Supporting Information

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Filtering Data and Grouping Permits into Strategies

We filtered the data in a number of ways before fitting our model. We began with 17.84 million rows of data. We removed revenue from permit–year combinations that made up $<10\%$ of annual revenue for a given permit holder. We removed permit holders whose median revenue was less than \$10,000 USD (adjusted to 2009 values) to focus on individuals actively engaged in commercial fishing. This reduced the total revenue from 42 billion 2009 USD to 41 billion 2009 USD.

To limit the number of permits and permit strategies and focus on the main fisheries, we removed all permits with <50 unique permit holders across all years. We also removed permits for freshwater species and for experimental fisheries. A list of all CFEC permit codes and descriptions is available at https://www.cfec.state.ak.us/misc/FshyDesC.htm.

We then proceeded to combine similar permits in the following steps. We combined a number of permits that were the same except for vessel size. We combined permits for otter trawl, longline finfish, pot gear, king crab, and shrimp. We grouped a number of permits that were targeting a single species and differed only in region fished. For example, someone fishing herring roe in Kodiak (G34K) and someone fishing herring roe in Alaska Peninsula (G34M) were both considered to have a herring roe permit strategy. We combined permits across each of the following: Dungeness crab, herring roe purse seining, herring roe gillnet, herring hand picked, herring pound fishing, sea cucumber, sea urchin, and tanner crabs.

Combining salmon permits was more difficult because the species composition varies widely based on geography. We grouped salmon permits within gear type–region combinations that shared similar species composition. For the drift gillnet (S03) permits, we combined permits from Cook Inlet, Bristol Bay, and Alaska Peninsula because sockeye represents $>90\%$ of species revenue. For the purse seine permits (S01), there was a wide variety in species revenue by area ($\sim$85% pink salmon in Prince William Sound to 85% sockeye salmon on the Alaskan Peninsula). Of the five permits, only two had similar species compositions, so we grouped Kodiak and Cook Inlet. For the set gillnet salmon permits (S04), there was some variety but also clear sockeye specialists. We grouped permits that had $>80\%$ sockeye revenue. This combined permits across Prince William Sound, Cook Inlet, Kodiak, Alaska Peninsula, and Bristol Bay. We grouped permits from Norton Sound and Kuskokwim because of similar species compositions. The remaining salmon permits were relatively unique and were left ungrouped.

After this process of combining permits, we were left with 23 unique fishing strategies (Table S1), which we aggregated within each person–year combination. For example, if someone fished halibut and sablefish in the same year, their strategy for that year would be halibut-sablefish. We removed data for pairs of years in which people switched strategies from one year to the next since we were working with changes in revenue from year to year and so needed consistent strategies across any pair of years for a permit holder. We removed strategies with <100 unique permit holders across all years to focus on the major strategies, leaving us with a total of 34 (unique or combined) strategies. Finally, we removed all person–year combinations without revenue recorded in the following year, to calculate percent change in revenue from year to year. This reduced the rows (person–year combinations) in the final dataset from 347,111 to 280,807.

Model Checking with Two-Stage Approach

We checked our models with a two-stage modeling approach using the R package lme4 (50). To do this, we fit the initial model of the mean component $\log(R_{i,t})$ and then fit the second model to the log absolute value of the residuals, $\log|\widehat{\log(R_{i,t})} - \log(R_{i,t})|$. Most importantly, (*i*) this model does not carry uncertainty from the first mean component model to the variance component model, but (*ii*) it also leaves the residuals in the mean component model strongly heteroskedastic and therefore improperly weights individual data points, and (*iii*) does not allow for proper modeling of the strategy-level predictors, η_1 and η_2. Nonetheless, it provides a check that our results from the Stan model are approximately correct and allows us to quickly iterate and build intuition about the models. A version of the Stan model without the variance component matched the estimates of the same model in lme4 almost exactly.

