e^{-M\gamma}$ is the proportion of natural mortality between the start of the year and the fishery, S_i^c and S_i^r are the selectivity and retention at shell height i, respectively, F_t is the instantaneous rate of fishing mortality in year t, shell height i, and $Z_{t,i}$ is the total mortality in year t, shell height i computed as

$$Z_{t,i} = M + \sum_i F_t S_i^c (S_i^r + (1 - S_i^r) h) \tag{22}$$

where h is handing mortality of discarded scallops, assumed to be $h = 0.2$. Discarded catch biomass was estimated as

$$D_{t,i}^{pre} = w_i N_{t,i} e^{-M\gamma} \frac{F_t S_i^c (1 - S_i^r)(1 - e^{Z_{t,i}})}{Z_{t,i}} \tag{23}$$

The likelihood component relating to retained catch and discards are

$$LL^{catch} = \lambda_C \sum_t \left[\frac{(\text{ln}C_t^{obs} - \text{ln}C_t^{pre})^2}{2\sigma_C^2} + \text{ln}(\sigma_C \sqrt{2\pi}) \right] \tag{24}$$

$$LL^{discards} = \lambda_D \sum_t \left[\frac{(\text{ln}D_t^{obs} - \text{ln}D_t^{pre})^2}{2\sigma_D^2} + \text{ln}(\sigma_D \sqrt{2\pi}) \right] \tag{25}$$

where λ_C and λ_D area weights used to assign emphasis to likelihood components, with values $\lambda_C = 4$ and $\lambda_D = 2$. A smoothness penalty was specified for F deviations $\epsilon_{F,t}$ as

$$LL^{Fpen} = 3 \sum \epsilon_{F,t}^2 \tag{26}$$

Fishery CPUE

Fishery CPUE (U) was estimated as

$$U_t^{pre} = q \sum_i w_i N_{t,i} e^{-M\gamma} S_i^c S_i^r \tag{27}$$

where q is the scaling coefficient catchability. The fishery CPUE likelihood component is

$$LL^{CPUE} = \lambda_U \left[0.5 \sum_t \text{ln}(2\pi\sigma_{\tau,t}^2) + \sum_t \frac{(\text{ln}U_t^{obs} - \text{ln}U_t^{pre})^2}{2\sigma_{\tau,t}^2} \right] \tag{28}$$

where $\sigma_{\tau,t} = \sigma_{U,t} + \sigma_{add}$, in which $\sigma_{U,t}$ is the uncertainty in CPUE in year, t, and σ_{add} is estimated additional error.

Survey Biomass

Survey biomass was estimated as

$$I_t^{pre} = \sum_i w_i N_{t,i} S_i^s \tag{29}$$

where $N_{t,i}$ is the numbers at shell height on May 1 (i.e., the start of the year) and S_i^s refers to selectivity by shell height specific to the ADF&G dredge survey. Survey catchability is assumed to be $q = 1$. The survey biomass likelihood component is

$$LL^{survey} = \lambda_I \left[0.5 \sum_t \text{ln}(2\pi\sigma_{I,t}^2) + \sum_t \frac{(\text{ln}I_t^{obs} - \text{ln}I_t^{pre})^2}{2\sigma_{I,t}^2} \right] \tag{30}$$

where $\sigma_{I,t}$ is the standard error of survey biomass in t.

Shell Height Compositions

Predicted shell height compositions ($P_{t,i}^{pre}$) were the normalized catch or survey biomass at shell height

$$P_{t,i}^{pre} = \frac{C_{t,i}}{\sum_i C_{t,i}} \tag{31}$$

where $C_{t,i}$ is either the predicted retained catch ($C_{t,i}^{pre}$), discarded catch ($D_{t,i}^{pre}$), or survey biomass ($I_{t,i}^{pre}$) in terms of numbers of scallops (i.e., by dividing by w_i). Likelihood components for size composition data were based on the Dirichlet multinomial as

$$LL^{sh} = \sum_{t} \frac{\Gamma(n_t + 1)}{\prod_i \Gamma(n_t P^{obs}_{t,i} + 1)} \frac{\Gamma(\theta n_t)}{\Gamma(n_t + \theta n_t)} \prod_{i} \frac{\Gamma(n_t P^{obs}_{t,i} + \theta n_t P^{pre}_{t,i})}{\Gamma(\theta n_t P^{pre}_{t,i})} \tag{32}$$

where n is the input sample size and θ is a parameter accounting for overdispersion (Thorson et al., 2017). The estimated effective sample size n_{eff} is given by

$$n_{eff,t} = \frac{1 + \theta n_t}{1 + \theta} \tag{33}$$

Objective Function

The objective function $\mathcal{Q}$ was the sum of likelihood components

$$\mathcal{Q} = LL^{catch} + LL^{discards} + LL^{Fpen} + LL^{CPUE} + LL^{survey} + \sum_{i} LL^{sh}_{i} + LL^{Rpen} + LL^{N_{dev}} \tag{34}$$

Results and Discussion

Convergence

All models produced a jitter run that converged to the putative MLE with a positive definite Hessian. Multiple local minima were identified for all models. The majority of jitter runs in KNE and YAK converged to the MLE, whereas more runs converged to local minima for KSH, EKI, and WKI. Jittering results are detailed in Tables 3 - 7. All models had maximum gradients < 0.0001 (KSH = 2e^{-8}, ln $\bar{R}$; KNE = 4.9^{-6}, ln $\bar{R}$; WKI = 1.87e^{-6}, ln R_{init}; EKI = 1.73e^{-6}, ln $\bar{R}$; YAK = 1.33e^{-5}, $\epsilon_{R,2016}$). All parameters were estimated within bounds, except dredge survey size at 50% selectivity which was at its lower bound. Dredge survey selectivity was estimated poorly in all districts besides YAK (see below, Table 9).

Fits to Data Components

The model fit retained catch data well in all districts fairly well. Fits to discarded catch were also fairly accurate in more heavily fished districts (KSH, KNE, and YAK), but less so in WKI and EKI (Figure 10).

The model tended to fit standardized CPUE data somewhat poorly (Figure 11). In KSH, predicted CPUE generally follows the observed trend, but over predicts CPUE considerably in years before 2003/04. Predicted CPUE in KNE misses the early observed data in a similar way. In addition, predicted CPUE in KNE follows the recently occurring rebound in CPUE, but underpredicted CPUE during 2019 - 2021. Predicted CPUE trends in WKI and EKI fail to capture the contrast in the observed data, while in YAK the model did not capture the trend of the observed CPUE until $\sim$ 2016 (Figure 11). Survey biomass estimates are few and do not indicate much trend in WKI, EKI, or YAK. The model fit increased in survey biomass observed in KSH and KNE, but generally averaged across smaller changes from year to year. In WKI, EKI, and YAK, predicted CPUE mostly captured the average (Figure 12).

Aggregated retained and discarded size distributions were captured adequately well, though large residual patterns or mischaracterized distributions were evident in several years. Among the retained catch compositions, the model tended to under-predict the mode size and over-predict the largest size bins in most years. Estimated discarded size compositions had similar issues, but also over-predicted smaller size bins in several years in all districts (Figure 13 - 24). Fits to dredge survey size compositions were relatively poor for Kodiak districts. The model failed to pick up on several prominent size cohorts in both KSH and KNE. Survey size compositions were better approximated in WKI, EKI, and YAK (Figure 26 - 28).

Contribution of likelihood components are detailed in Table 8 and selected parameter estimates are in Table 9.

Selectivity

Fishery selectivities were fairly steep after 80 mm shell height. Selectivity in WKI and EKI never appeared to reach an asymptotic maximum within the size range, especially for EKI which may have not reached near-full selectivity had the plus group not been forced to 1 (Figure 29). Dredge survey selectivity was not well defined (i.e., as indicated by very large standard errors) and effectively reduced to full selectivity over the size range for KSH, KNE, WKI, and EKI. Near-full selectivity may be plausible given that the dredge has a 1.5" (38 mm) polyurethane mesh liner inside the 4" (101 mm) ring mesh (Burt et al. 2021). Additionally, recruitment deviations may be flexible enough to fit observed size composition data without size dependent selectivity in these districts. The YAK model estimated nearly linear selectivity over the size range (Figure 29). Again, selectivity in the plus group is forced to 1, but it is also worth noting that annual size compositions tend in YAK to be left skewed compared with other districts (except for EKI) that have more clearly defined recruitment pulses (Figure 27).

Recruitment and Spawning Stock Biomass

Recruitment variability was high in all districts, but comparatively less so in WKI and EKI (Figure 30). Kodiak districts (KSH, KNE) underwent a period of low recruitment during the mid-2000s to mid-2010s, after which estimated recruitment returned to previous levels in KSH and a time series high in KNE (2018). Estimated recruitment in has been low roughly stationary since 2015 in WKI and 2000 in EKI (Figure 30). The YAK model suggests frequent spikes in recruitment throughout the time series, with the last large pulse occurring in 2018 (Figure 30).

Estimated spawning stock biomass (SSB) in KSH and KNE decreased from the beginning of the time series before rebounding swiftly after 2016 (Figure 31). WKI SSB reached its minimum in the mid-2010s before rebounding to the most recent high period in from 2015 - 2020. Since 2020, WKI SSB has been on a downward trend. EKI SSB has been stationary at low levels since 2011, while YAK SSB has been stationary and high since the late-2000s (Figure 31).

KSH and KNE models both had large, positive retrospective patterns in SSB (Figure 32). Retrospective patterns highlight heavy reliance on the short, sparse survey time series. Even with only five peels, there is considerable loss of information driving abundance and size composition in the latter part of the time series. Additionally, changes in survey information appear to have a strong influence on recruitment and estimability of dredge survey selectivity, at least in KSH (Figure 33 and 34). As a result, retrospective patterns as presented here may more so be diagnosing data sensitivity rather than structural misspecification.

Conclusions

Alaska weathervane scallop beds have undergone a wide range of different fishing histories, mortality events, and recruitment patterns, so a one-size-fits-all approach to modeling population dynamics is difficult to achieve without compromising resolution. The model structure used here adequately captured the observed population dynamics without undue complexity and is the most widely applicable undertaking of a modeling framework for this stock to date. Some clear structural misspecification exists (e.g., dredge survey selectivity), which can be revisited should the SPT continue to pursue a model-based stock assessment.

The analysis presented here stopped short of applying a harvest control rule to determine biological reference points. Following the existing framework used by the NPFMC Crab and Groundfish Plan Teams, a harvest control that assumes maximum $\mathrm{F}_{\mathrm{OFL}} = M$ is likely the most suitable given availability of a stock biomass estimate informed by integrated fishery and survey data, though life history and reproductive information are lacking. The value of M assumed here was based on an analysis by Kruse and Funk (1995) which considered a variety of estimation methods including maximum age (Kaiser 1986; Hennick 1973), growth analysis (Alverson and Carney 1975), and catch curve analysis (Robson and Chapman 1961). The resulting median estimate ($M = 0.13$) was used as the basis for optimum yield in the FMP (NPFMC 2014). It may be worthwhile to revisit M using a more modern age-based method (Dureuil and Froese 2021), an index of clappers (i.e., empty shells) (Merrill and Posgay 1964), or this population dynamics model.

Another consideration is that a population dynamics model as constructed here could not feasibly be extended to data-limited portions of the stock. KSH, KNE, WKI, EKI, and YAK all have relatively long fishing histories with complete observer data and dredge survey data (since 2016). Area H has a historic dredge survey time series and is part of the modern ADF&G dredge survey (2016 - present), though fishing in the Kamishak district is unlikely to be prosecuted in the foreseeable future by current fishery participants due to Cook Inlet specific gear restrictions (i.e. a single 6 ft dredge). Kodiak Southwest District (KSW) has had consistent fishery data since 2009, whereas Areas M (AK Peninsula), O (Dutch Harbor), and Q (Bering Sea) have had sporadic fishing effort since 2020. No areas west of KSH have ever had a dredge survey. Jackson (2024) proposed a 'core / non-core' combination approach to determining a stock-wide reference point that summed outputs of a sloping harvest control rule for 'core' areas (KSH, KNE, WKI, EKI, and YAK) and a total catch based reference point for 'non-core' areas (H, KSW, KSE, M, O, Q). Stock delineation based on data availability may be the most pragmatic approach to better informing harvest specification since precise information on biological stock delineation in Alaska is unavailable.

Table

Table 1: Results of CPUE standardization model selection by district. The first line of each district details the best model, followed by the change in AIC, deviance explained, and degrees of freedom for each additional covariate.

District	Model Terms	AIC	Deviance Explained	Degrees of Freedom
KSH	~ Year + Month	254,058	0.402	35.000
	+ Dredge Width	-306	0.009	1.000
	+ s(depth)	-145	0.007	7.640
	+ Vessel	31	< 0.001	3.000
	+ Bed	-30	0.002	2.000
KNE	~ Year + Bed + Month + s(depth)	141,585	0.324	49.700
	+ Dredge Width	-98	0.007	0.989
	+ Vessel	-29	0.004	2.950
WKI	~ Year + s(depth)	13,176	0.645	26.050
	+ Month	8	0.008	3.890
	+ Vessel	3	0.002	9.280
EKI	~ Year + Month	13,852	0.382	17.000
	+ s(depth)	11	0.023	6.070
	+Vessel	8	0.005	2.000
YAK	~ Year + Month + Vessel + Dredge Width + Bed + s(depth)	496,130	0.226	53.000

Table 2: ADF&G dredge survey observed round biomass (t) and associated CVs by district.

2016	1,162 (0.12)		1,102 (0.36)	723 (0.24)	
2017	1,152 (0.12)	787 (0.33)			5,264 (0.14)
2018	1,959 (0.12)			629 (0.2)	5,701 (0.11)
2019			917 (0.35)		8,394 (0.09)
2020	4,049 (0.16)	1,564 (0.32)			
2021			1,318 (0.28)	712 (0.18)	5,792 (0.19)
2022	5,249 (0.18)	2,924 (0.43)			
2023			1,079 (0.27)	597 (0.2)	7,467 (0.18)
2025	5,182 (0.12)	3,152 (0.31)			

Table 3: Objective function, number of runs reaching a specific outcome, and maxiimum gradient compoent for 200 KSH jitter runs.

Objective Function	Number of Runs	Maximum Gradient
1575.11334	55	2e-08
1575.13555	33	1e-08
1575.42254	4	2.617e-05
1576.88484	107	5e-08
Undefined	1	

Table 4: Objective function, number of runs reaching a specific outcome, and maxiimum gradient compoent for 200 KNE jitter runs.

Objective Function	Number of Runs	Maximum Gradient
1339.81972	159	4.9e-06
1339.82054	8	1.311e-05
1341.30738	3	6.606e-05
1658.78958	1	6679.04223235
1662.41989	1	8049.99963536
2246.97767	2	0.00416101
2251.47877	1	0.00550051
2251.47887	1	0.00439508
2251.47909	2	0.00191107
2251.47913	1	0.00145181
2251.47914	1	0.00141241
2251.47919	1	0.00091408
2251.47920	1	0.00132906
2251.47922	1	0.0010393
2251.47925	3	0.00018677
Undefined	14	

Table 5: Objective function, number of runs reaching a specific outcome, and maxiimum gradient compoent for 200 WKI jitter runs.

Objective Function	Number of Runs	Maximum Gradient
1004.67605	10	1.87e-06
1309.58676	1	1441.33306338
1309.75439	1	1420.6390273
1309.98284	1	1470.46506351
1309.99717	1	1537.24295427
1310.04942	1	1462.17045489
1310.24291	1	1442.99630034
1310.33964	1	1482.55859537
1310.51555	1	1454.82919483
1310.58379	1	1375.25565323
1310.68699	1	1480.3856633
1310.77757	1	2150.88746217
1311.47491	1	1652.02549641
1312.48817	1	1897.08842057
1313.85893	1	5813.91486512
1315.61347	1	1321.47937307
1315.71448	1	1337.03187477
1320.31228	1	9145.12285727
1570.92249	1	0.00107147
1570.92256	7	0.00031024
1570.92258	1	0.06967382
1572.61992	1	0.00187992
1572.62003	3	0.00044993
1572.62004	123	0.00033872
1572.62005	5	0.00021988
1572.62006	13	9.781e-05
1572.62007	9	2.86e-05
3581.63032	1	0.00568324
3581.63035	1	0.00915272
Undefined	8	

Table 6: Objective function, number of runs reaching a specific outcome, and maxiimum gradient compoent for 200 EKI jitter runs.

Objective Function	Number of Runs	Maximum Gradient
646.86558	14	1.73e-06
656.64577	12	5.2e-06
666.73671	28	9.42e-06
667.95852	1	0.00014199
672.29870	12	1.453e-05
673.30660	2	7.78e-05
Undefined	6	

Table 7: Objective function, number of runs reaching a specific outcome, and maxiimum gradient compoent for 200 YAK jitter runs.

Objective Function	Number of Runs	Maximum Gradient
1403.52285	168	1.325e-05
1419.88606	1	0.00128459
2206.91573	1	10156.49491427
2209.81446	1	10209.56217561
2209.98870	1	10356.15425613
2210.24447	1	10467.72856462
2210.27795	1	9992.32587796
2210.50024	1	10406.53968443
2210.65340	1	10348.55303853
2211.96137	1	10798.25889283
2220.20481	1	10544.00345386
3054.83175	1	0.03152737
3054.83338	1	0.01341049
3054.83342	1	0.01294607
3054.83350	1	0.01207186
3054.83375	1	0.0094851
3054.83376	1	0.00935649
3054.83387	1	0.00820066
3054.83403	1	0.0817686
3054.83405	1	0.00640441
3054.83409	1	0.00591727
3054.83429	1	0.00559679
3054.83433	2	0.00409544
3054.83434	1	0.00317729
3054.83447	1	0.00122342
3054.83448	1	0.00262008
3060.24564	1	0.02267983
3062.88979	1	0.01342396
Undefined	4	

Table 8: Comparision of likelihood components and number of parameters by district model.

