Appendix S1

The effects of population synchrony, life history, and access constraints on benefits from fishing portfolios

Kiva L. Oken, Daniel S. Holland, André E. Punt

Ecological Applications

Tuning fishery parameters

We parameterized fixed costs, variable costs, and catchability to ensure total costs in a year with average recruitment would be equal to total revenue for a marginal fisher who might be considering entry into the fishery. We based the calculations on a fleet consisting of the same number of vessels as held permits for the fishery in the baseline “medium access” scenario (Table 3, described in “Scenarios” section). We considered an inefficient marginal vessel to have a weekly variable cost at the upper 95th percentile of the variable cost distribution. For the tuning only, we assigned vessel-specific variable costs based on quantiles of the lognormal distribution to avoid Monte Carlo error. That is, rather than randomly simulating the variable costs for each vessel, vessel 1 had a cost at the 1/(number of vessels+1)quantile of the distribution, vessel 2 at the 2/(number of vessels+1) quantile, etc. The profitability constraint for species *s* can be expressed mathematically as:

where *εs,y\** equals zero (average recruitment), and *v\** is the marginal vessel described above.

For crab and salmon, we manually adjusted *qs* and to achieve an acceptable annual ratio of variable costs to fixed costs for an average fisher (40% of total costs are variable for crab, 89% for salmon) and acceptable patterns of depletion over the year (Fig. 6, center column). While the parameterization of catchability and fixed costs was somewhat arbitrary, our primary goal was to model a diversity of fisheries that range in capital intensity and depletion patterns, as we observe in the CCLME. Although there is substantial heterogeneity among vessels in all three fisheries, the crab fishery is relatively more capital intensive (when amortization of vessel and permit values are included in fixed costs as we assume here). Crab permits often sell for over $500,000 while salmon troll permits sell for $20-30,000 (Dock street Brokers). Vessel prices for crab boats are also higher than salmon trollers, and crabbers also make substantial investments in pots.

Tuning the fishery parameters for groundfish was more complex than for crab and salmon because the groundfish population dynamics respond to the fishery dynamics. First, we solved for catchability so that total yield is equal to that which leads the population to equilibrate at 40% of the unfished biomass (the actual management target for most U.S. West Coast groundfish species). To calculate this catchability, we projected the fishery for 40 weeks assuming 100% participation each week and solved for the catchability that led to the target yield. We used 40 weeks since vessels do not actually fish every week of the year in reality, nor in our model since some vessels spend part of the year in other fisheries. Next, we manually adjusted the mean variable cost (*cg*) and solved for the fixed cost () such that the marginal vessel described above had no net profit at the target equilibrium conditions. That is, we calculated

where *B40%* is 40% of unfished biomass and *H40%* is the harvest rate leading to that condition, and other variables are defined in Table 2. The first term in the equation is the revenue earned per vessel under equilibrium conditions at 40% of unfished biomass and *F*-1 is the inverse lognormal cumulative density function (“qlnorm” in R). The mean variable cost was tuned to achieve an acceptable annual ratio of variable to fixed costs for an average vessel in an average year with a population equilibrated at 40% of the unfished biomass (66% of total costs are variable assuming 40 weeks of fishing). The groundfish fleet is also highly heterogeneous with both small operations fishing in state waters and large offshore trawlers, but this assumption of an intermediate ratio of variable to total cost is roughly in line with average cost structures of intermediate size trawlers participating in the dover sole-thrornyhead-sablefish (DTS) component of the fishery and longline and pot vessels that target sablefish (Northwest Fisheries Science Center, 2020). As we note in the main text, we are not attempting to parameterize these fleets accurately, but qualitatively our assumptions about relative levels of fixed and variable costs are broadly representative of these fisheries.

We conducted two post hoc checks for groundfish to ensure the process described above led to reasonable dynamics despite the assumptions made. First, we checked that all vessels would actually fish for 40 weeks under the cost structure, as no constraint actively prevented vessels from leaving the fishery earlier during the year. We calculated per vessel revenue during the 40th week of the year and ensured it was greater than the variable cost for the least cost-efficient vessel (costs calculated deterministically based on quantiles, note this is different than the “marginal” vessel). Second, we visually checked that the fishery was roughly in equilibrium and that the groundfish population did not consistently tend to grow or decline considerably during simulations that included all three fisheries (Fig. S1).

Works Cited

Dock Street Brokers. <<https://dockstreetbrokers.com/permits/west-coast-permits>> Accessed May 22, 2020.