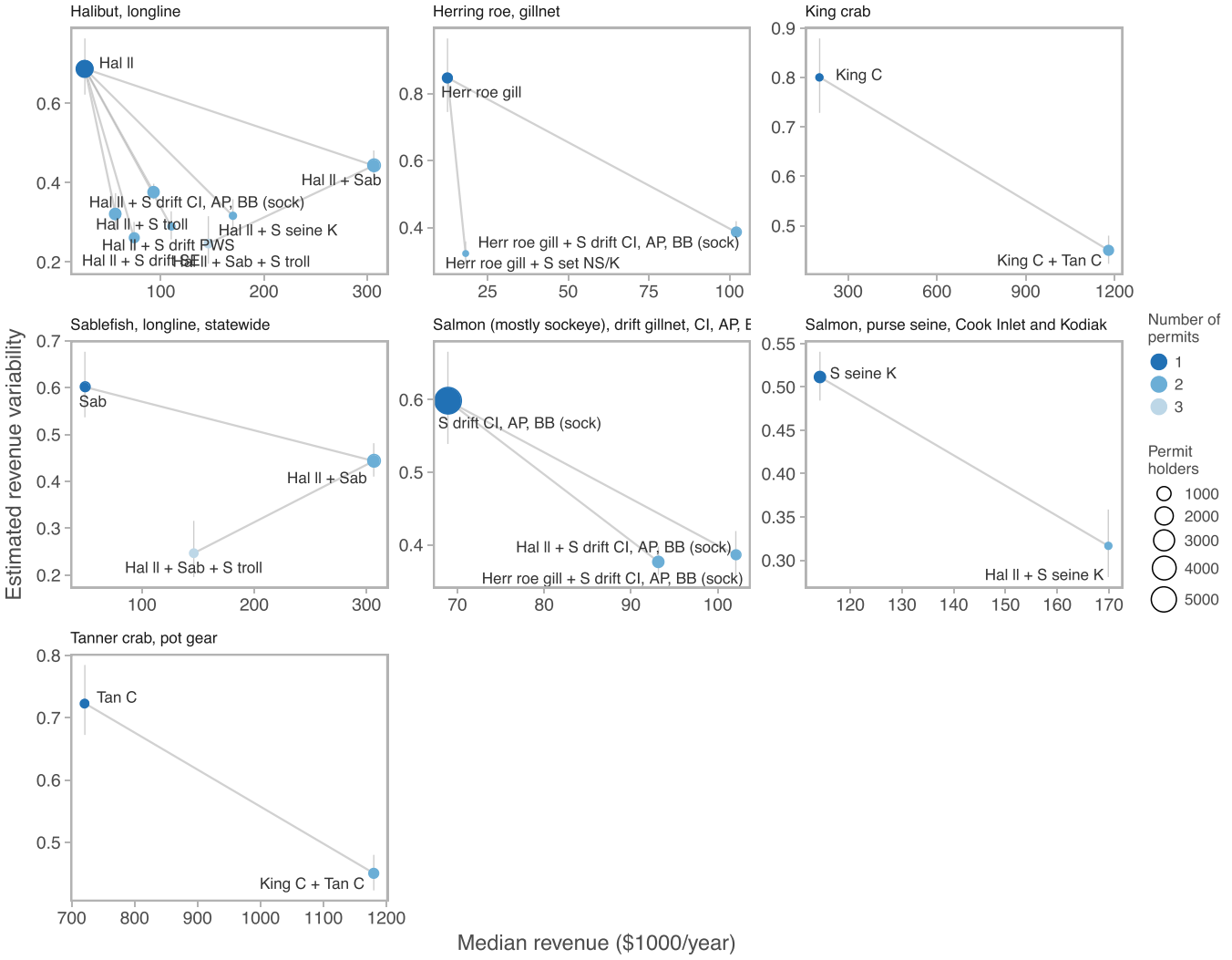

Fig. S1. The effect of adding a permit to one's strategy on estimated revenue variability and median revenue. This is an extended version of Fig. 2 that includes all major strategy combinations. Species groups: Dun C, dungeness crab; Fin, finfish; Hal, halibut; Herr, herring; King C, king crab; S, salmon; Sab, sablefish; Sea cuc, sea cucumber; sock, sockeye salmon; Tan C, tanner crab. Gears: drift, drift gillnet; gill, gillnet for herring; ll, longline; otter, otter trawl; set, setnet. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.

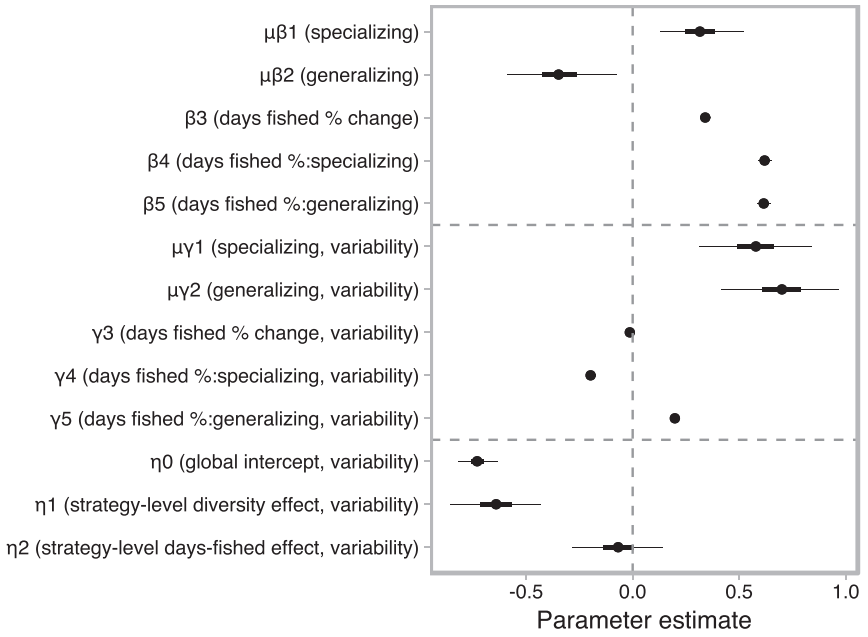

Fig. S2. Main effects from the hierarchical model predicting revenue (β) and variability (γ) in revenue. The η coefficients represent strategy-level predictors relating mean species diversity and mean days fished within a strategy (both centered by their means and divided by 2 times their standard deviations) to the magnitude of residual error. Note that μ_{β_1}, β_4, μ_{γ_1}, and γ_4 have been multiplied by -1 to make these coefficients interpretable as effects of increasing specialization (as opposed to decreasing specialization).