Component	KSH	KNE	WKI	EKI	YAK
Retained Catch	-274.910	-291.354	-169.190	-120.331	-241.604
Discarded Catch	27.932	44.661	89.925	5.703	88.322
Fishery CPUE	-12.189	-7.535	5.859	-13.284	-23.293
Survey Biomass	-7.954	-4.009	-3.607	-5.743	-4.816
Retained SH Composition	642.044	587.915	326.305	224.783	550.411
Discarded SH Composition	868.171	757.636	541.552	371.816	783.738
Survey SH Composition	195.142	136.113	105.208	87.707	142.209
Recruitment	61.618	39.962	23.344	23.975	33.346
Penalties	0.034	0.045	0.024	0.020	0.009
Initial Conditions	0.014	0.794	9.172	17.577	0.183
N Parameters	98	98	76	71	96
Total NLL	1575.113	1339.820	1004.676	666.737	1403.523

Table 9: Select parameter estimates and associated standard errors for each district model.

Parameter	KSH	KNE	WKI	EKI	YAK
ln R_{init}	17.973 (0.088)	17.07 (0.061)	15.742 (0.051)	15.231 (0.124)	17.809 (0.104)
ln $\bar{R}$	15.353 (0.091)	14.725 (0.098)	13.572 (0.156)	13.56 (0.132)	16.372 (0.097)
Rec α	60.455 (1.961)	51.742 (2.455)	57.74 (3.523)	56.749 (2.285)	53.393 (1.301)
Rec β	4.448 (1.412)	5.897 (2.05)	2.109 (1.326)	0.902 (0.386)	1.58 (0.364)
Fishery Sel ln θ_{50}	4.575 (0.014)	4.688 (0.015)	4.82 (0.07)	5.014 (0.059)	4.602 (0.014)
Fishery Sel ln σ_θ	2.475 (0.044)	2.467 (0.044)	2.879 (0.106)	2.708 (0.062)	2.335 (0.042)
Survey Sel ln θ_{50}	3.689 (0.002)	0.69 (21183.519)	3.793 (33.383)	3.782 (8054.086)	4.62 (0.148)
Survey Sel ln σ_θ	1.366 (1.192)	0.414 (9718.813)	-3.413e+00 (2362.61)	-3.600e+00 (3844.734)	3.538 (0.247)
Retention Sel ln θ_{50}	4.726 (0.004)	4.748 (0.005)	4.674 (0.009)	4.715 (0.012)	4.679 (0.003)
Retention Sel ln σ_θ	1.91 (0.029)	2.123 (0.033)	1.954 (0.058)	2.143 (0.069)	1.84 (0.029)
ln $\bar{F}$	-1.476e+00 (2.214)	-1.454e+00 (2.215)	-1.692e+00 (2.968)	-1.565e+00 (3.464)	-1.695e+00 (2.283)
ln Overdisperion Ret Comp	-6.341e-01 (0.168)	-1.468e+00 (0.134)	-2.210e+00 (0.179)	-1.163e+00 (0.261)	-9.798e-01 (0.157)
ln Overdisperion Disc Comp	-8.182e-01 (0.121)	-3.720e-01 (0.144)	-2.077e+00 (0.135)	-2.040e+00 (0.153)	0.294 (0.23)
ln Overdisperion Survey Comp	-4.250e-01 (0.287)	-7.992e-01 (0.302)	-2.318e-01 (0.474)	-1.011e+00 (0.362)	0.22 (0.417)
Fishery q	5.236e-04 (4.436e-05)	0.001 (1.224e-04)	0.003 (9.110e-04)	0.004 (0.001)	2.175e-04 (1.820e-05)
ln extra CV Fishery CPUE	-8.975e-01 (0.152)	-7.261e-01 (0.169)	0.008 (0.249)	-1.871e+00 (0.358)	-1.315e+00 (0.152)

Figures

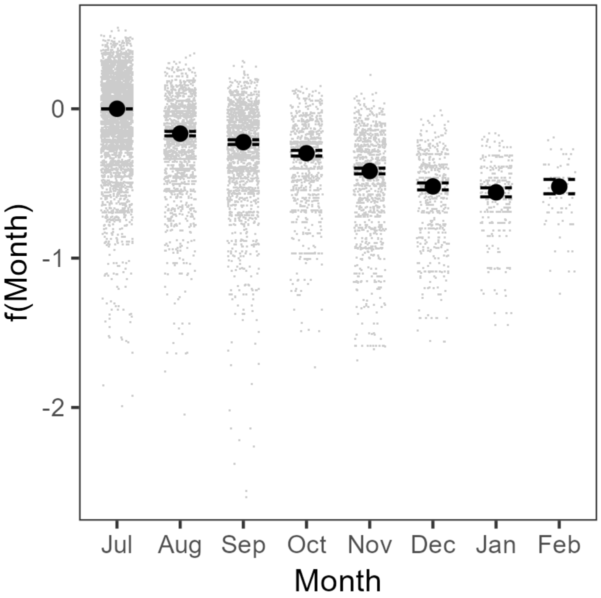

Figure 1: Marginal effect of month based on 'best' GAM fit to KSH CPUE.

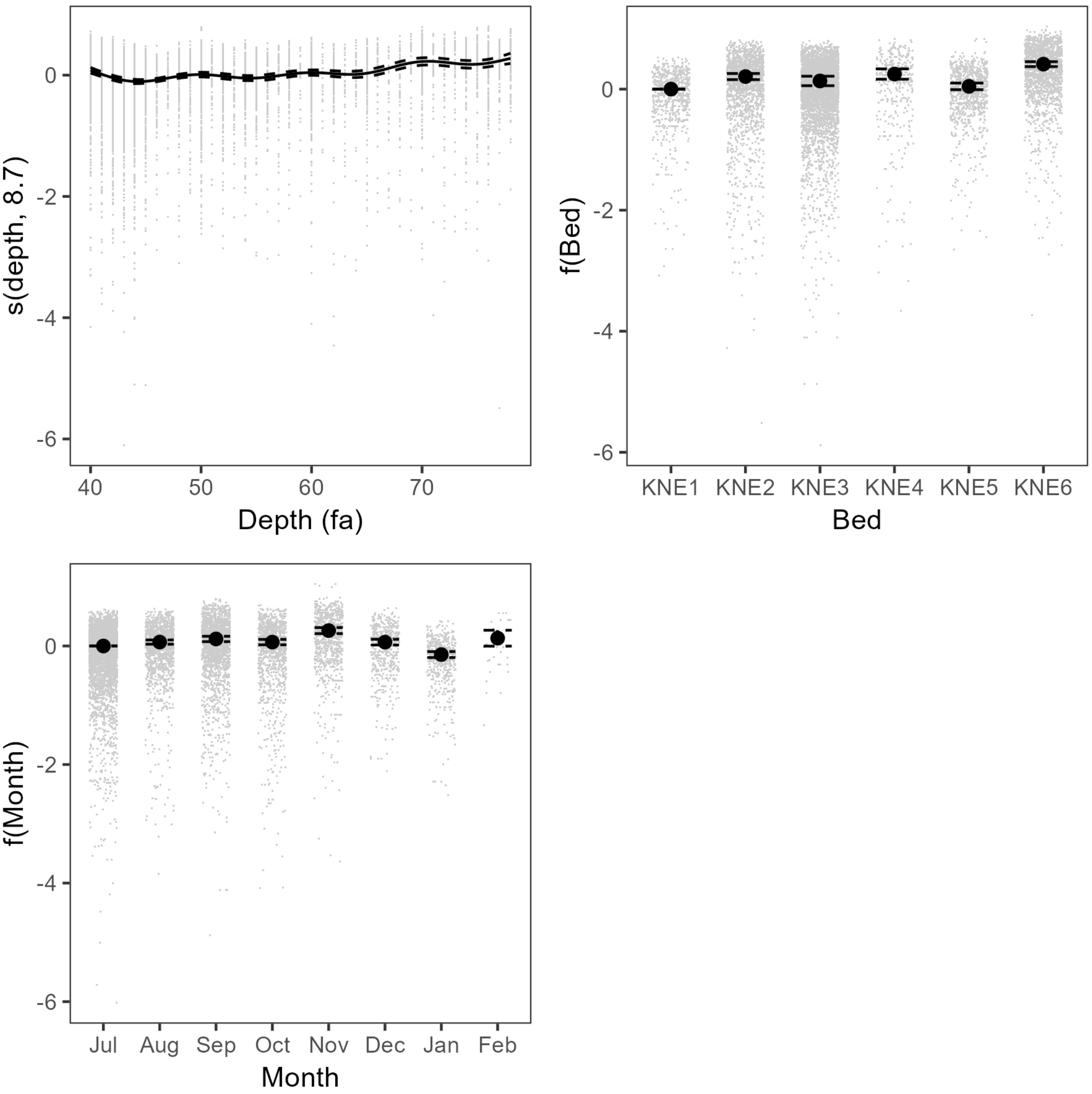

Figure 2: Marginal effect of month, bed, and smoothed depth based on 'best' GAM fit to KNE CPUE.

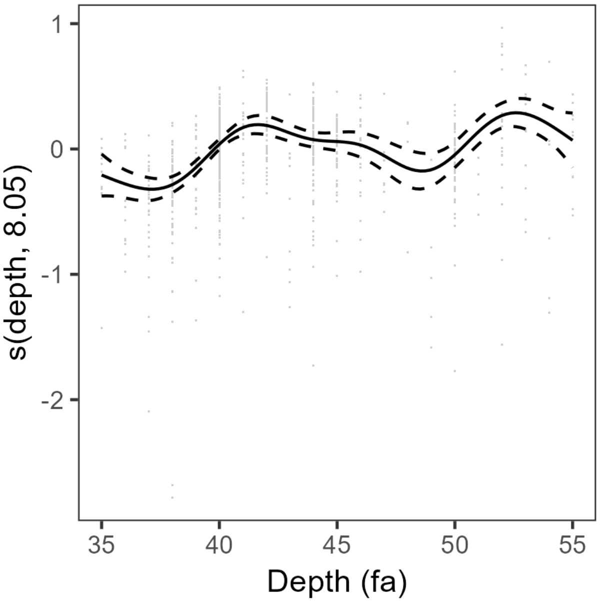

Figure 3: Marginal effect of smoothed depth based on 'best' GAM fit to WKI CPUE.

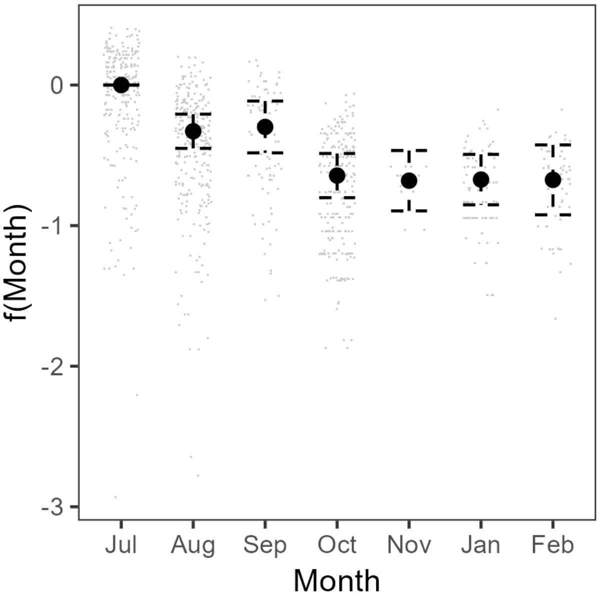

Figure 4: Marginal effect of month based on 'best' GAM fit to EKI CPUE.

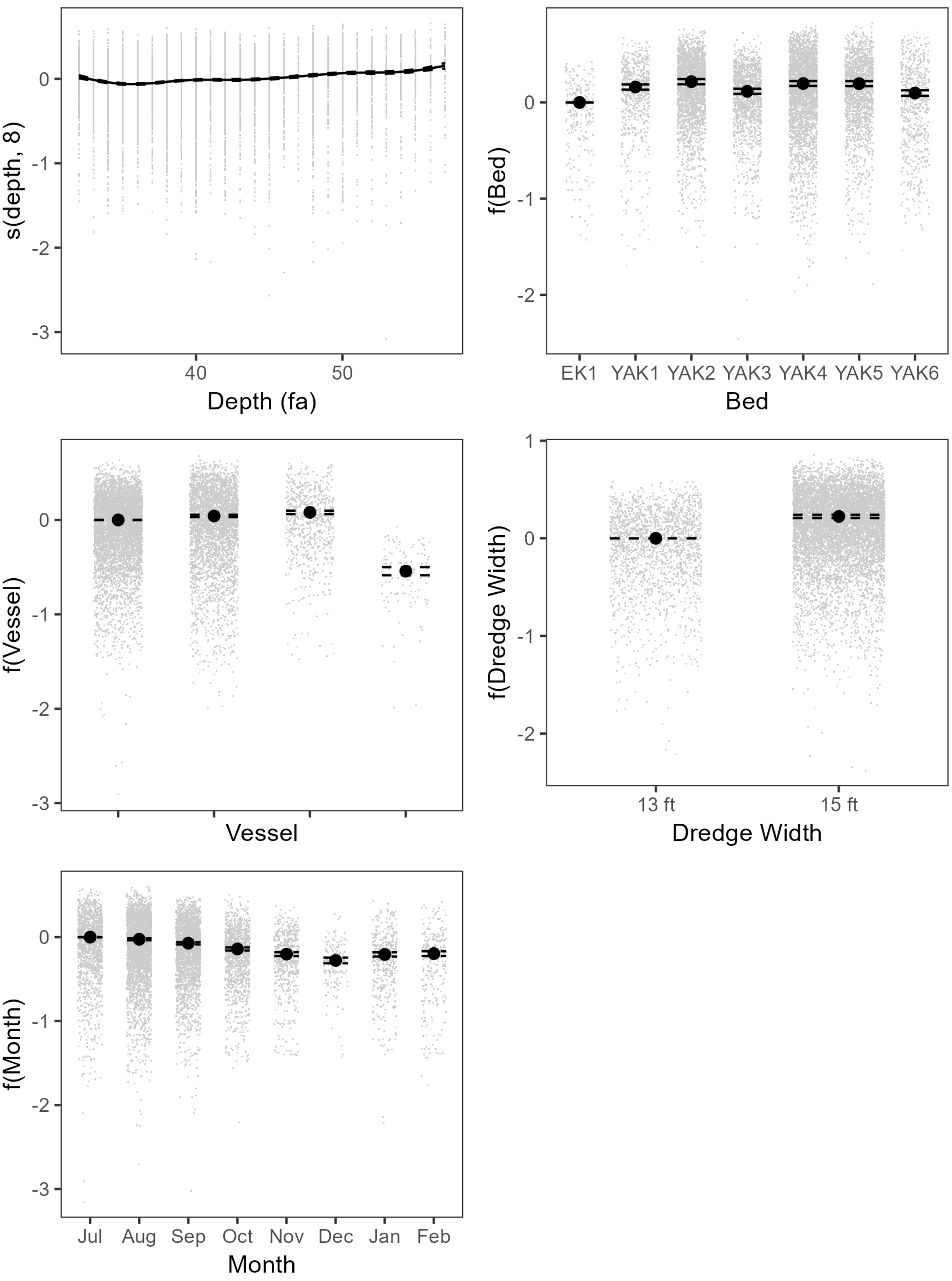

Figure 5: Marginal effect of smoothed depth, bed, vessel, month, and dredge width based on 'best' GAM fit to YAK CPUE.

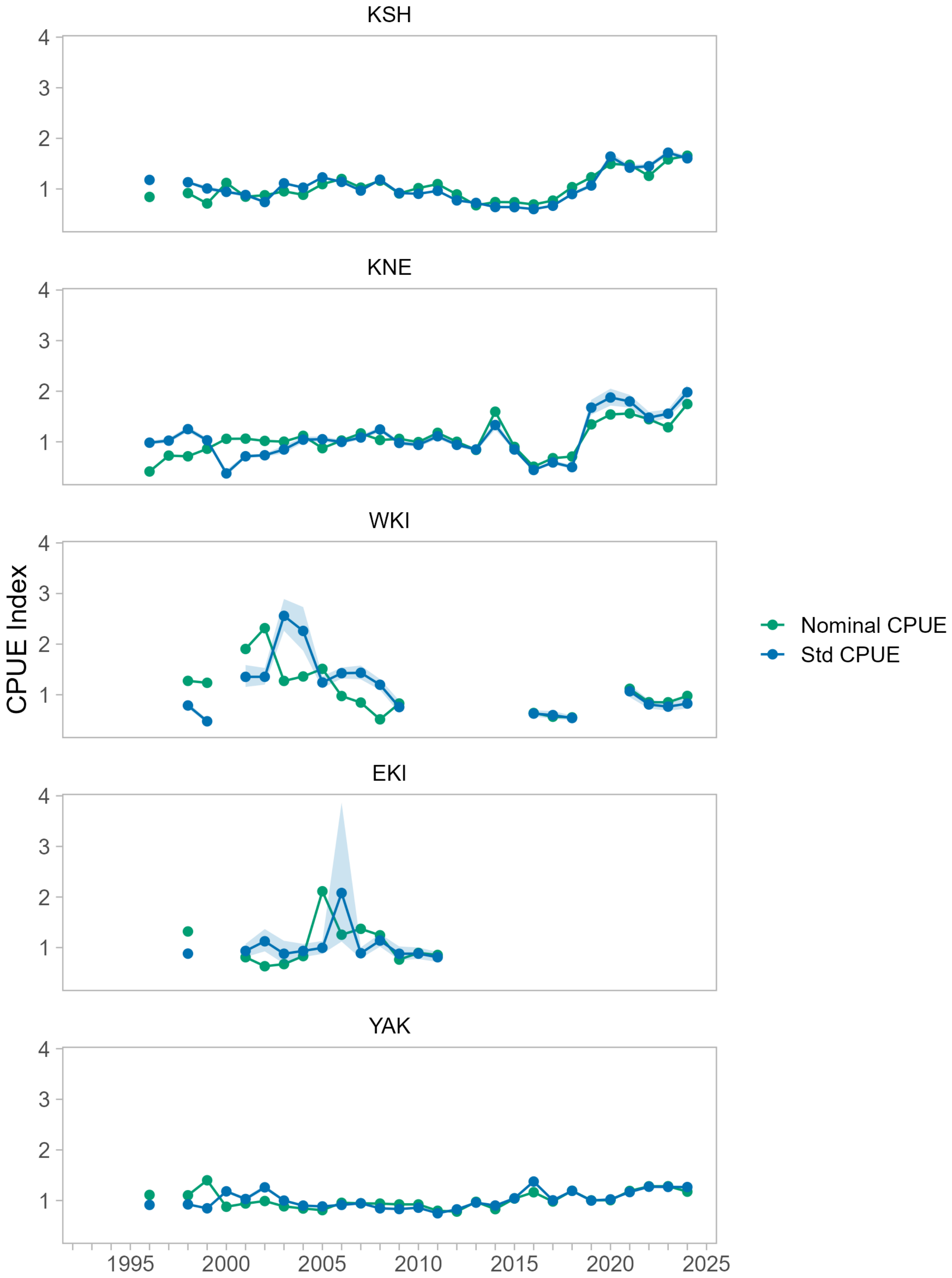

Figure 6: Marginal effect of smoothed depth, bed, vessel, month, and dredge width based on 'best' GAM fit to YAK CPUE.