Northwest Fisheries Science Center. <<https://dataexplorer.northwestscience.fisheries.noaa.gov/fisheye/PerformanceMetrics/>> Accessed May 22, 2020.

Table S1 Summary of fishery-wide profit patterns and revenue standard deviation. Statistics are calculated over time of profit or revenue summed across all vessels and species, yielding one value per simulation. Entries in the column itself are averages across simulations.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Mean profit | Profit SD | Revenue SD |
| **Access** |  |  |  |
| Easy Access | -0.17 | 0.48 | 0.59 |
| Medium Access | 0.25 | 0.48 | 0.6 |
| Hard Access | -0.01 | 0.51 | 0.63 |
| **Synchrony** | |  |  |
| Asynchronous | 0.26 | 0.44 | 0.53 |
| Independent | 0.25 | 0.48 | 0.6 |
| Synchronous | 0.25 | 0.53 | 0.66 |
| **Synchrony & Access** | |  |  |
| Asynchronous Easy Access | -0.17 | 0.43 | 0.51 |
| Synchronous Easy Access | -0.17 | 0.53 | 0.67 |
| Asynchronous Hard Access | -0.01 | 0.47 | 0.57 |
| Synchronous Hard Access | -0.01 | 0.55 | 0.69 |

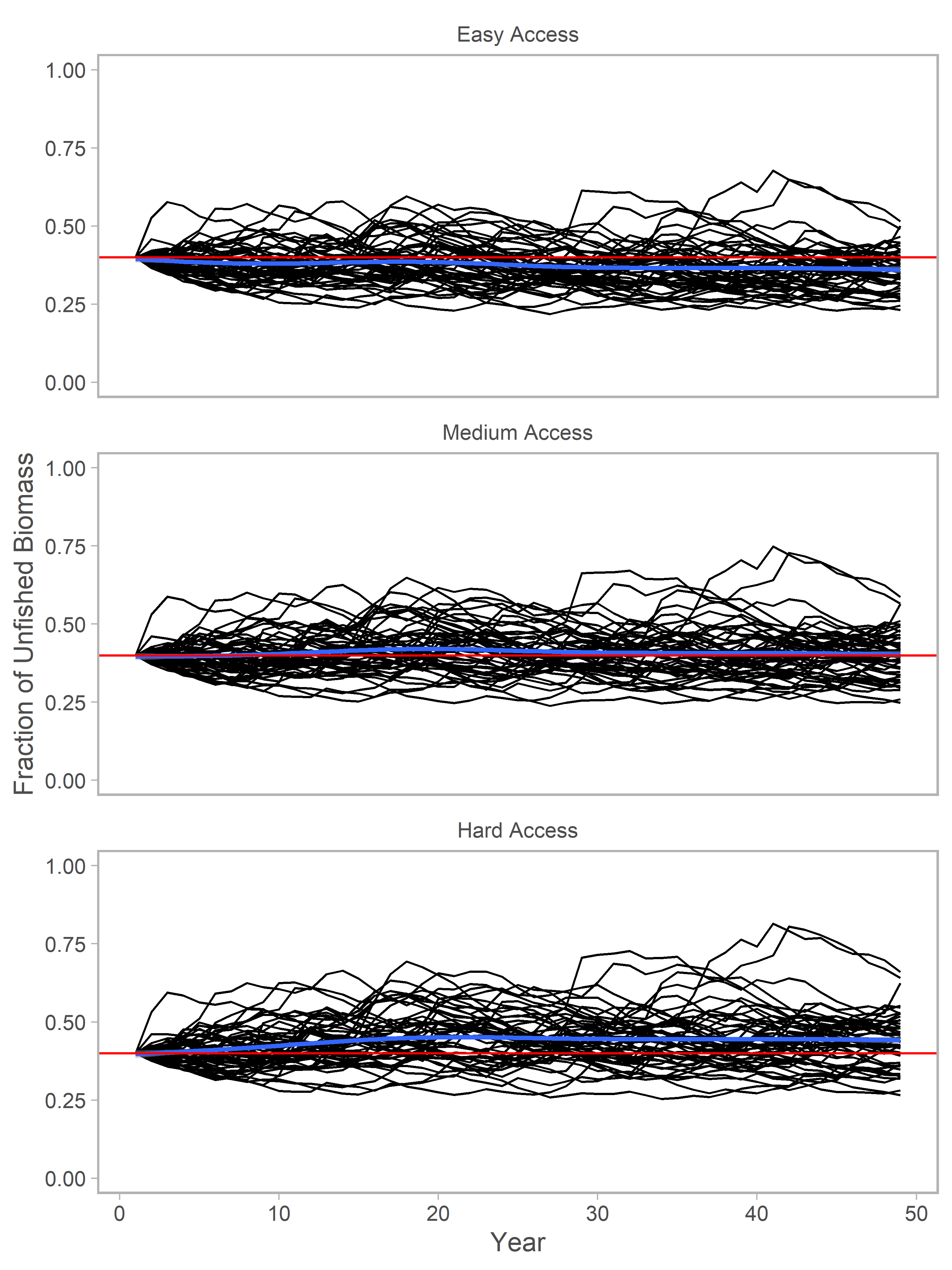


Fig. S1 Time series of week one biomass over 50 years for 50 simulations across access scenarios. The red horizontal line is initial biomass (40% of B0) and the blue line is GAM smoother showing biomass remains roughly stable on average under medium (baseline) access, declines slightly under hard access, and increases slightly under easy access.

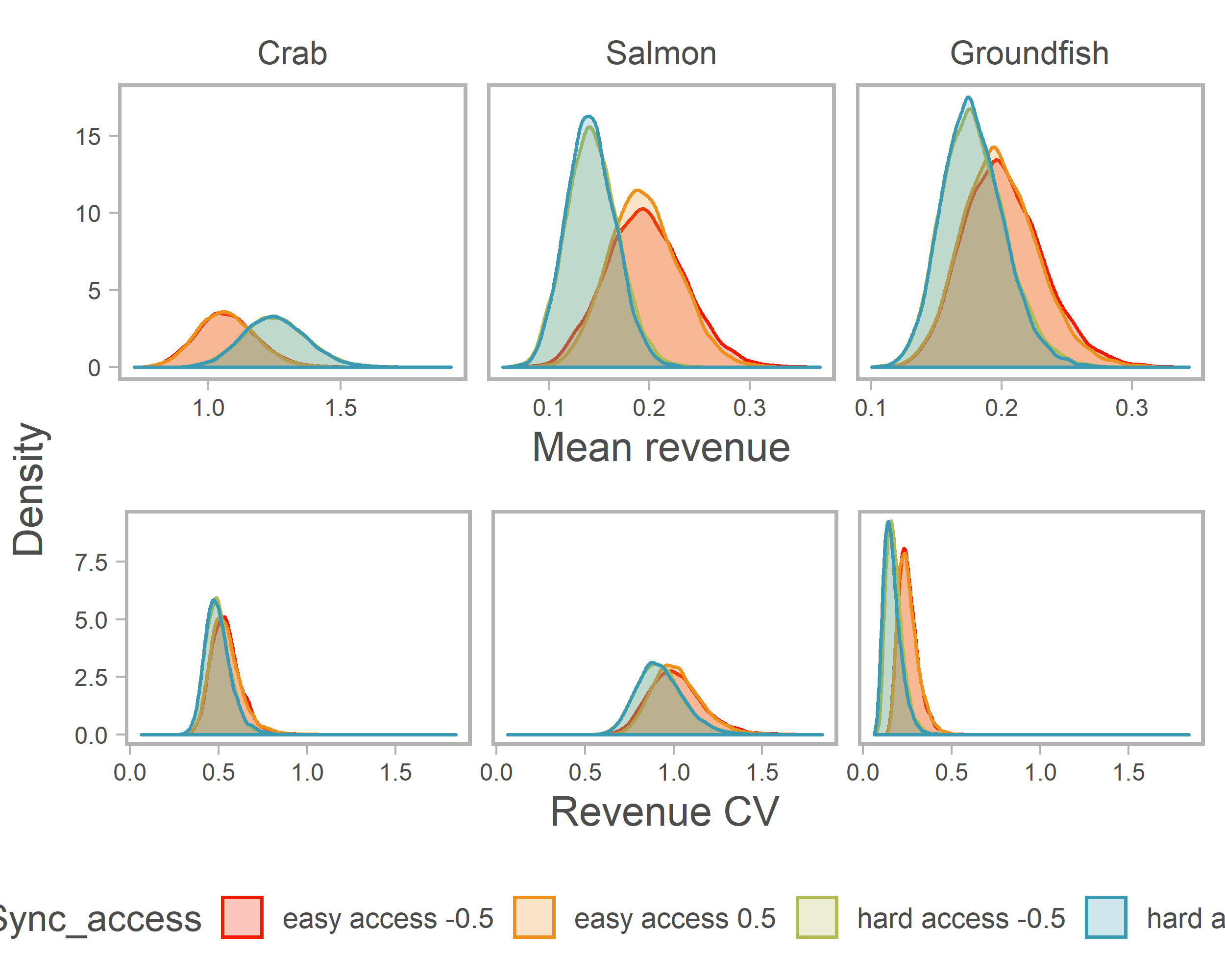


Fig. S2 Distribution of mean and coefficient of variation of revenue for each species under different synchrony and access scenarios. Note common x-axis scales for CV but variable scales for mean.