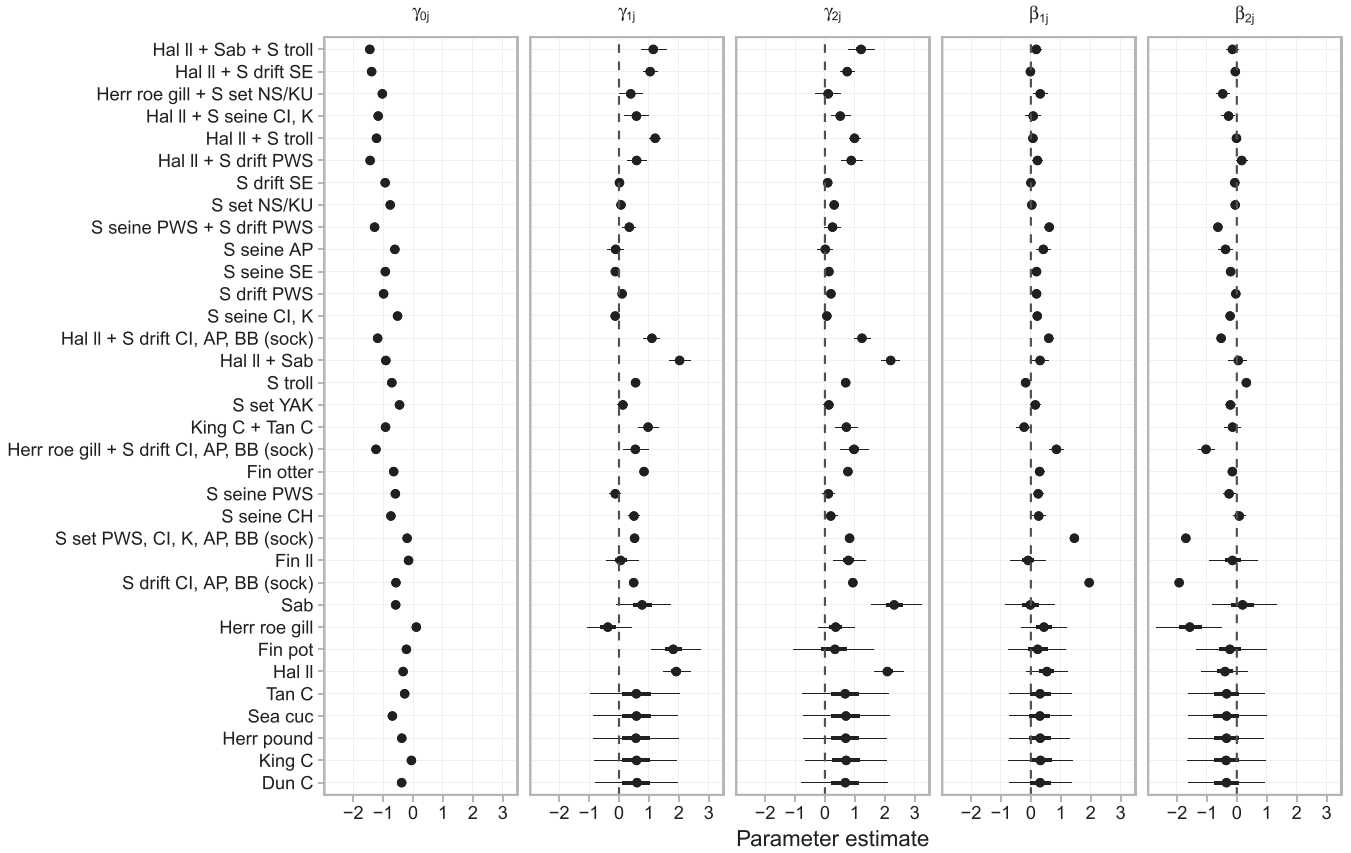

Fig. S3. Estimates of within-strategy effects from the hierarchical model. Panels refer to parameters in Eqs. **3** and **7**. Shown are medians (dots) and 50% and 95% credible intervals (thick and thin line segments). Strategies are ordered from high to low mean species diversity from top to bottom. Note that $\gamma_{1,j}$ and $\beta_{1,j}$ have been multiplied by -1 to make these coefficients interpretable as effects of increasing specialization (as opposed to decreasing specialization). Species groups: Dun C, dungeness crab; Fin, finfish; Hal, halibut; Herr, herring; King C, king crab; S, salmon; Sab, sablefish; Sea cuc, sea cucumber; sock, sockeye salmon; Tan C, tanner crab. Gears: drift, drift gillnet; gill, gillnet for herring; ll, longline; otter, otter trawl; set, setnet. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.