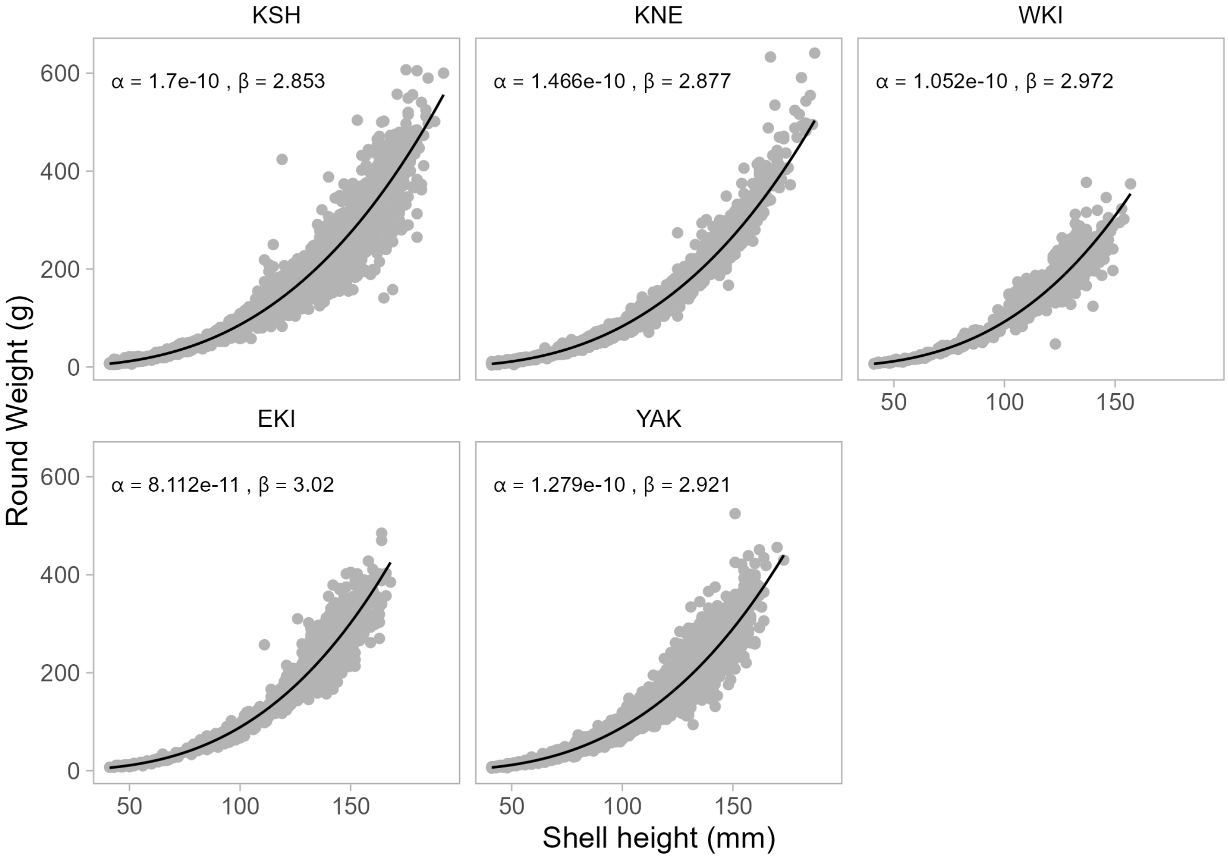

Figure 7: Round weight (g) at shell height (mm) by district. Parameters are scaled to weight in tonnes.

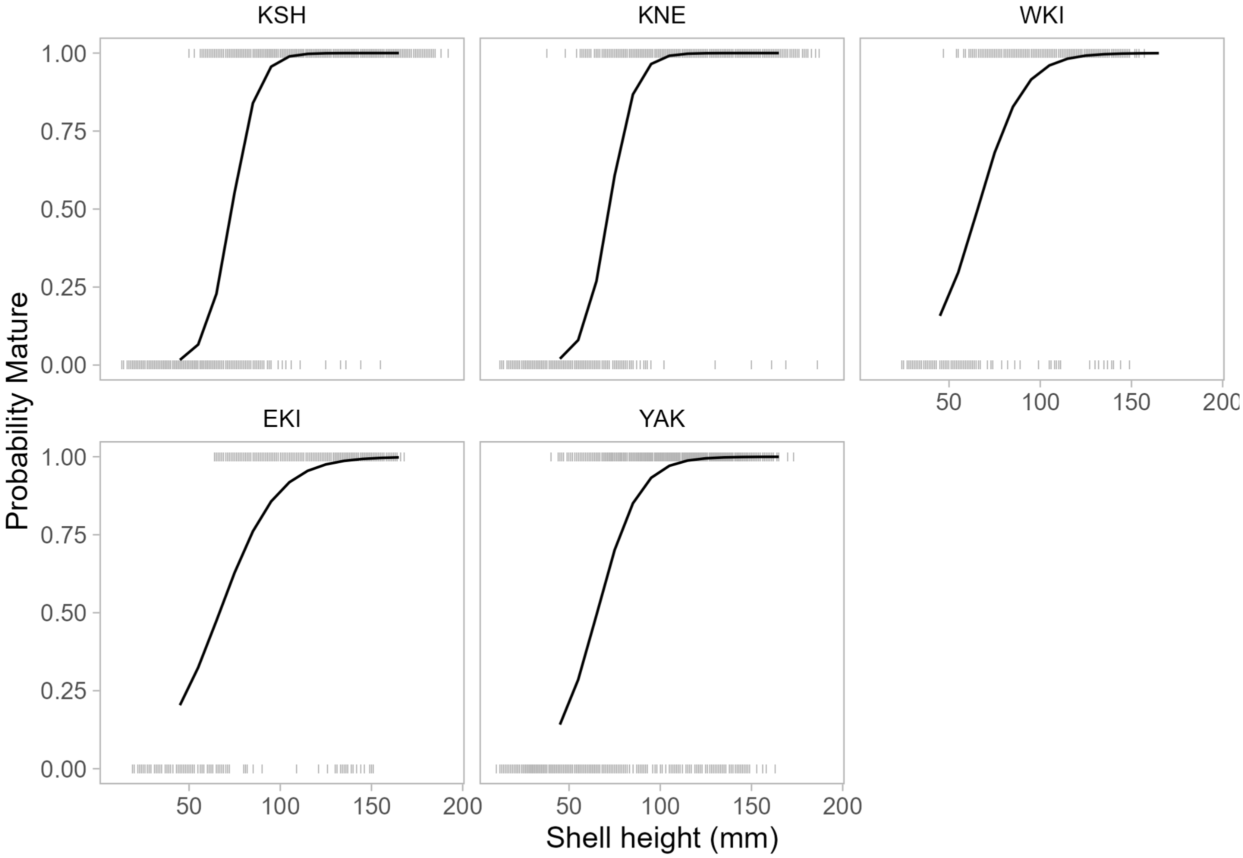

Figure 8: Probability of maturity as a function of shell height by district.

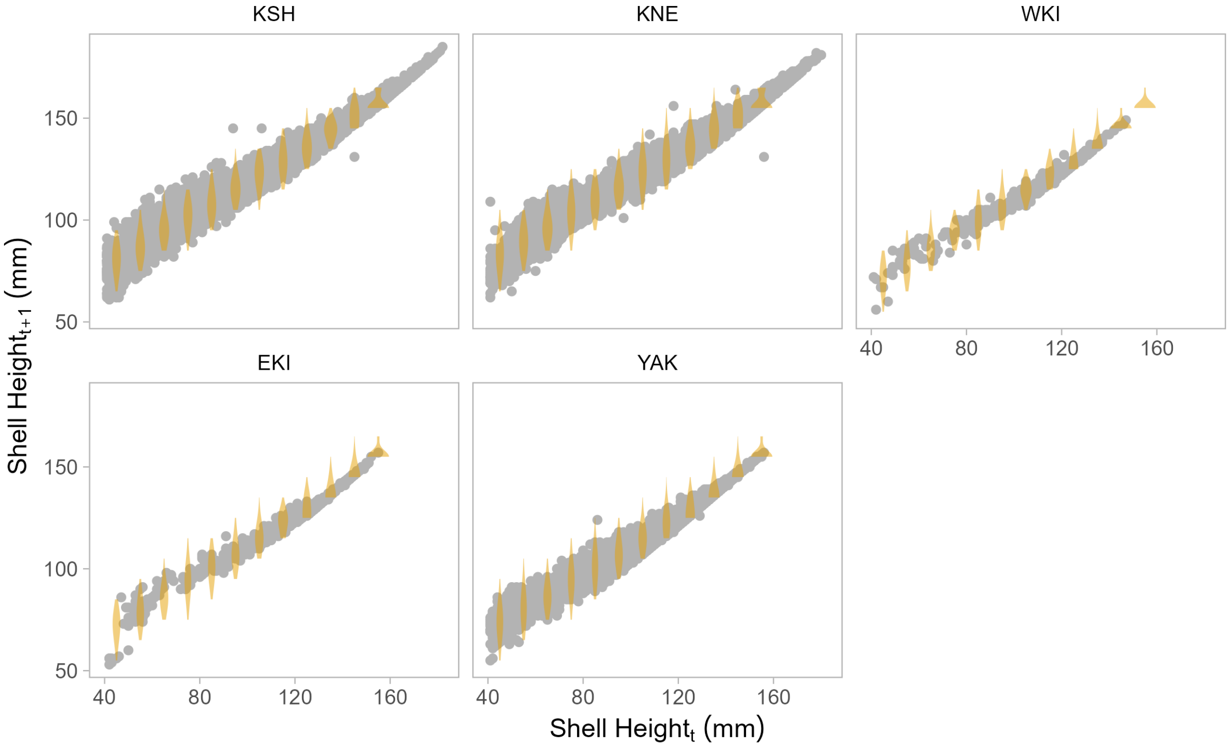

Figure 9: Shell height growth increment data and growth transition matrices (yellow violins) estimated outside of GMACS.

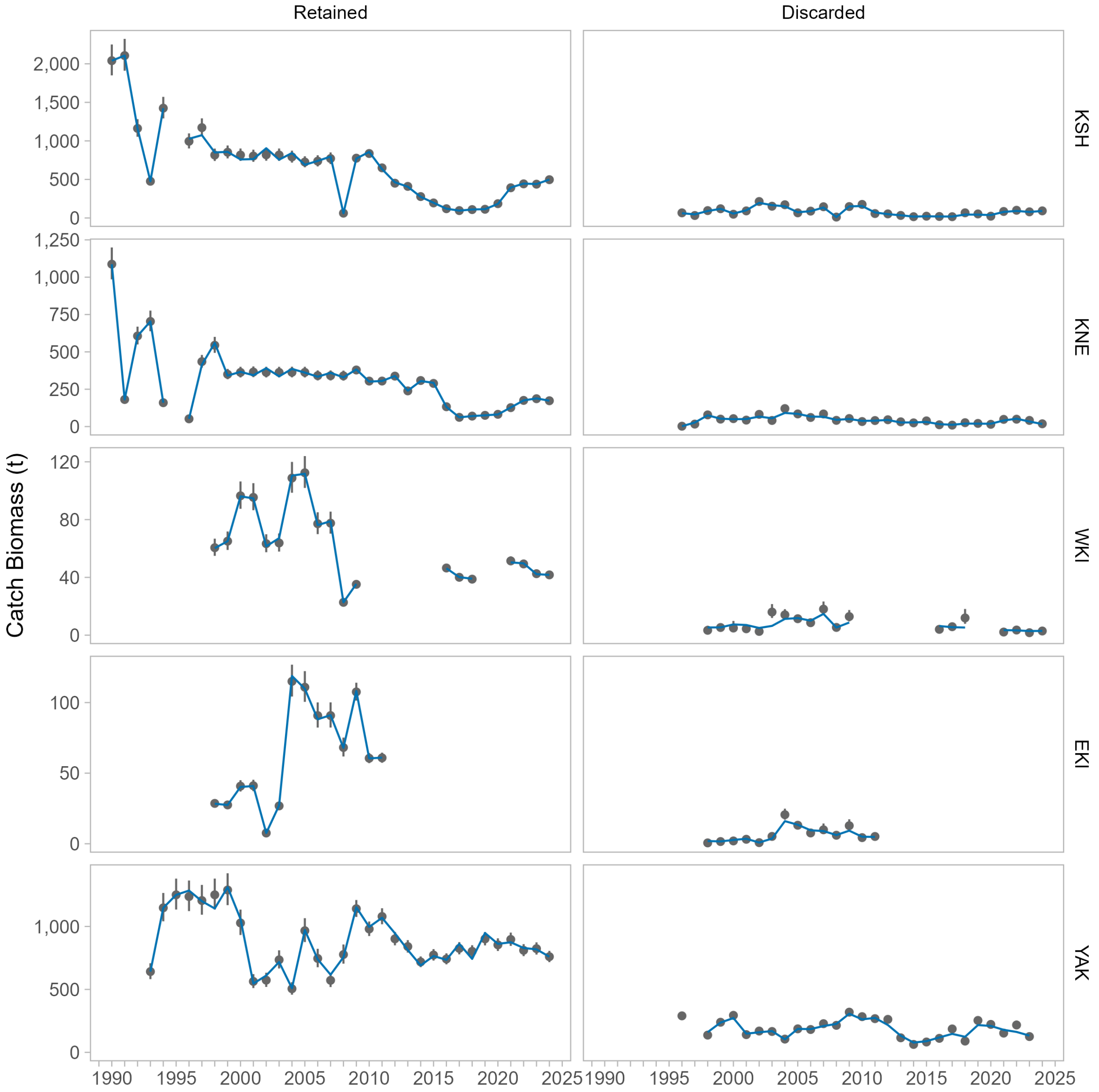

Figure 10: Fit to retained and discard catch data (t) by district.

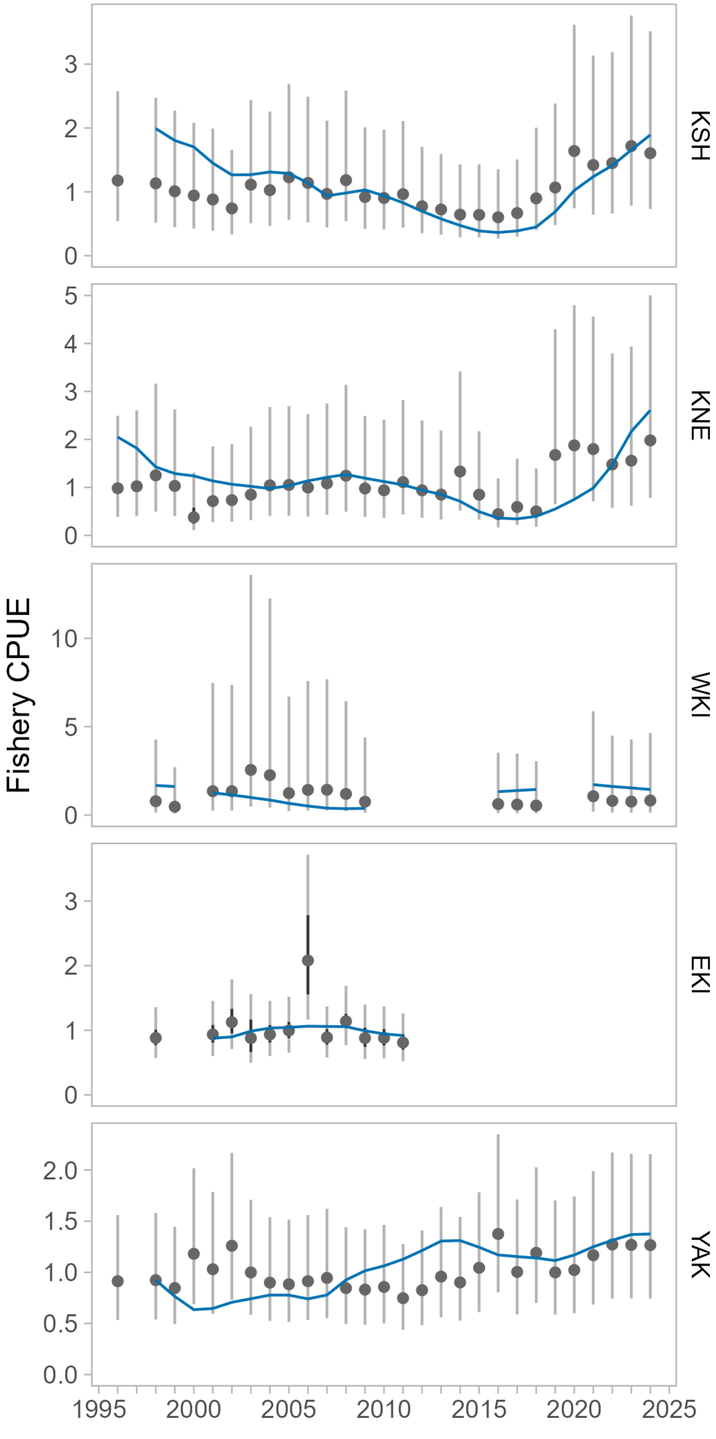

Figure 11: Fit to standardized fishery CPUE by district. Black error bars represent observed 95% confidence intervals and grey bars represent additional error as estimated by the model.

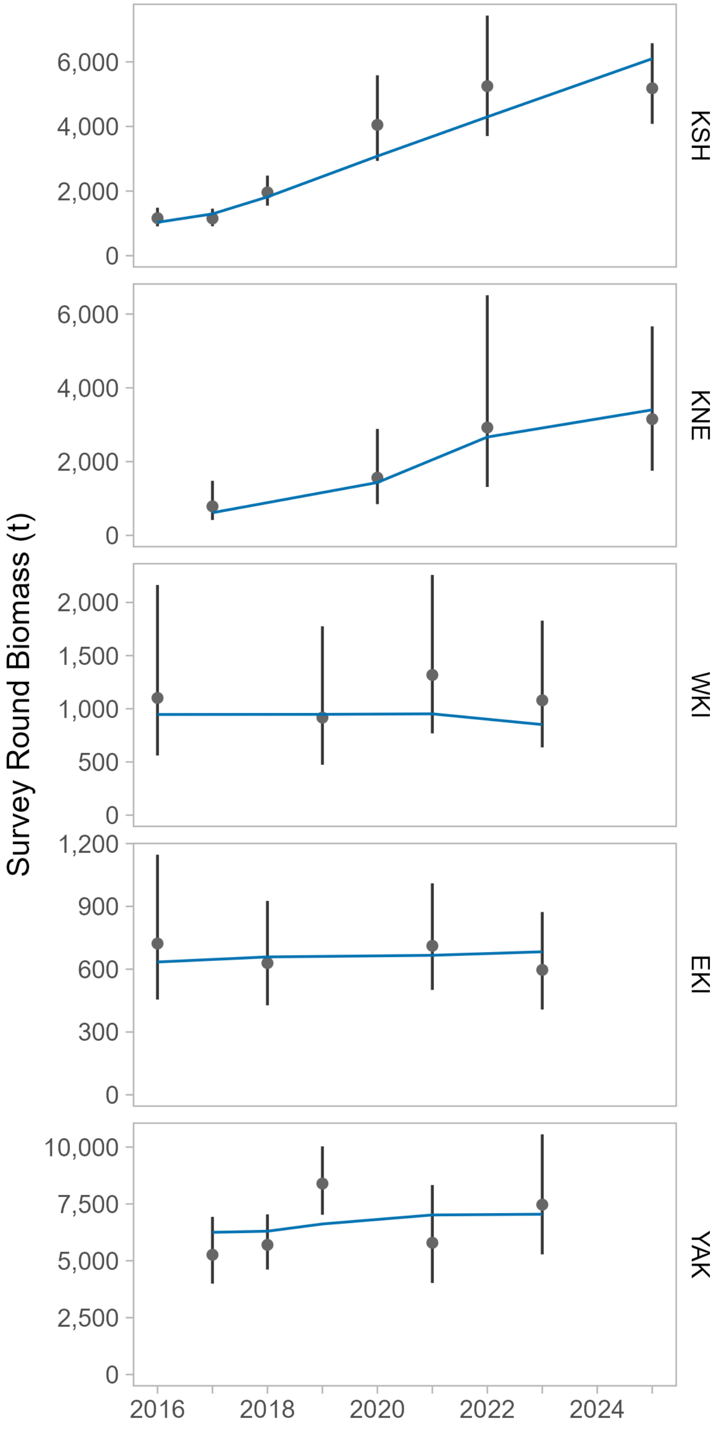

Figure 12: Fit to standardized fishery CPUE by district. Black error bars represent observed 95% confidence intervals.

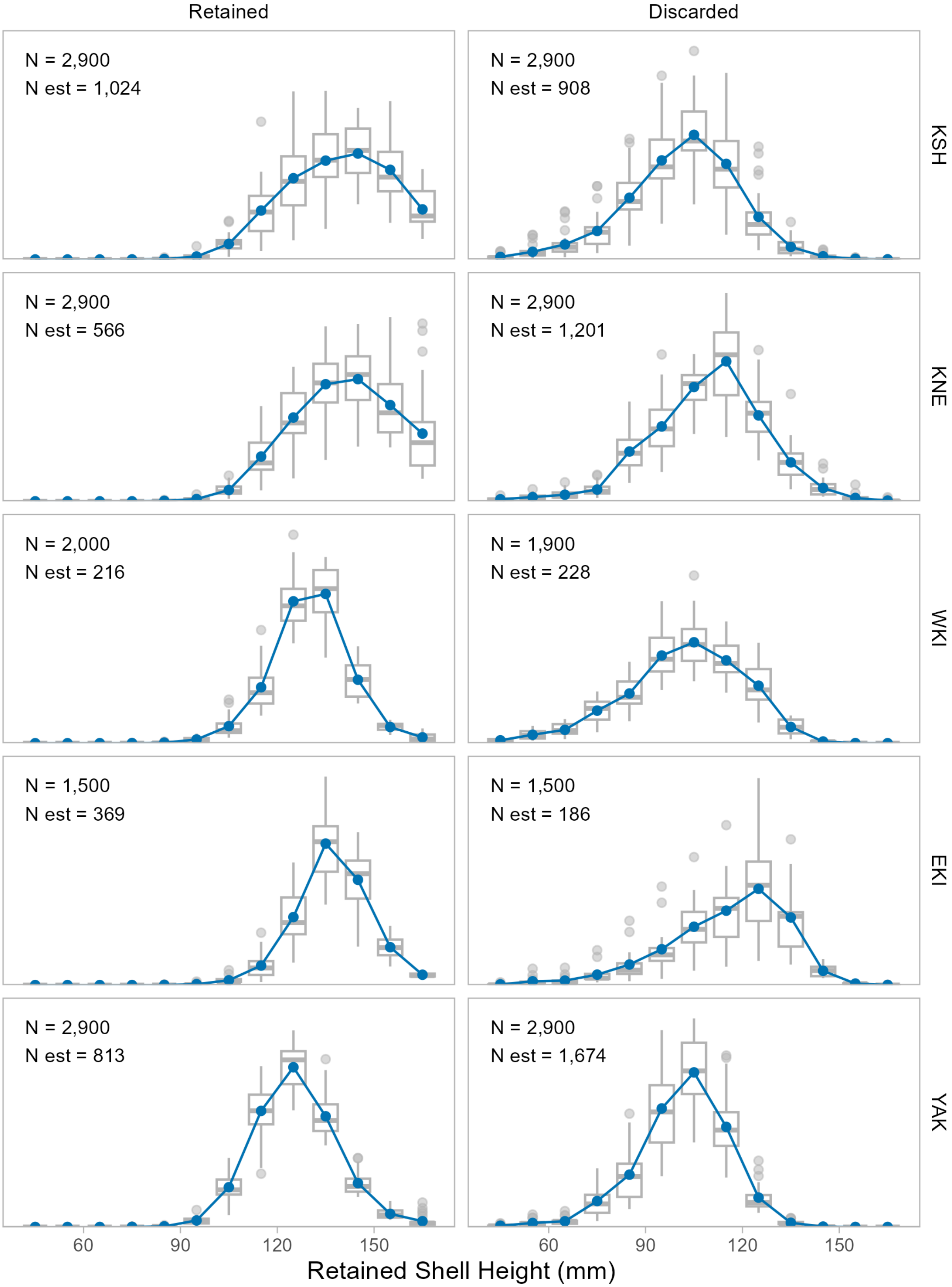

Figure 13: Fit to retained and discarded catch size composition data aggregated by district.

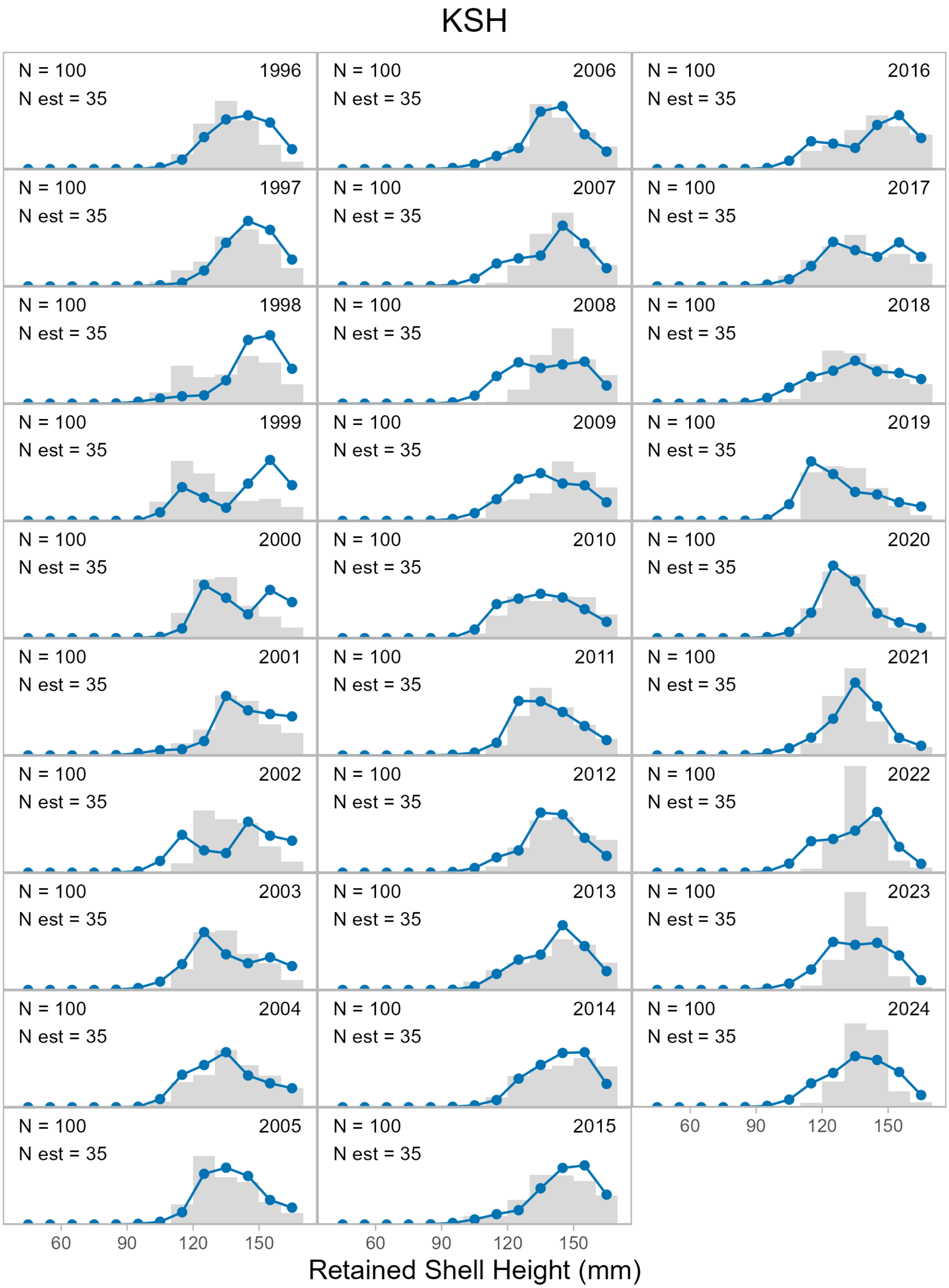

Figure 14: Fit to retained catch size composition data by year in the KSH district.

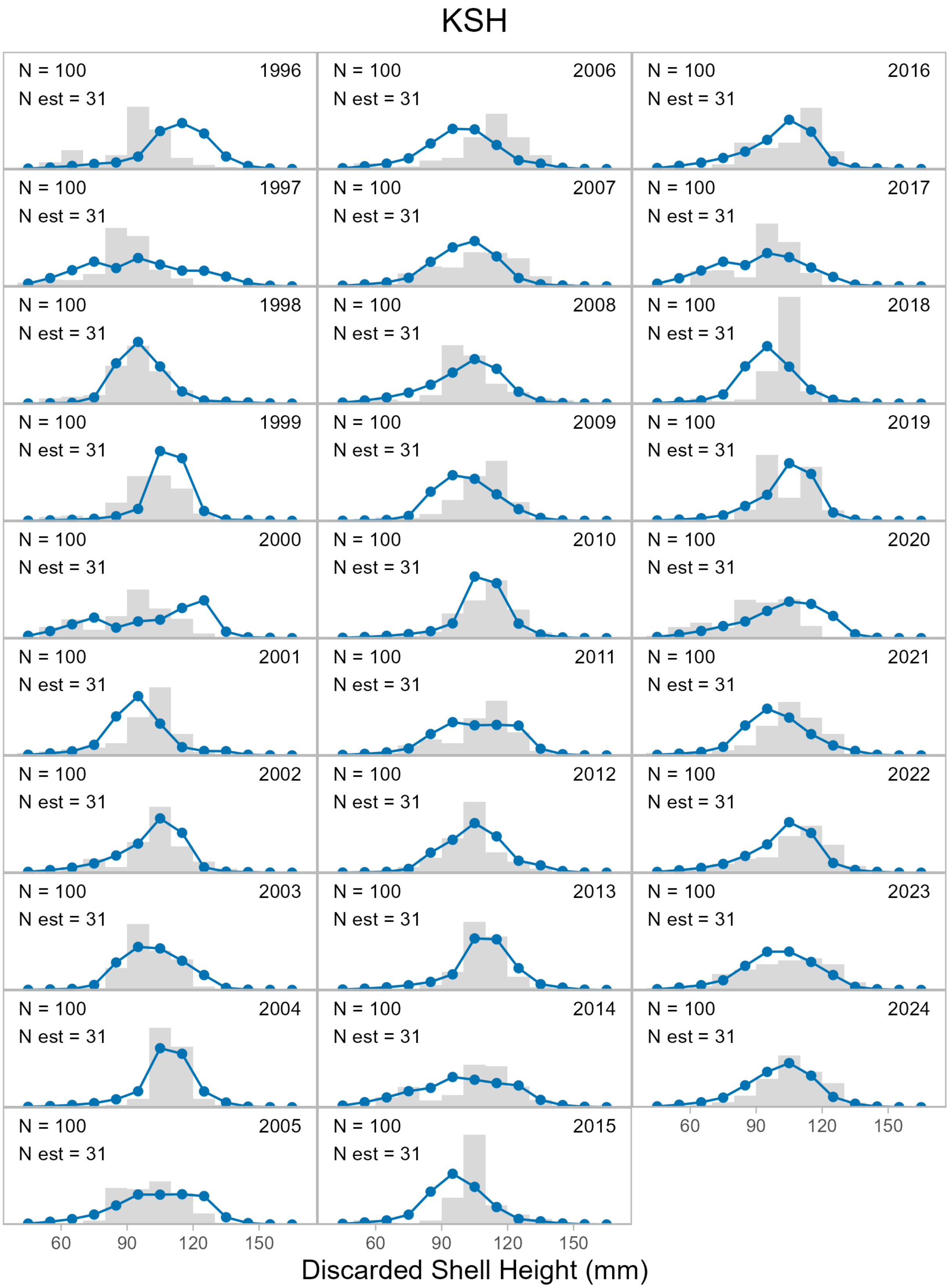

Figure 15: Fit to discardeded catch size composition data by year in the KSH district.

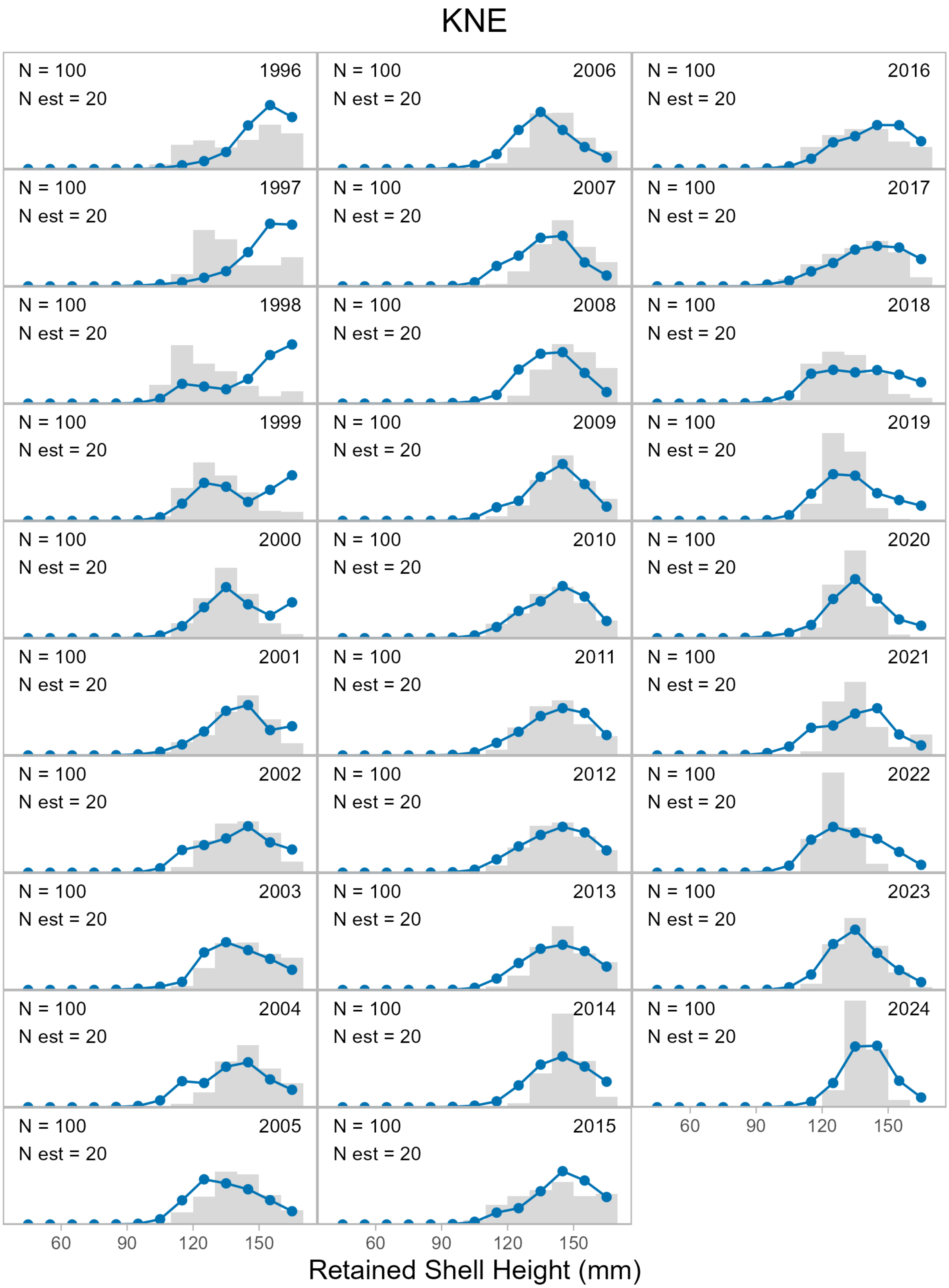

Figure 16: Fit to retained catch size composition data by year in the KNE district.