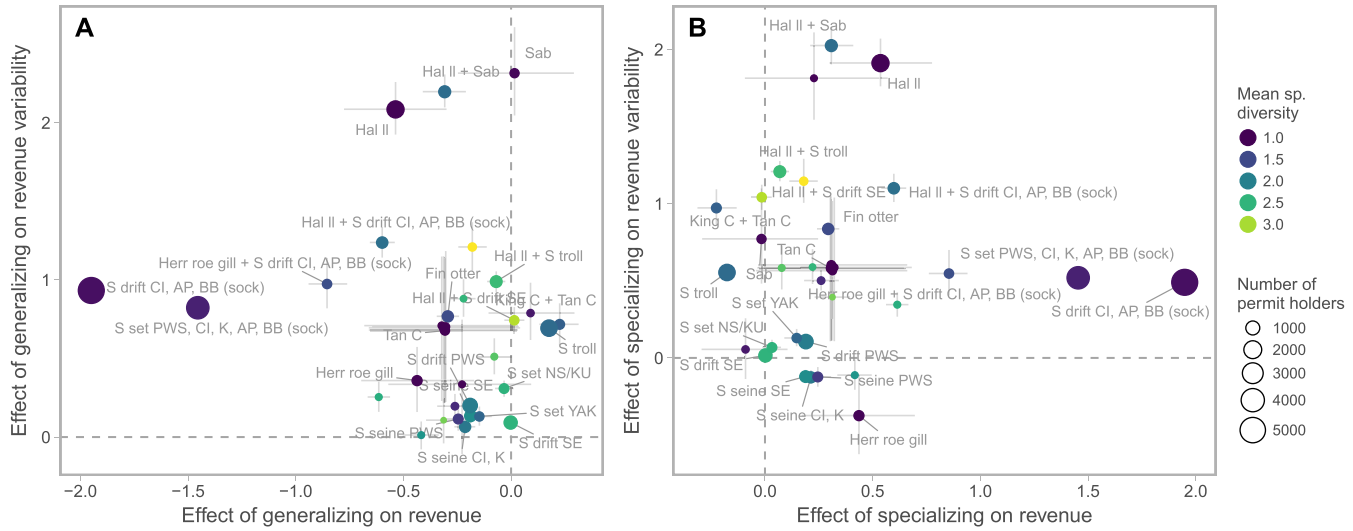

Fig. S4. Effects of (*A*) generalizing and (*B*) specializing from year to year for individual permit holders within the 34 most common strategies. Changing species diversity from year to year is associated with higher variability for individuals within the strategies above the zero line. Generalizing (*A*) or specializing (*B*) is associated with greater expected revenue ratios to the right of the zero line and lower expected revenue ratios to the left of the zero line. These effects are estimated holding fishing season length constant from year to year. Dots and line segments represent medians and 50% credible intervals of posteriors. *B* and Fig. 4 are the same. This is a bivariate display of the $\gamma_{1,j}$, $\gamma_{2,j}$, $\beta_{1,j}$, and $\beta_{2,j}$ coefficient estimates displayed in Fig. S3. Note that $\gamma_{1,j}$ (*B* vertical axis) and $\beta_{1,j}$ (*B* horizontal axis) have been multiplied by -1 to make these coefficients interpretable as effects of increasing specialization (as opposed to decreasing specialization). Species groups: Dun C, dungeness crab; Fin, finfish; Hal, halibut; Herr, herring; King C, king crab; S, salmon; Sab, sablefish; Sea cuc, sea cucumber; sock, sockeye salmon; Tan C, tanner crab. Gears: drift, drift gillnet; gill, gillnet for herring; ll, longline; otter, otter trawl; set, setnet. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.

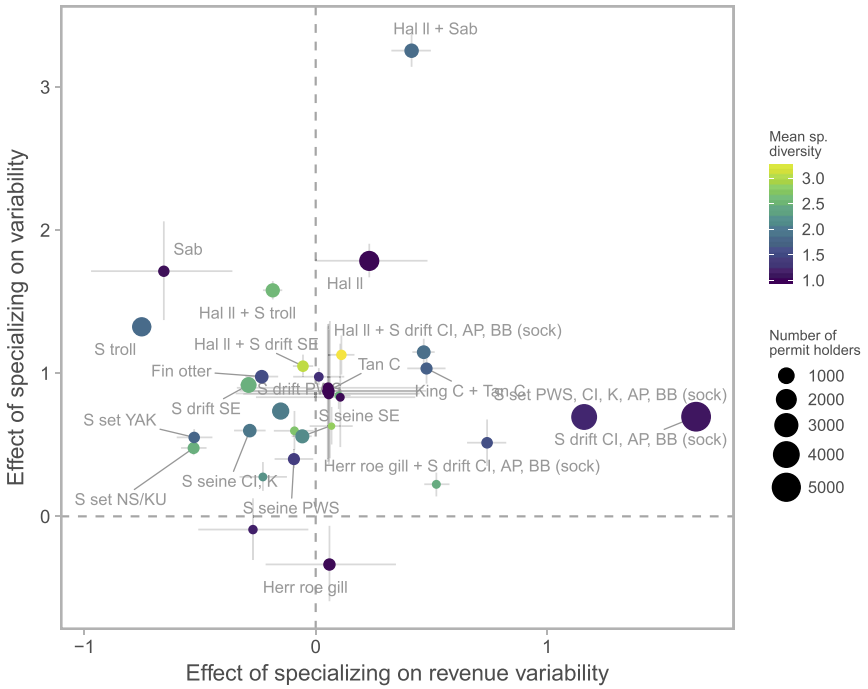

Fig. S5. Same as Fig. 4 but without the effort (days fished) predictor and without its interaction with species diversity. Species groups: Dun C, dungeness crab; Fin, finfish; Hal, halibut; Herr, herring; King C, king crab; S, salmon; sock, sockeye salmon; Sab, sablefish; Sea cuc, sea cucumber; Tan C, tanner crab. Gears: drift, drift gillnet; gill, gillnet for herring; ll, longline; otter, otter trawl; set, setnet. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.