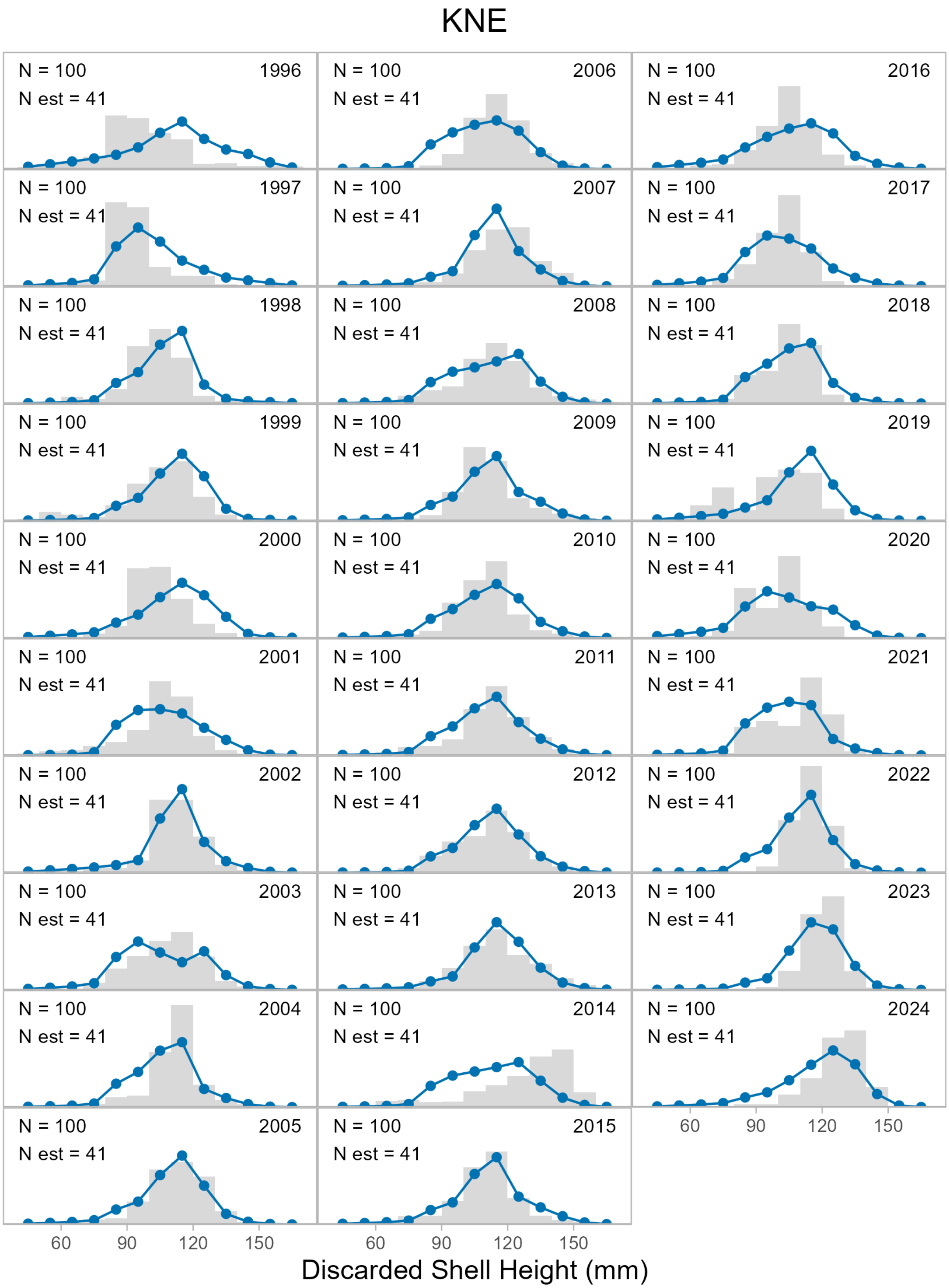

Figure 17: Fit to discardeded catch size composition data by year in the KNE district.

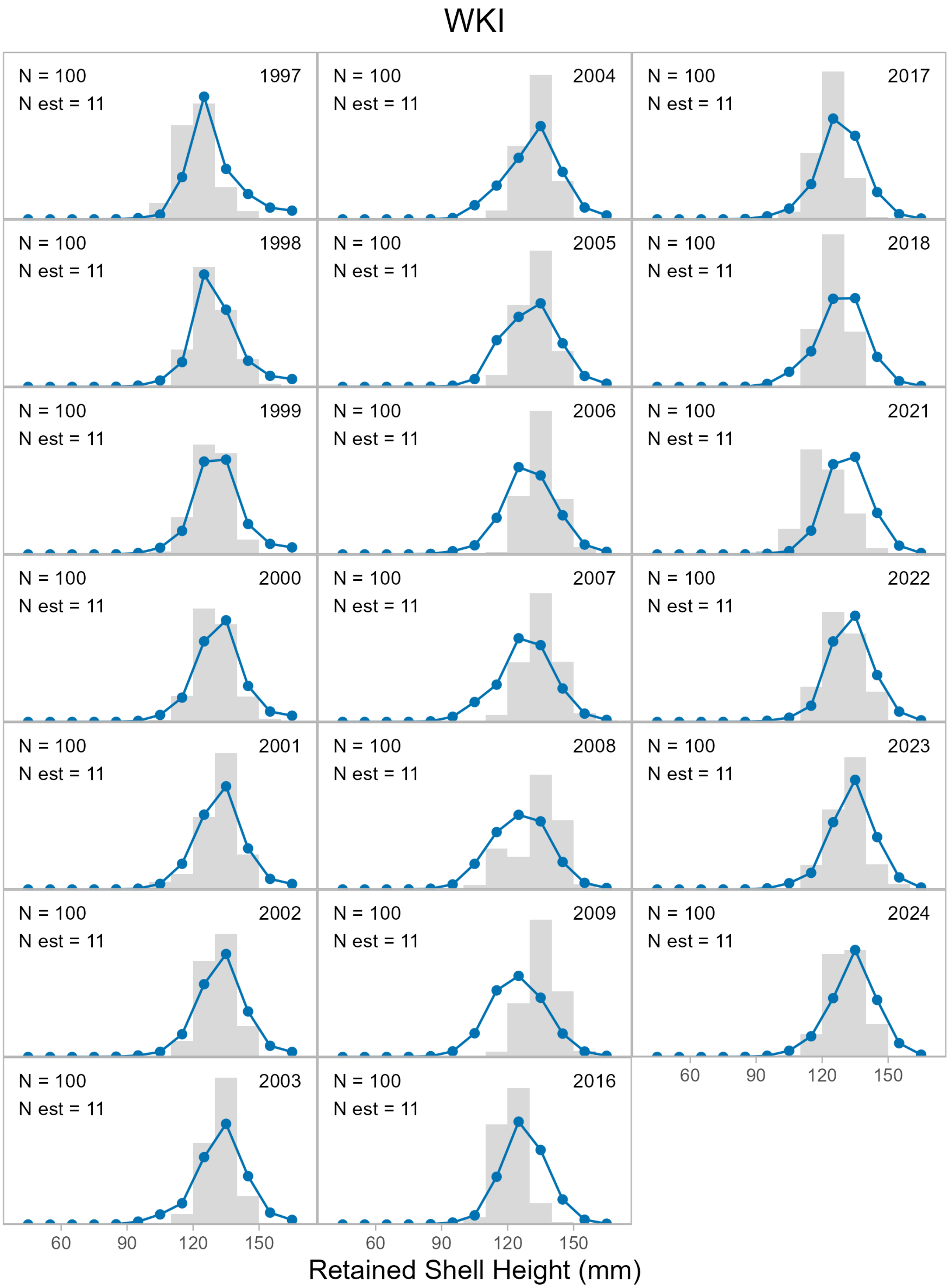

Figure 18: Fit to retained catch size composition data by year in the WKI district.

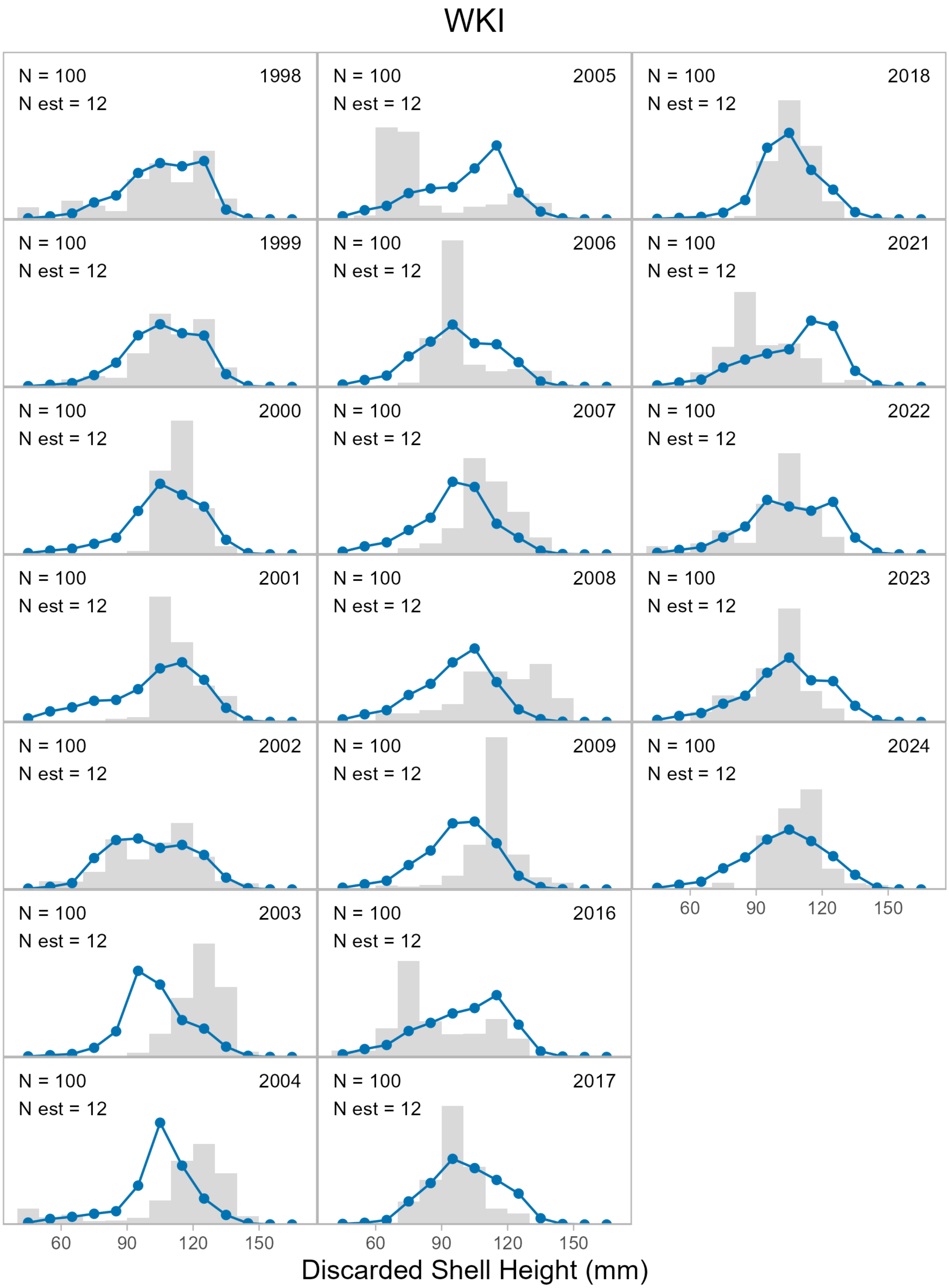

Figure 19: Fit to discardeded catch size composition data by year in the WKI district.

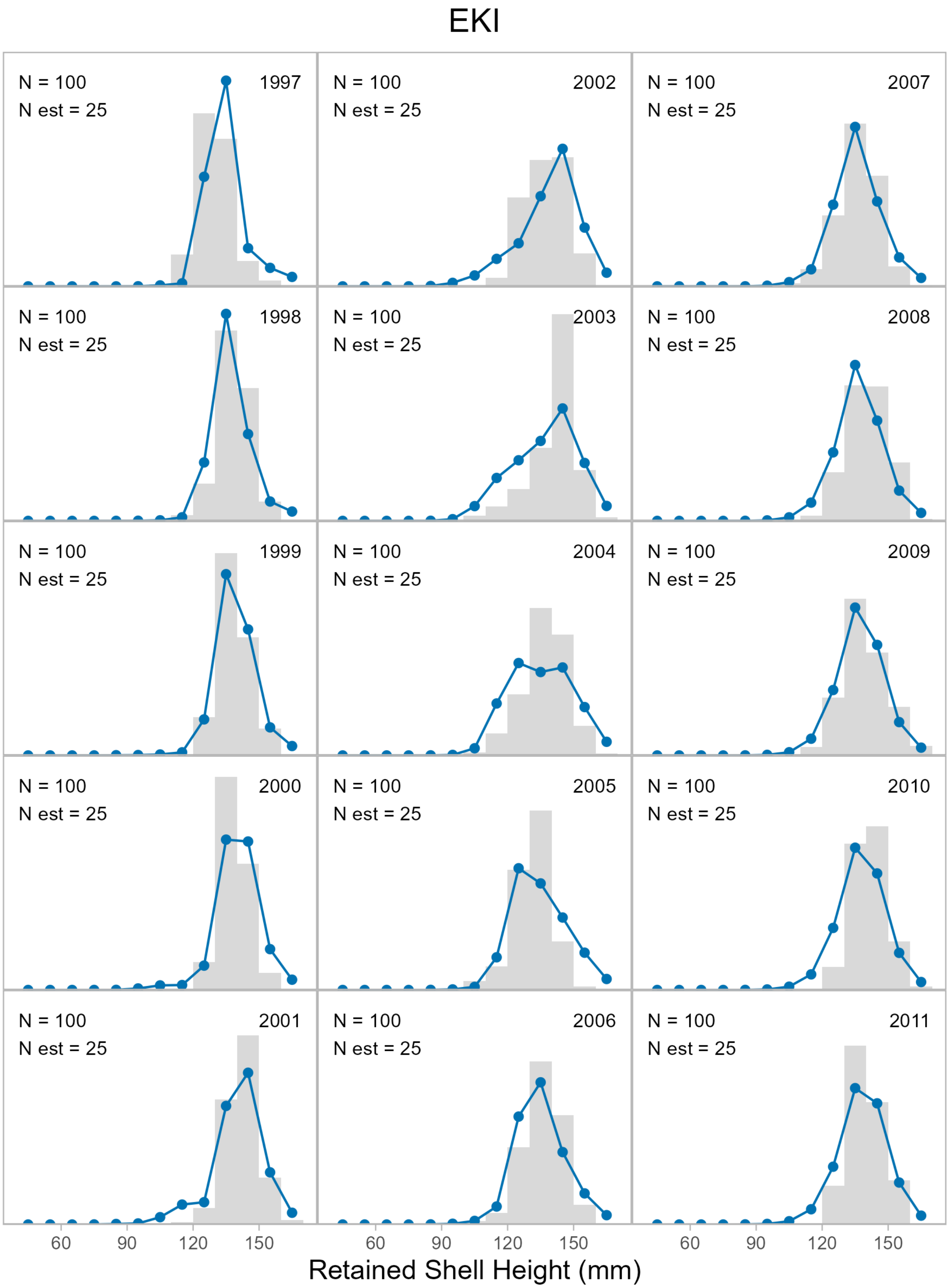

Figure 20: Fit to retained catch size composition data by year in the EKI district.