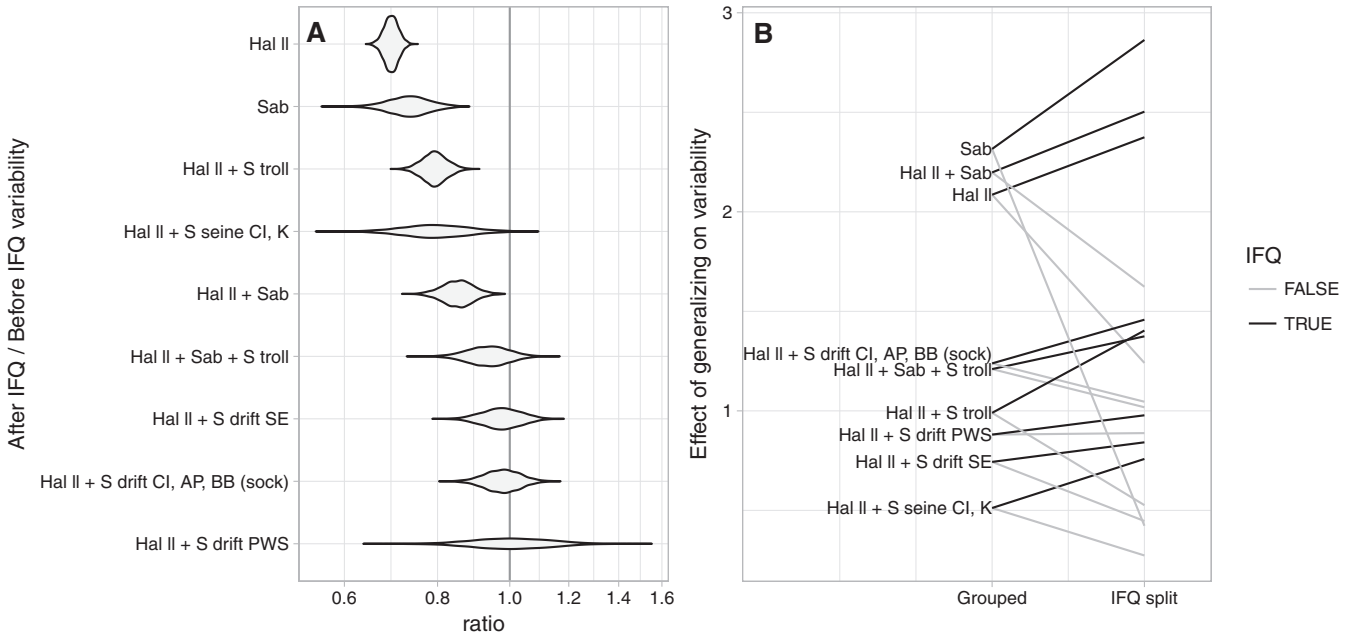

Fig. S6. The effect of IFQs on model estimates. (*A*) Posterior density of the ratio between strategy-level estimates of standardized revenue variability (γ_{0j}) after the introduction of IFQs vs. before the introduction of IFQs. (*B*) Estimates (medians) of the effect of generalizing (increasing species diversity) on variability (γ_{1j}) for the full model ("Grouped") compared with a model where separate effects are estimated before and after IFQs were introduced ("IFQ split"). Pattern looks similar for the effect of specializing on variability (γ_{2j}) and is not shown. Species groups: Hal, halibut; S, salmon; Sab, sablefish; sock, sockeye salmon. Gears: drift, drift gillnet; ll, longline. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.