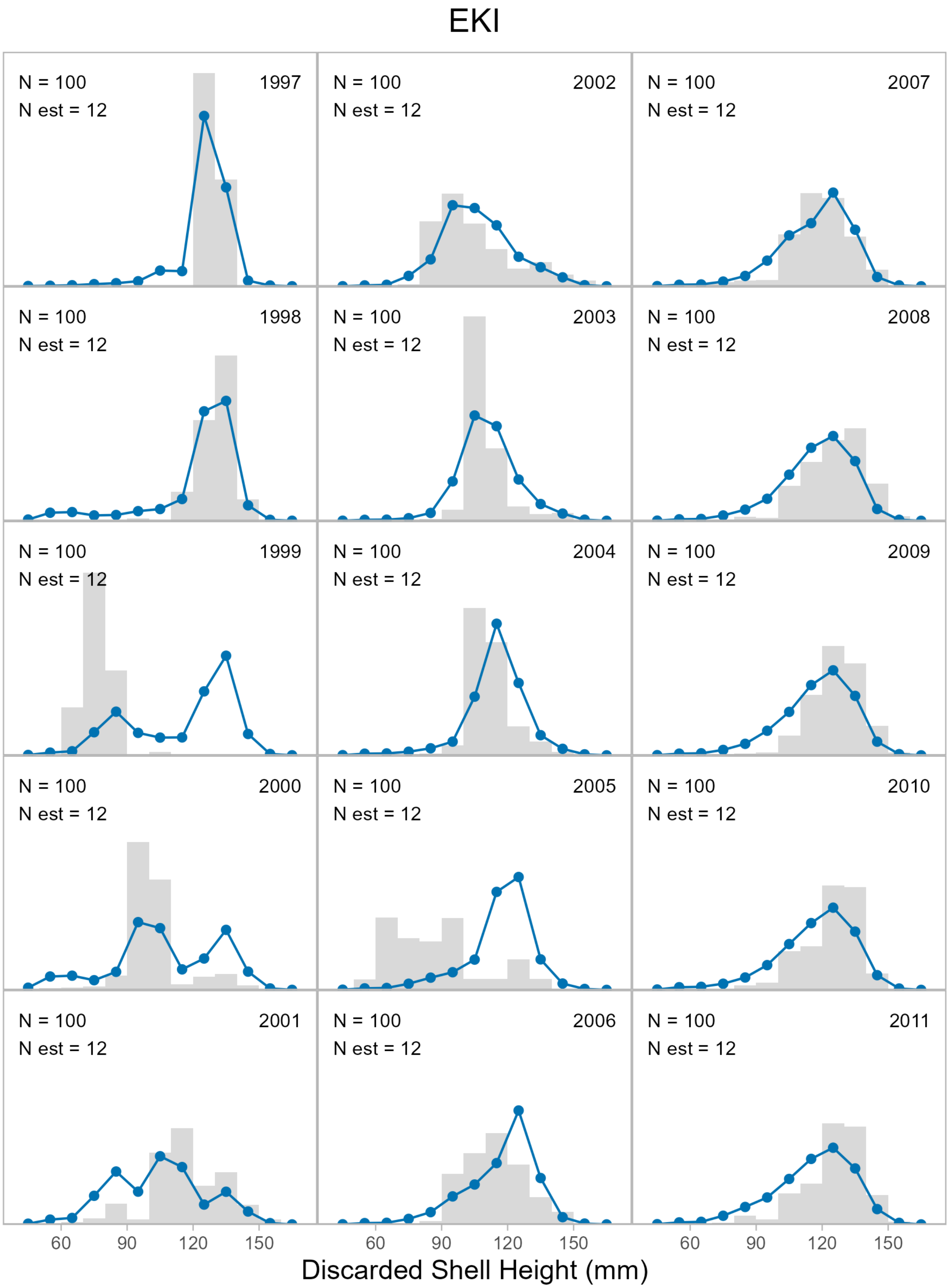

Figure 21: Fit to discardeded catch size composition data by year in the EKI district.

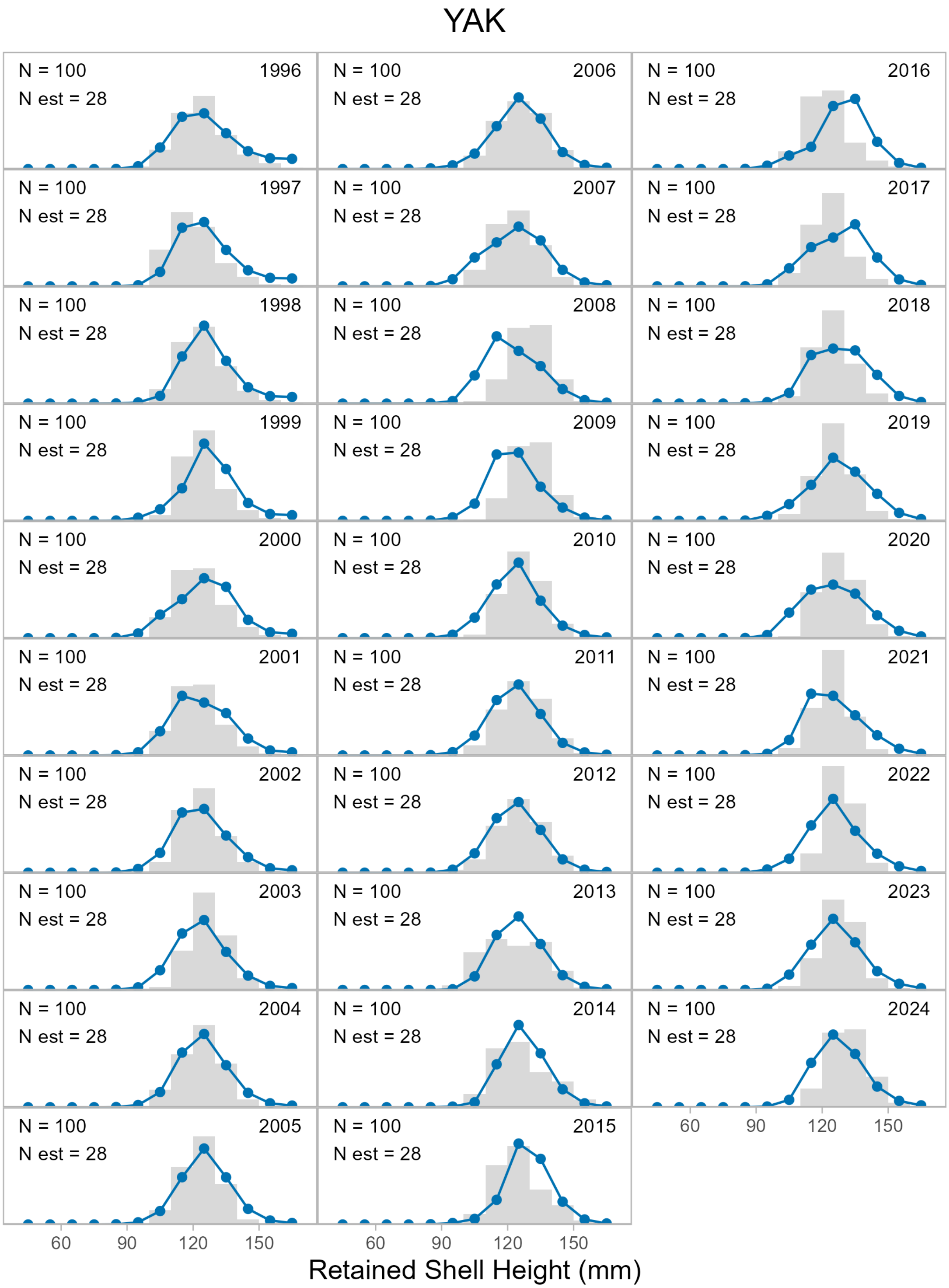

Figure 22: Fit to retained catch size composition data by year in the YAK district.

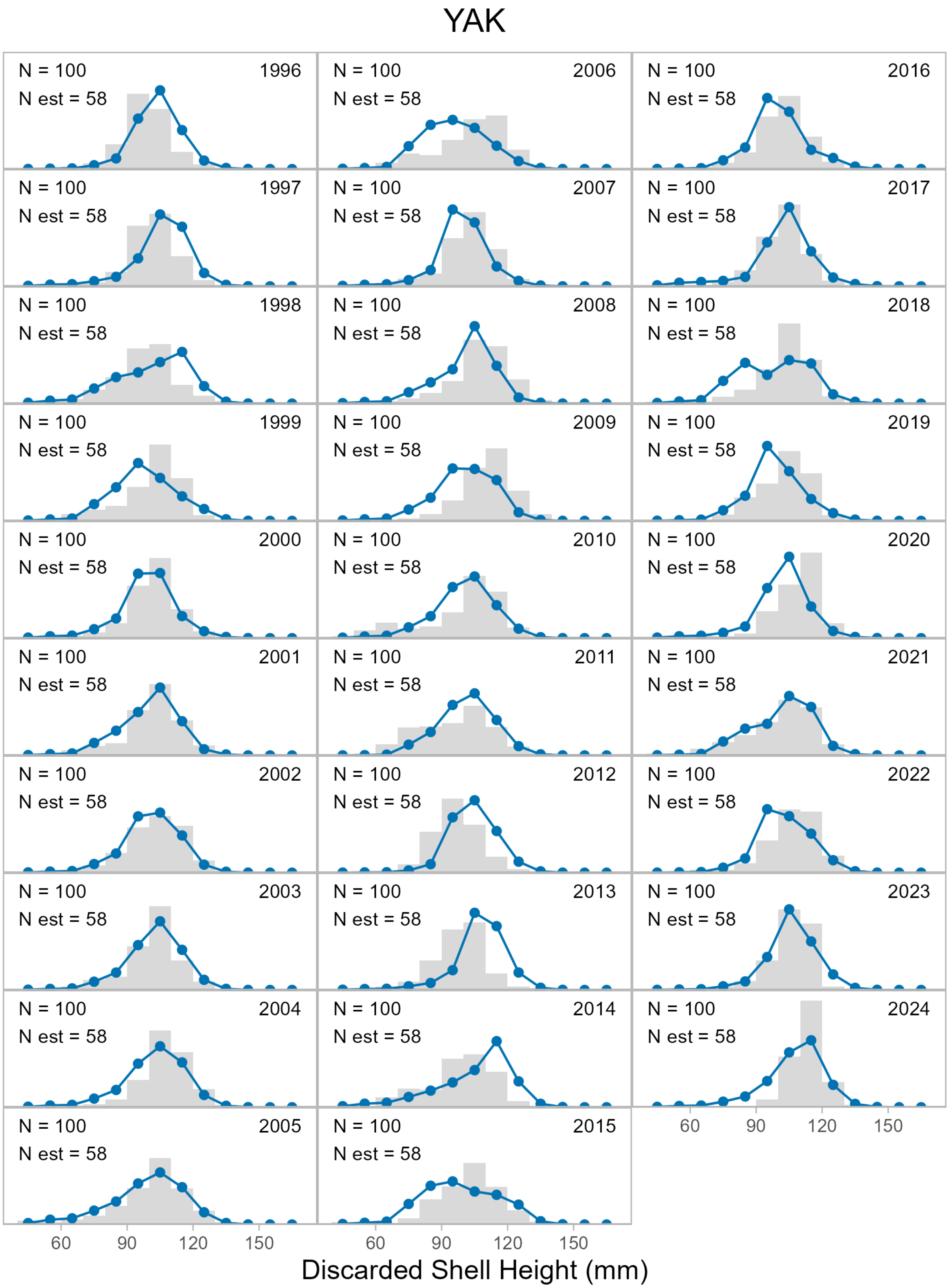

Figure 23: Fit to discardeded catch size composition data by year in the YAK district.

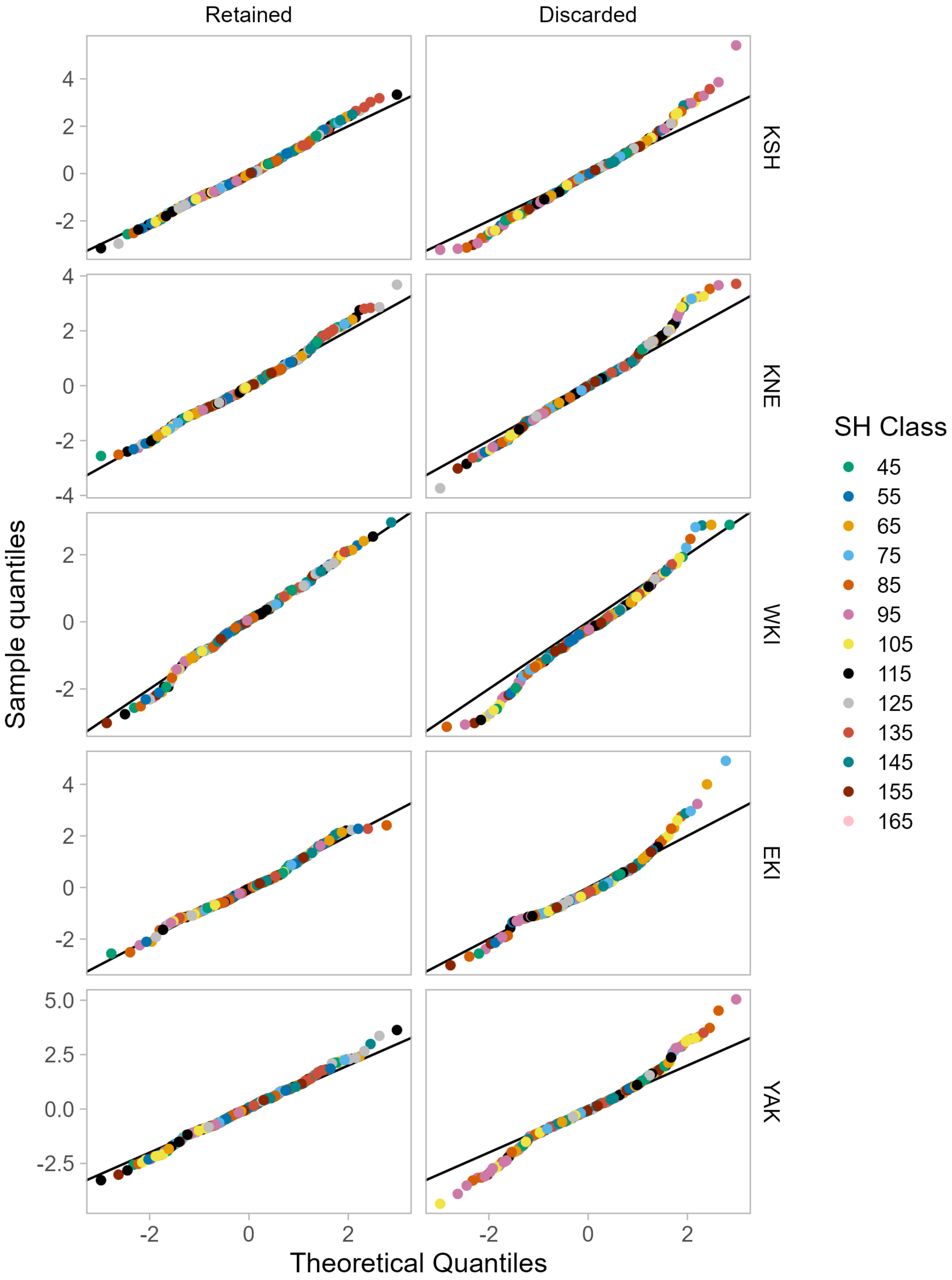

Figure 24: QQ plots of one-step-ahead residuals for retained and discarded catch size composition data by district.

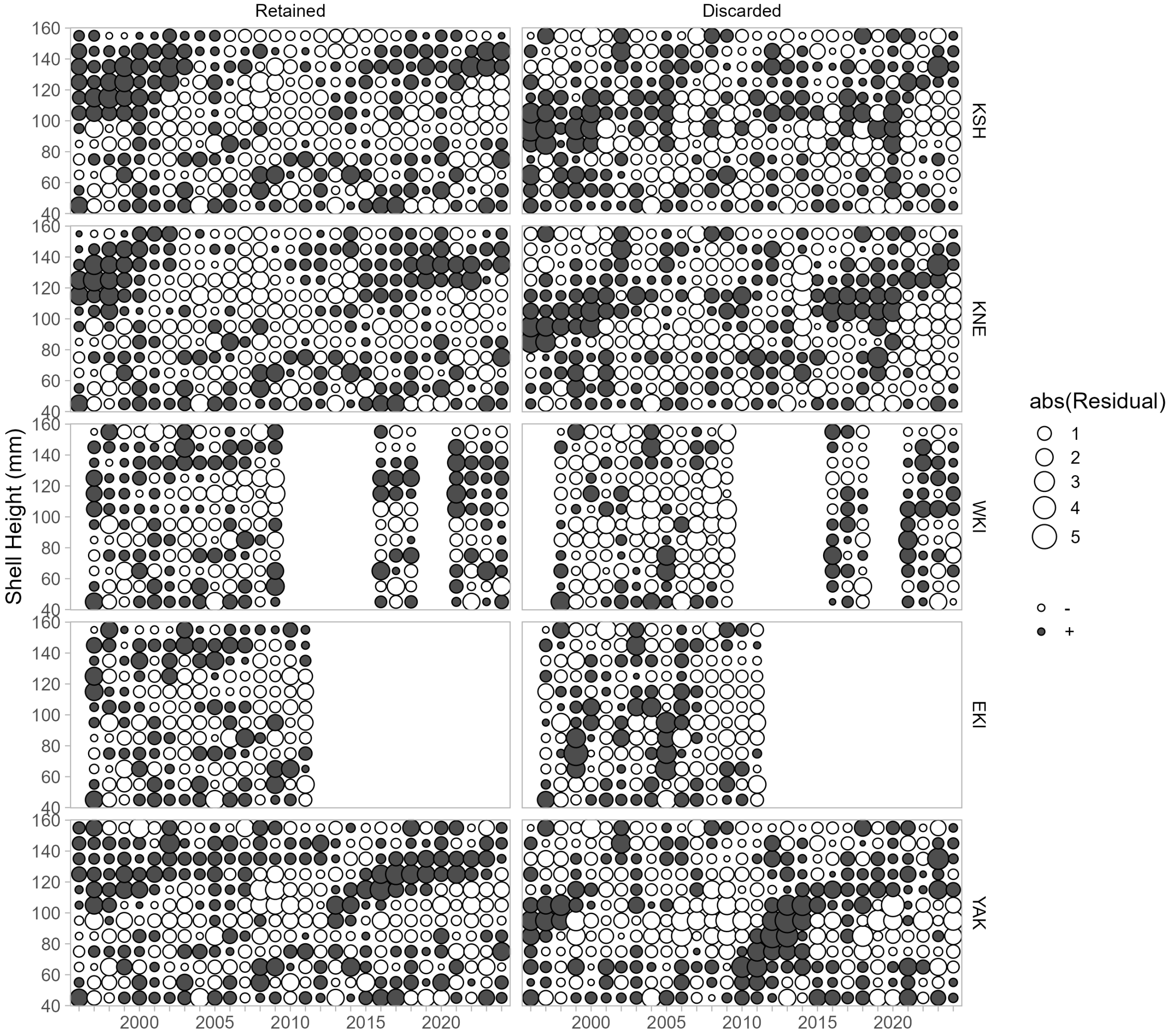

Figure 25: One-step-ahead residuals for retained and discarded catch size composition data by district.