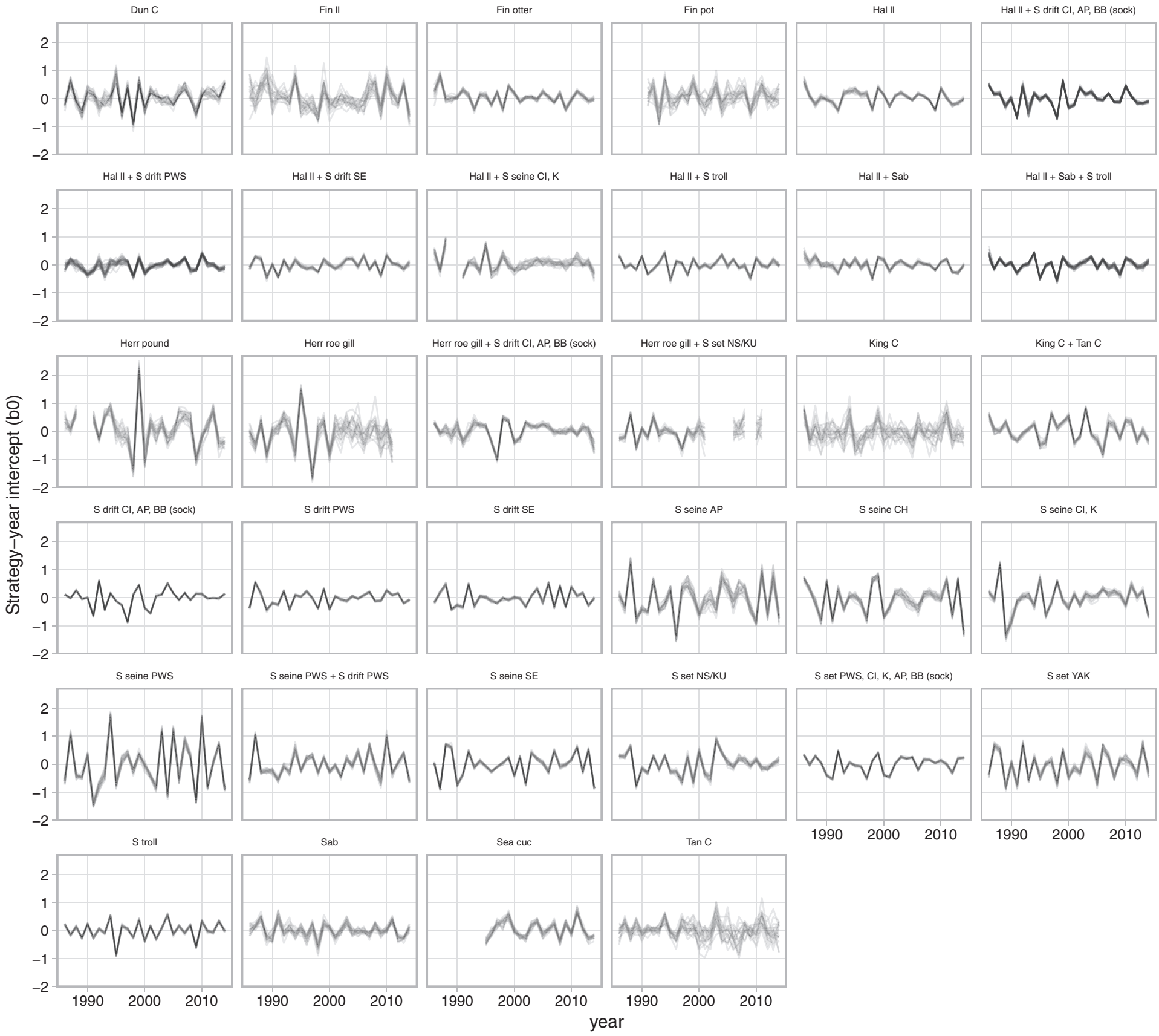

Fig. S7. Strategy–year intercept estimates ($\beta_{0,j,t}$ in Eq. **3**) from the hierarchical model. Shown are 40 samples from the posterior distribution. Species groups: Dun C, dungeness crab; Fin, finfish; Hal, halibut; Herr, herring; King C, king crab; S, salmon; Sab, sablefish; Sea cuc, sea cucumber; sock, sockeye salmon; Tan C, tanner crab. Gears: drift, drift gillnet; gill, gillnet for herring; ll, longline; otter, otter trawl; set, setnet. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.