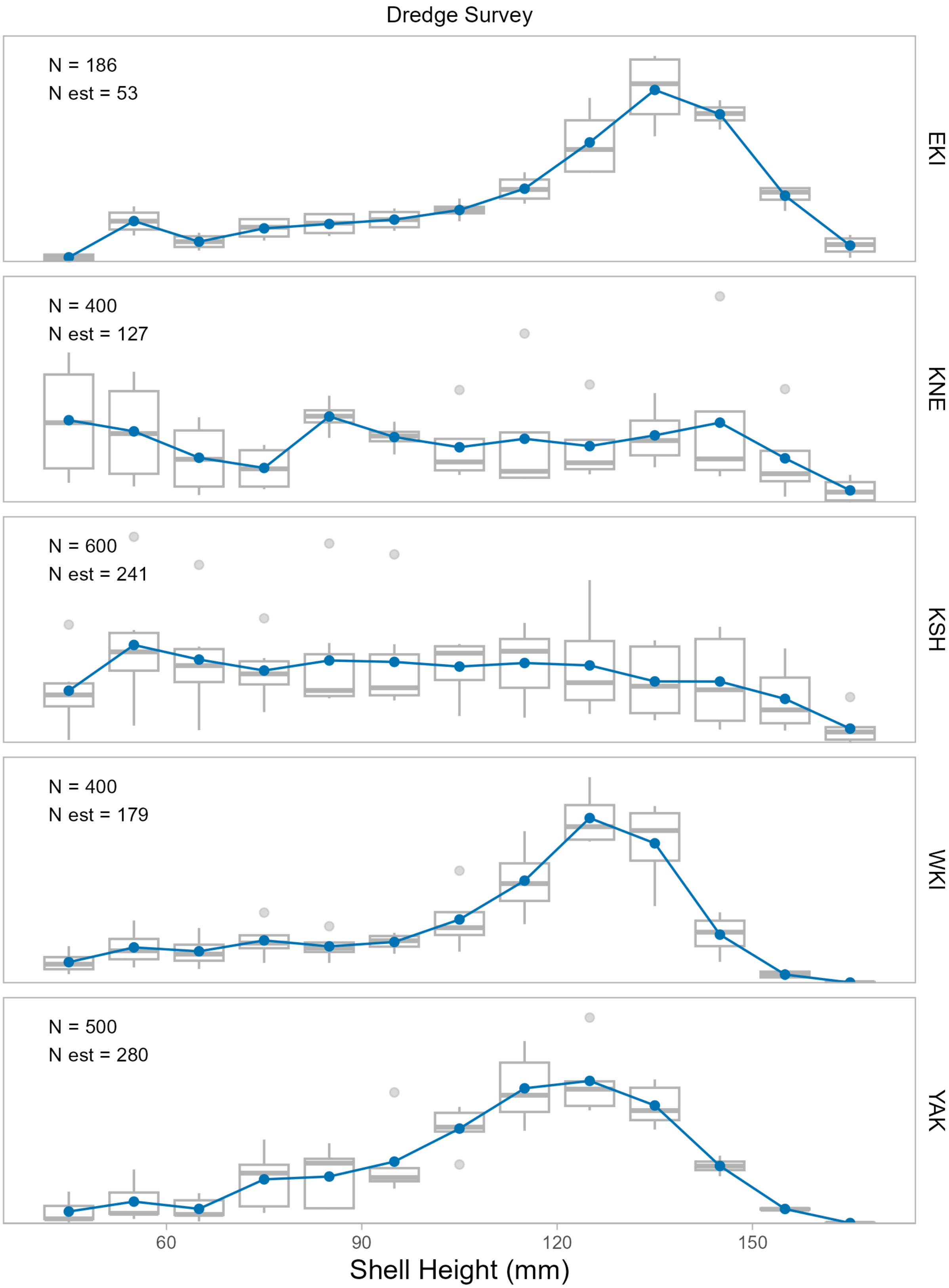

Figure 26: Fit to dredge survey size composition data aggregated by district.

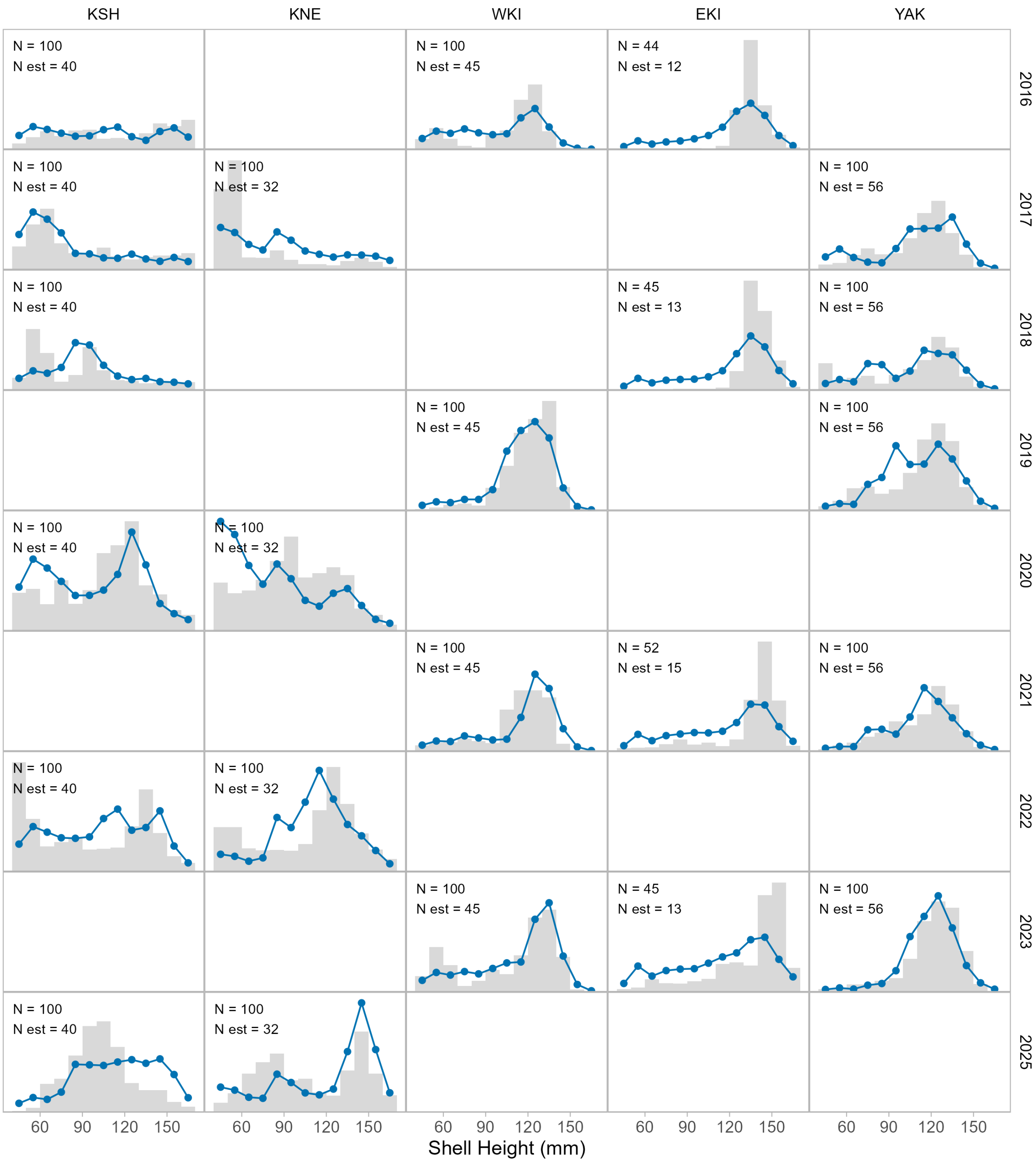

Figure 27: Fit to dredge survey size composition data by year and district. There was no dredge survey in 2024.

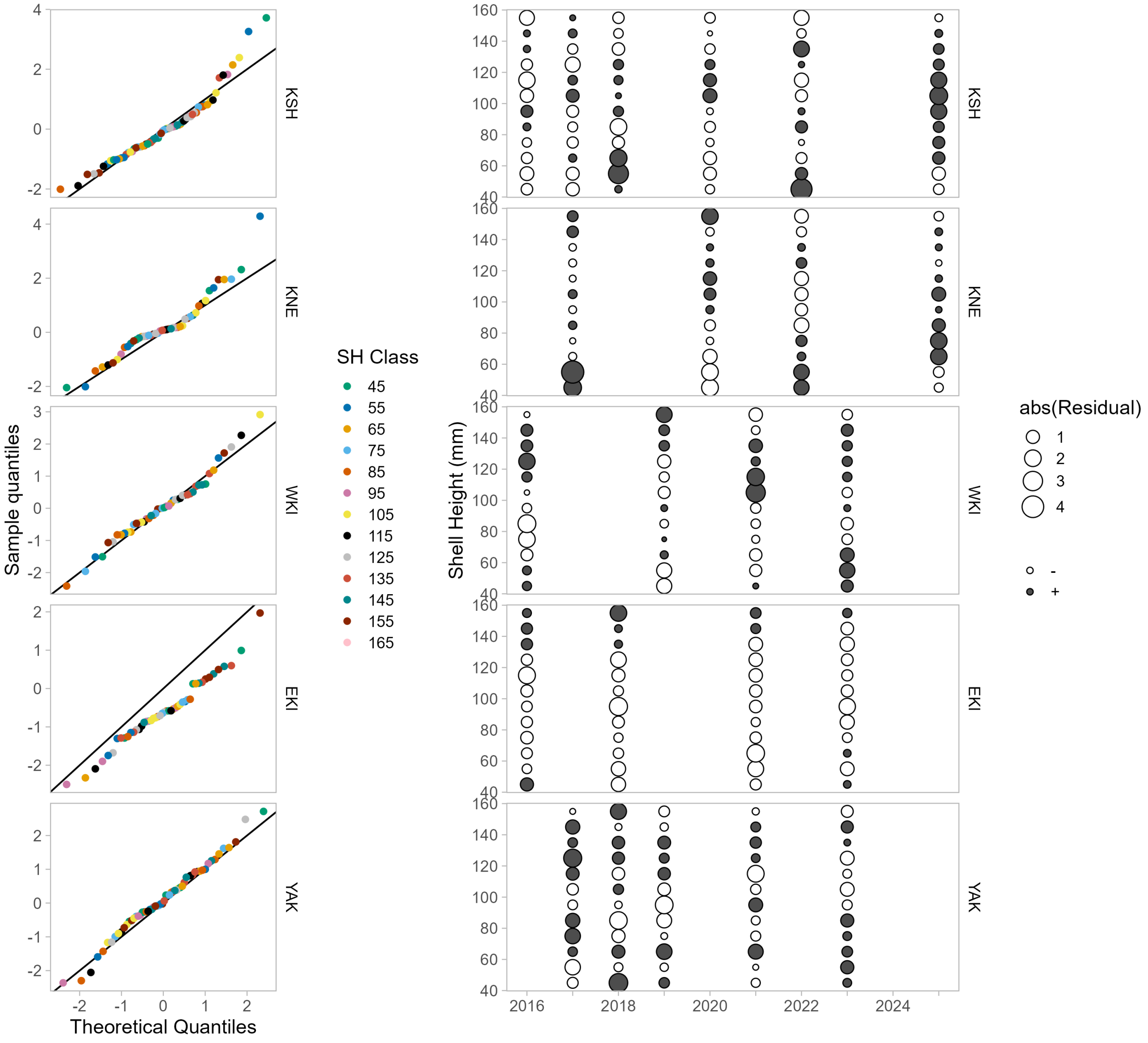

Figure 28: QQ plots (left) and associated one-step-ahead residuals (right) for dredge survey size composition data by district.

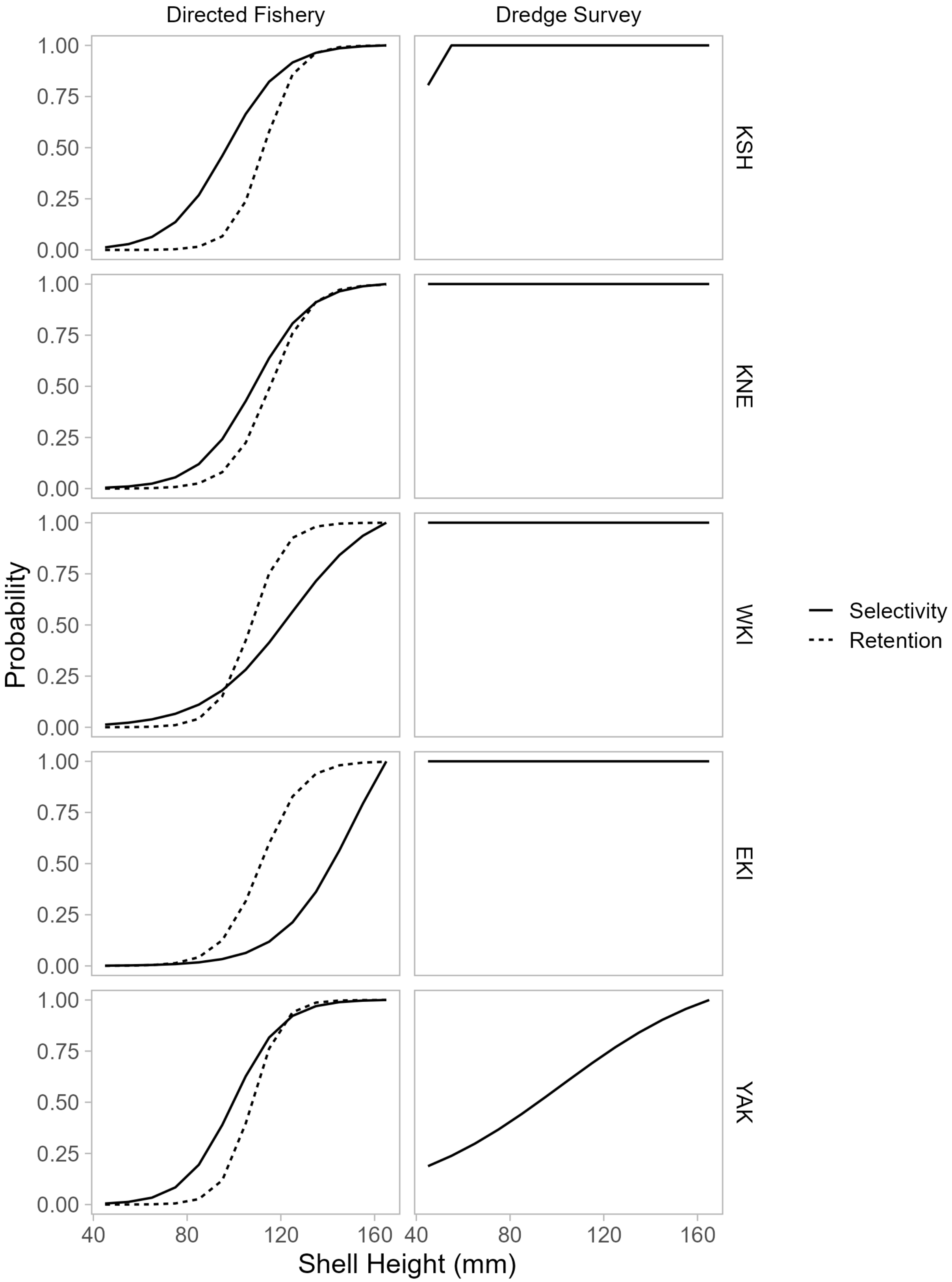

Figure 29: Estimated retention and selectivity for the directed fishery and dredge survey by district.