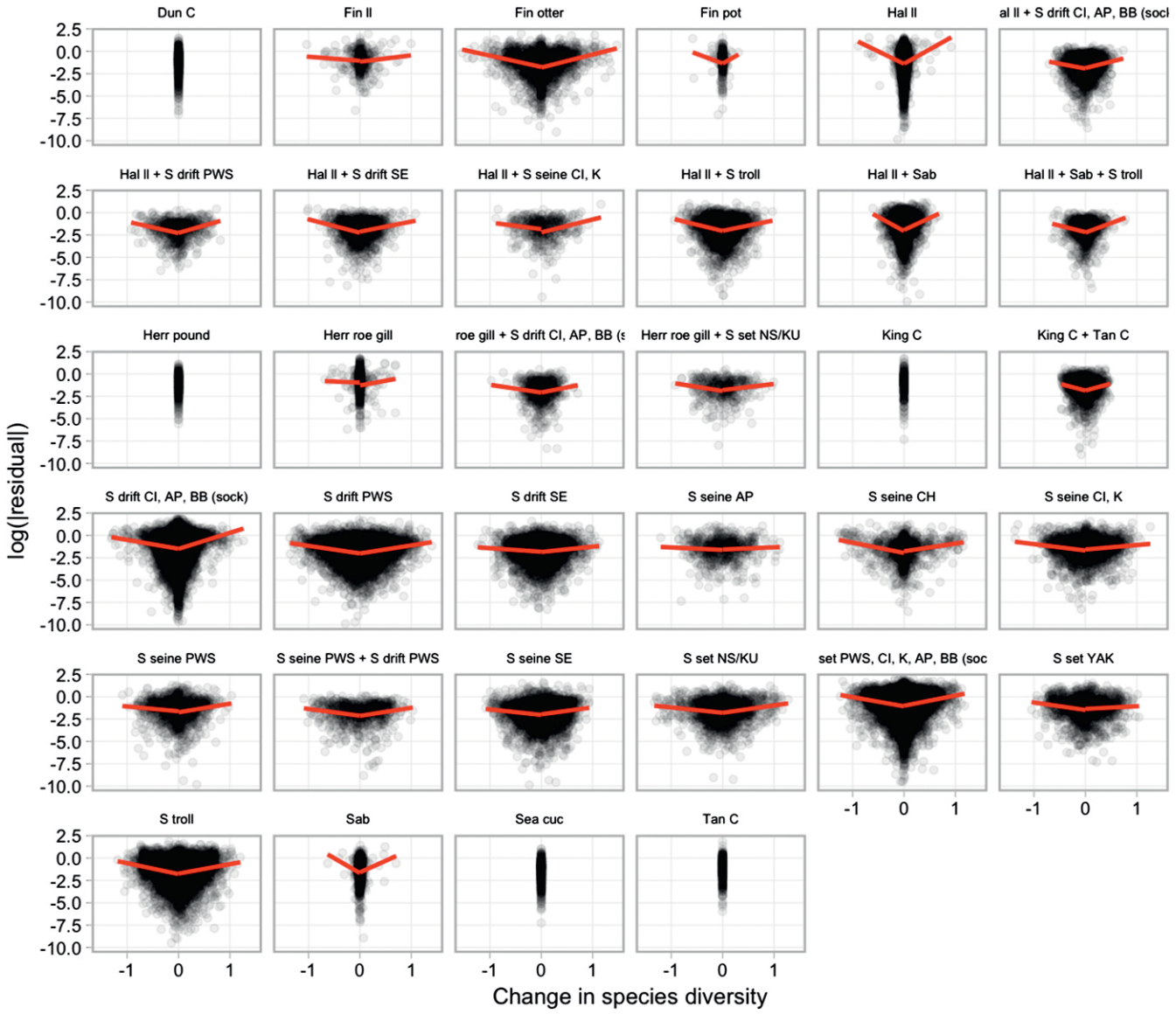

Fig. S8. The log absolute value residuals from the mean component model (Eq. **3**). These residuals are modeled in the variance component model (Eq. **7**). Breakpoint linear regression fits are overlaid in red for visual interpretation. Species groups: Dun C, dungeness crab; Fin, finfish; Hal, halibut; Herr, herring; King C, king crab; S, salmon; Sab, sablefish; Sea cuc, sea cucumber; sock, sockeye salmon; Tan C, tanner crab. Gears: drift, drift gillnet; gill, gillnet for herring; ll, longline; otter, otter trawl; set, setnet. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.