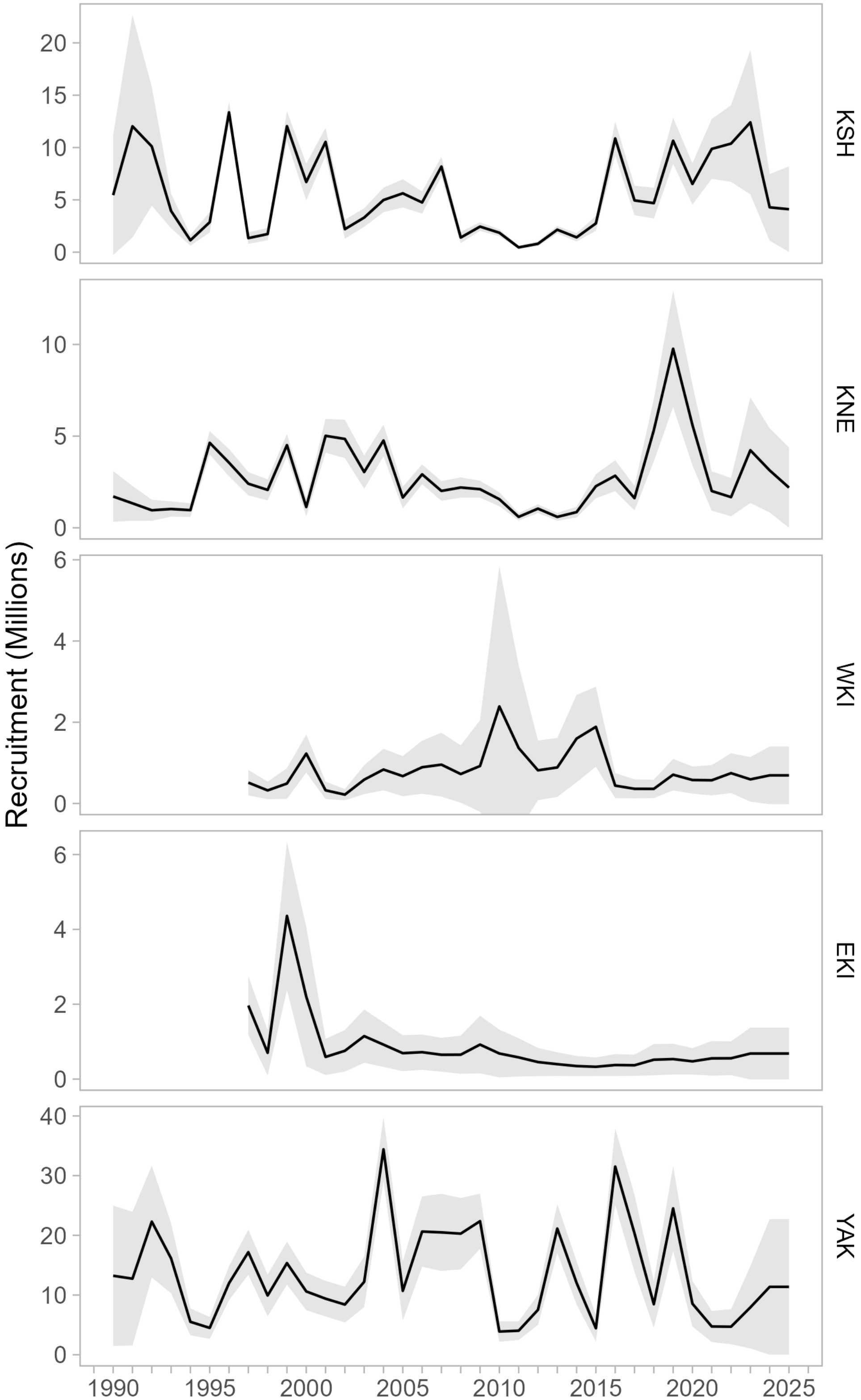

Figure 30: Estimated recreuitment and associated 95% confidence interval by district.

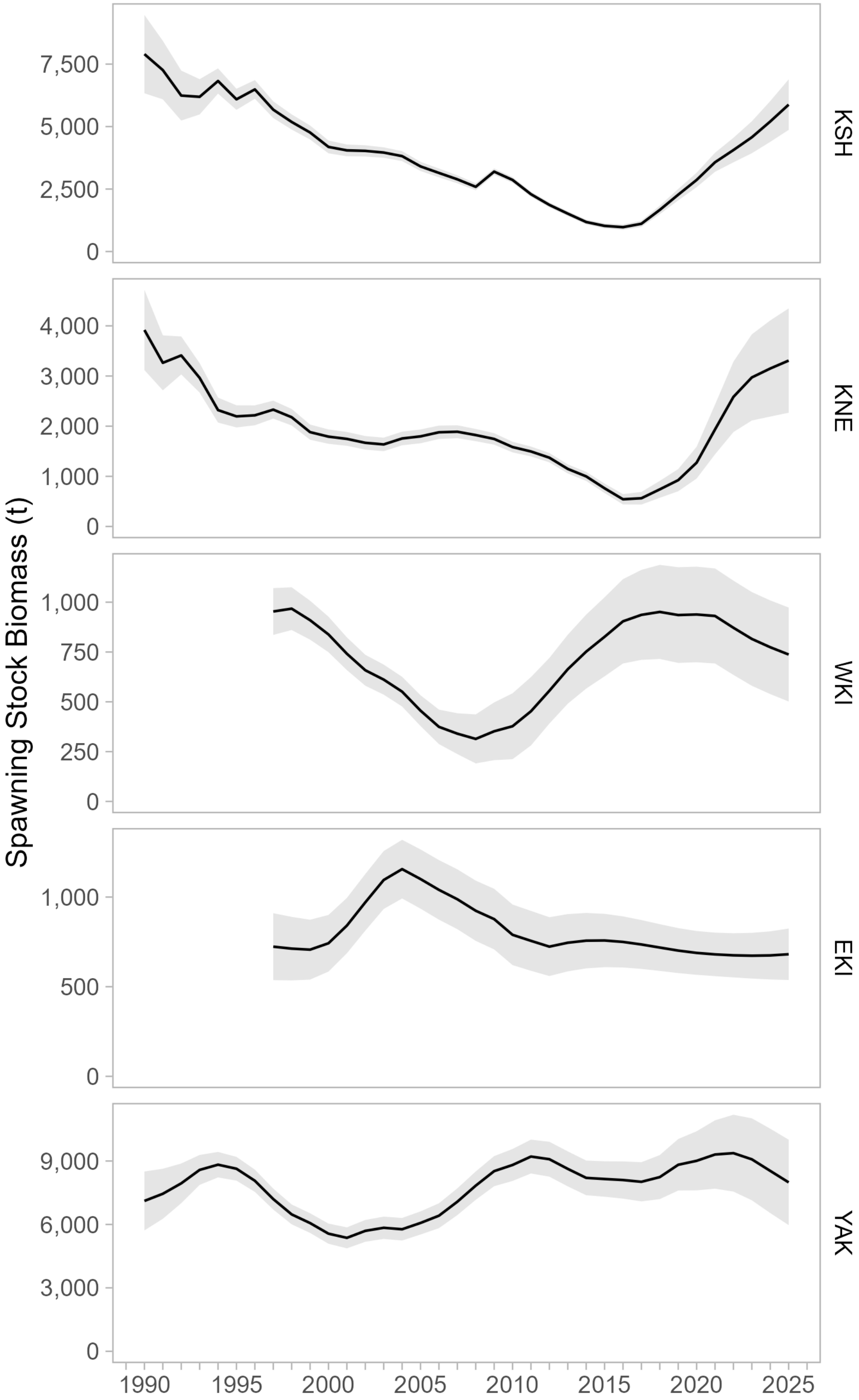

Figure 31: Estimated spawning stock biomass and associated 95% confidence interval by district.

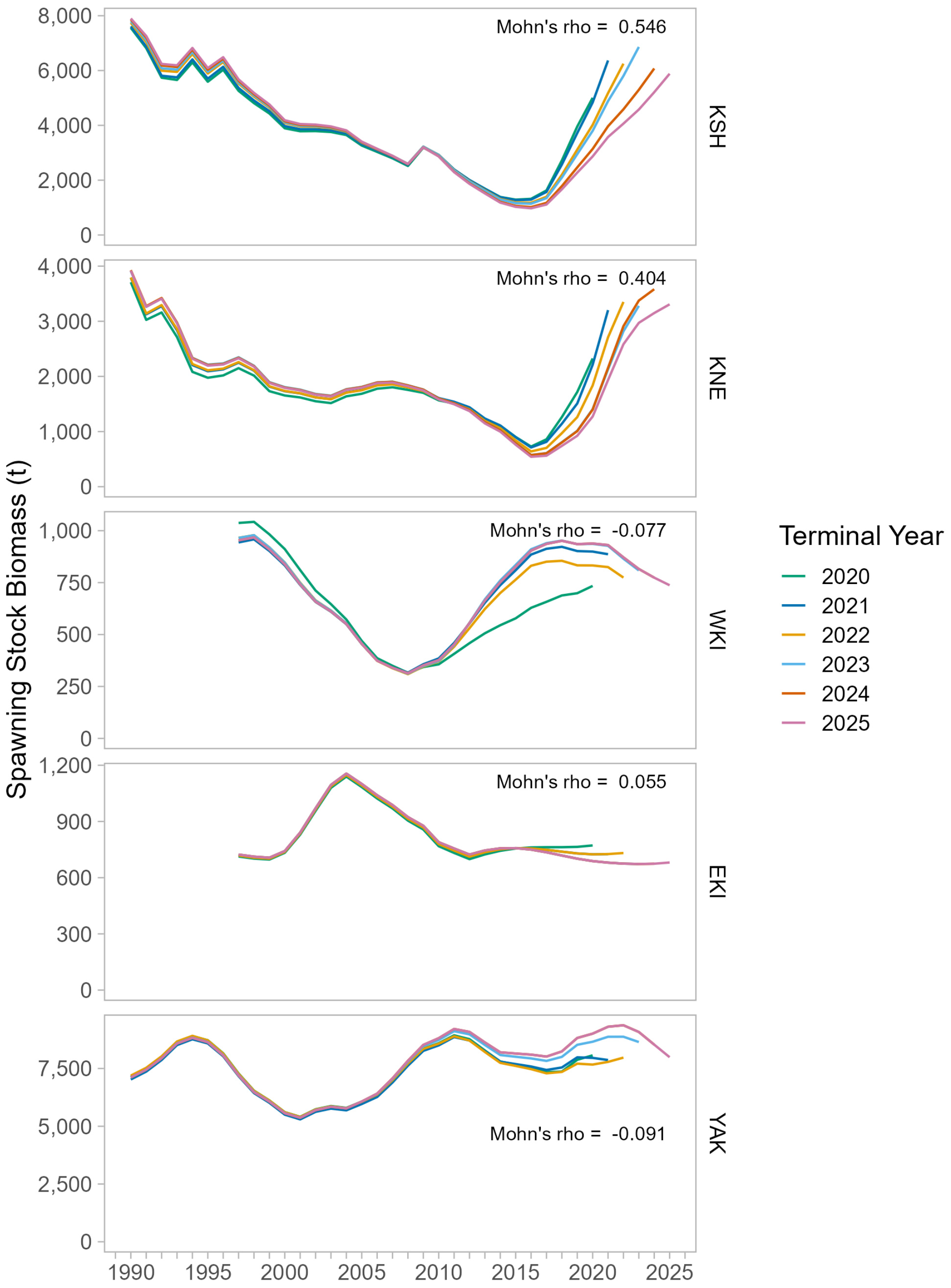

Figure 32: Retrospective pattern in spawning stock biomass and associated Mohn's rho given five peels by district.

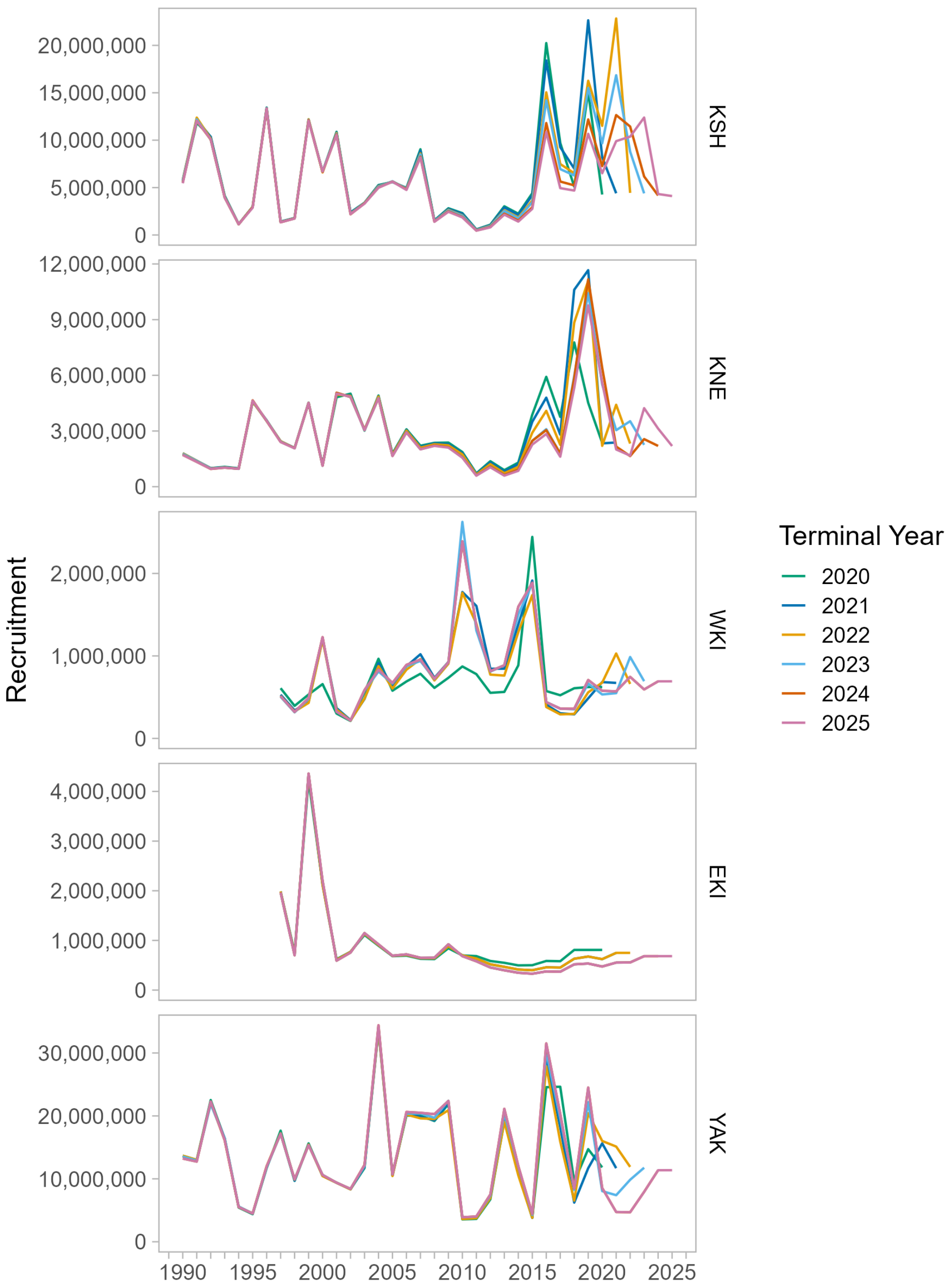

Figure 33: Retrospective pattern in recruitment given five peels by district.

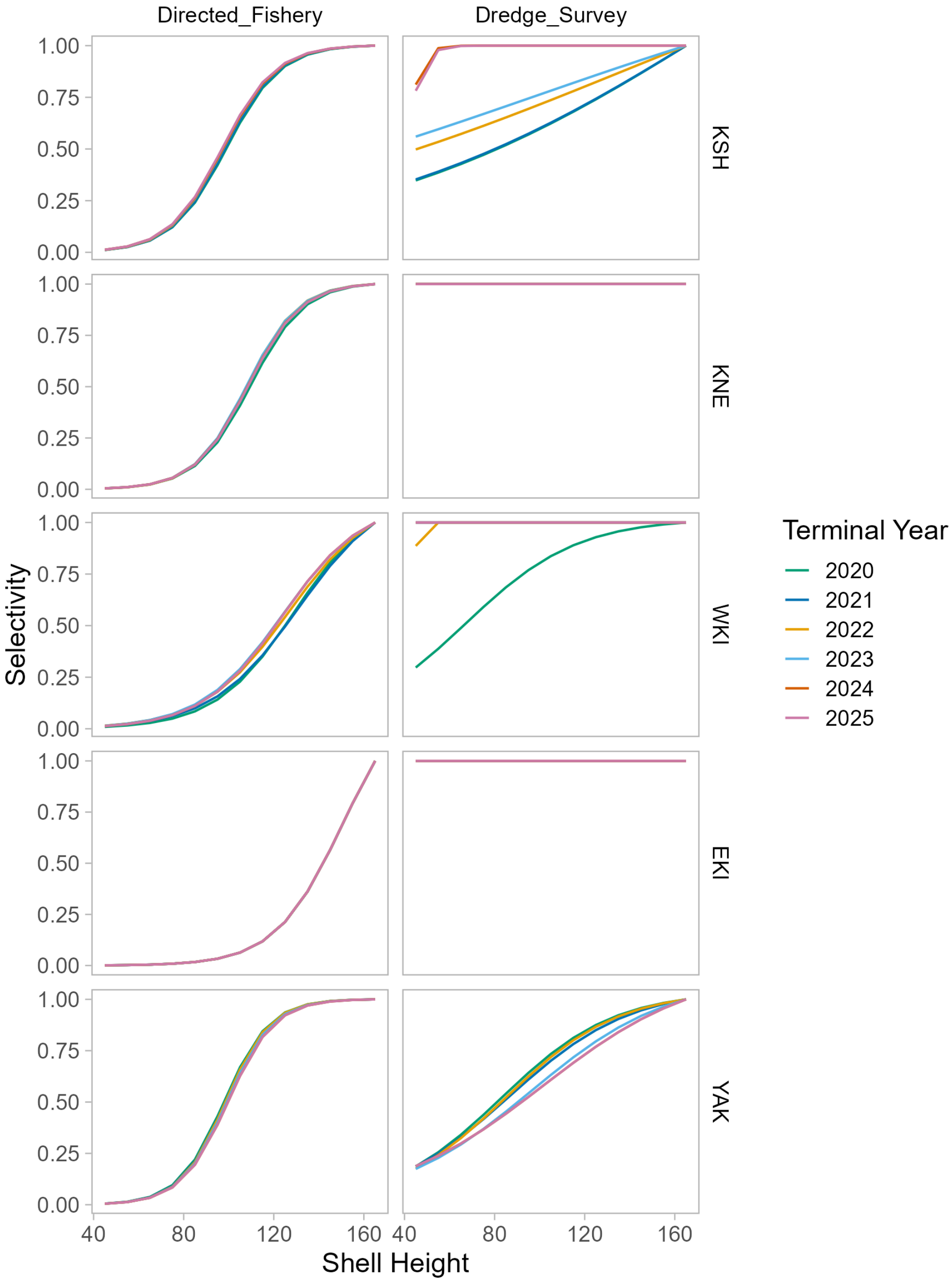

Figure 34: Retrospective pattern in selectivity given five peels by district.

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