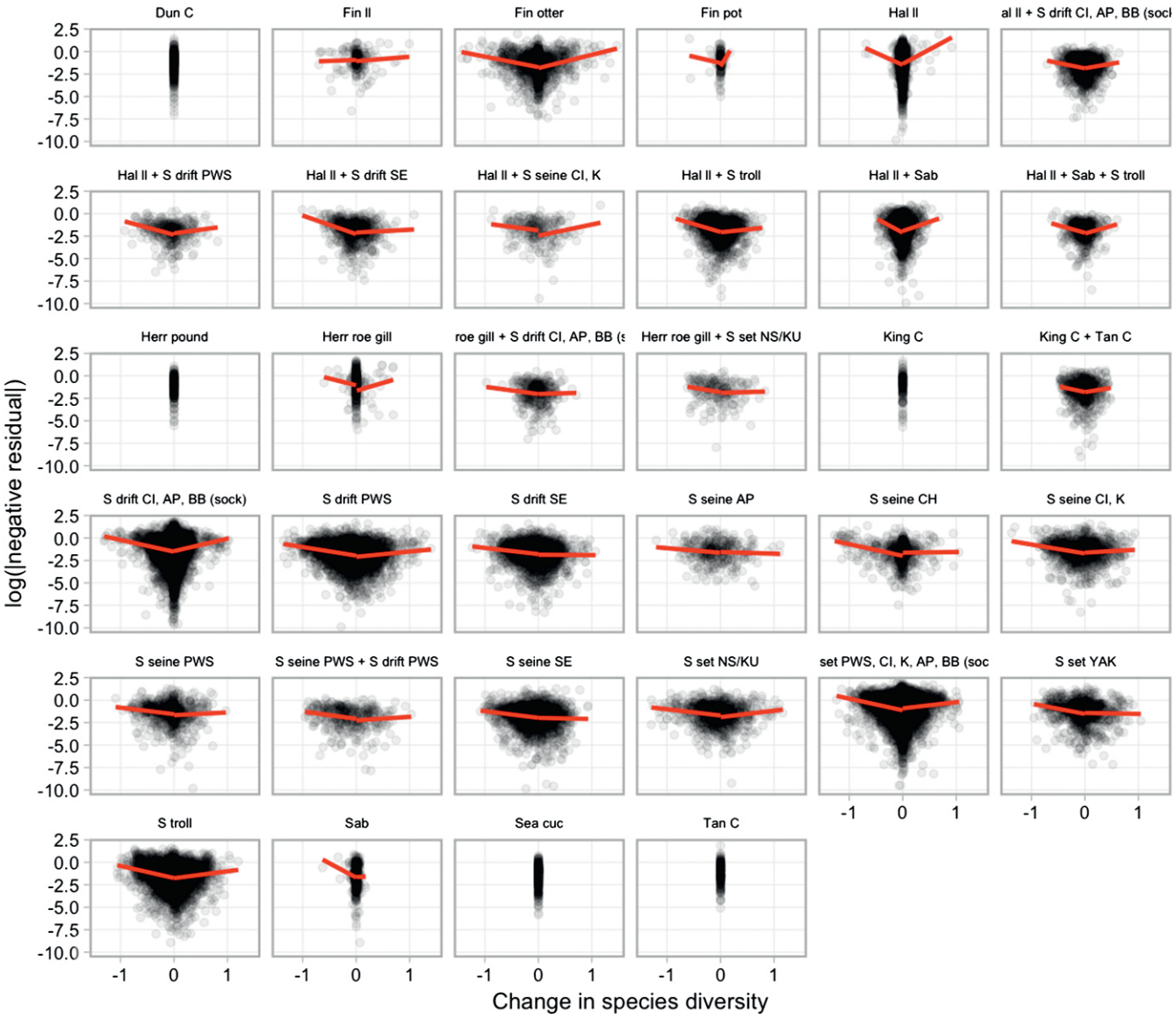

Fig. S9. The log absolute value of downside (negative) residuals from the main component model. Figure looks qualitatively the same as Fig. S8 and so justifies using variability (positive and negative residuals) as a measure of risk. Species groups: Dun C, dungeness crab; Fin, finfish; Hal, halibut; Herr, herring; King C, king crab; S, salmon; Sab, sablefish; Sea cuc, sea cucumber; sock, sockeye salmon; Tan C, tanner crab. Gears: drift, drift gillnet; gill, gillnet for herring; ll, longline; otter, otter trawl; set, setnet. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.

Table S1. Labels and descriptions of unique fishing strategies

Label	Description	Mean spp. diversity	Main species
Dun C	Dungeness crab	1.0	crab
King C	King crab	1.0	crab
Herr - pound	Herring, pound	1.0	herring
Sea cuc	Sea cucumber	1.0	sea cucumber
Tan C	Tanner crab, pot gear	1.0	crab
Hal - ll	Halibut, longline	1.0	halibut
Fin - pot	Finfish, pot gear, statewide	1.0	cod
Herr roe - gill	Herring roe, gillnet	1.0	herring
Sab	Sablefish, longline, statewide	1.0	sablefish
S - drift - CI, AP, BB (sock)	Salmon (mostly sockeye), drift gillnet, CI, AP, BB	1.1	sock
Fin - ll	Finfish, longline, statewide	1.1	pollock
S - set - PWS, CI, K, AP, BB (sock)	Salmon (mostly sockeye), set gillnet, PWS, CI, K, AP, BB	1.2	sock
S - seine - CH	Salmon, purse seine, Chignik	1.3	sock
S - seine - PWS	Salmon, purse seine, PWS	1.4	pink, chum
Fin - otter	Finfish, otter trawl, statewide	1.5	cod
S - set - YAK	Salmon, set gillnet, Yakutat	1.7	coho, sock
S - troll	Salmon, power troll, statewide	1.8	chnk, coho
S - seine - CI, K	Salmon, purse seine, Cook Inlet and Kodiak	1.9	pink, sock
S - drift - PWS	Salmon, drift gillnet, PWS	2.0	coho, pink, sock, chum
S - seine - SE	Salmon, purse seine, Southeast Alaska	2.1	pink, sock, chum
S - seine - AP	Salmon, purse seine, Alaska Penninsula	2.2	pink, sock, chum
S - set - NS/KU	Salmon, set gillnet, Norton Sound and Kuskokwim	2.5	chnk, coho, sock, chum
S - drift - SE	Salmon, drift gillnet, Southeast Alaska	2.5	coho, pink, sock, chum

In many cases, a particular strategy represents a group of similar permits across areas or vessel sizes. The column "Main species" indicates species that make up at least 10% of the total revenue across all years and individuals for that fishing strategy. Species groups: chnk, Chinook salmon; Dun C, dungeness crab; Fin, finfish; Hal, halibut; Herr, herring; King C, king crab; S, salmon; Sab, sablefish; Sea cuc, sea cucumber; sock, sockeye salmon; Tan C, tanner crab. Gears: drift, drift gillnet; gill, gillnet for herring; ll, longline; otter, otter trawl; set, setnet. Regions: AP, Alaska Peninsula; BB, Bristol Bay; CH, Chignik; CI, Cook Inlet; K, Kodiak; KU, Kuskokwim; NS, Norton Sound; PWS, Prince William Sound; SE, Southeast Alaska; YAK, Yakutat.