Fig. S3 Distribution of mean and coefficient of variation for individual vessels holding six possible permit portfolios under different synchrony and access scenarios. Mean and CV are calculated over time for each vessel in each simulation, and then averaged across vessels within a simulation. Distributions show variability across simulations. Note common x-axis scales for CV but variable scales for mean.

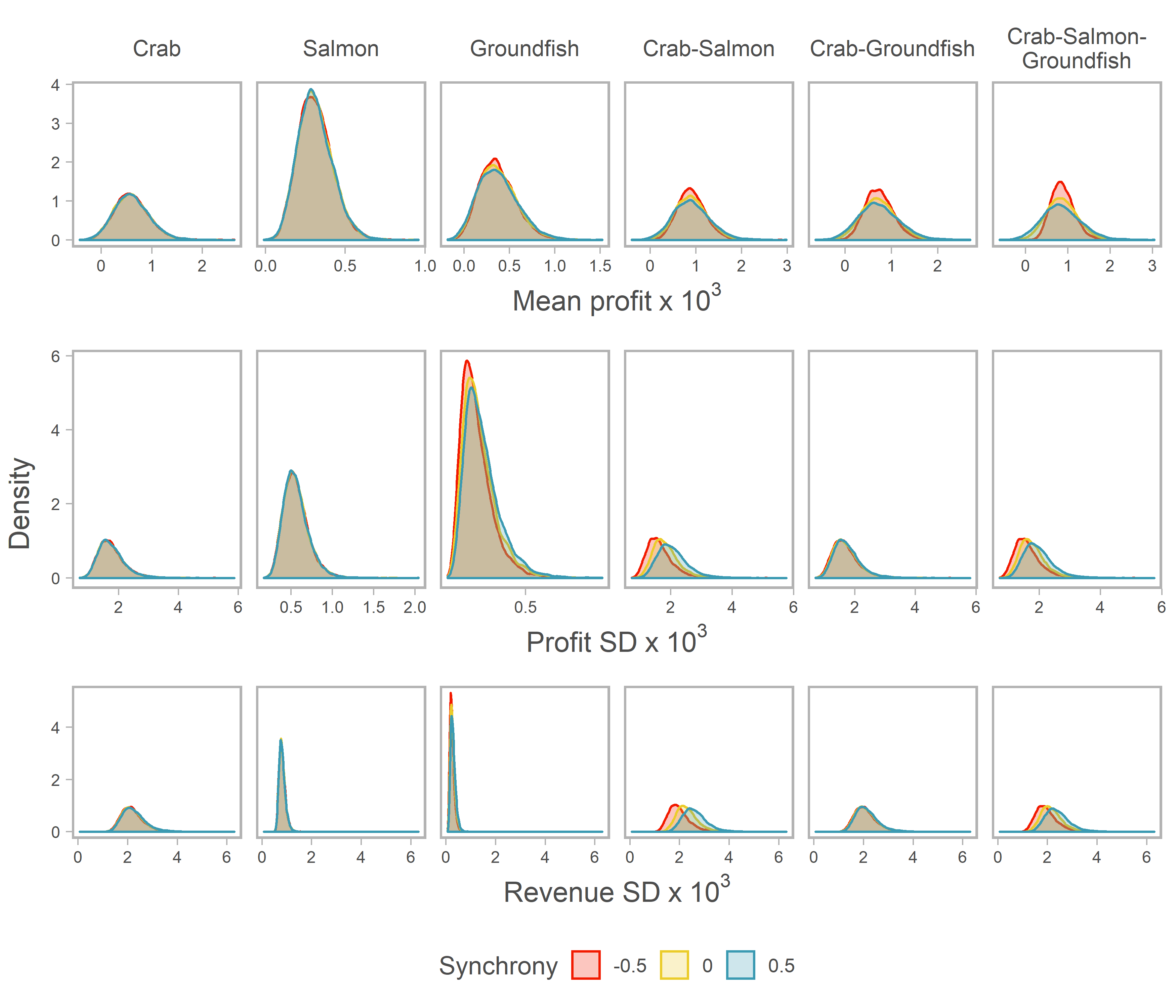
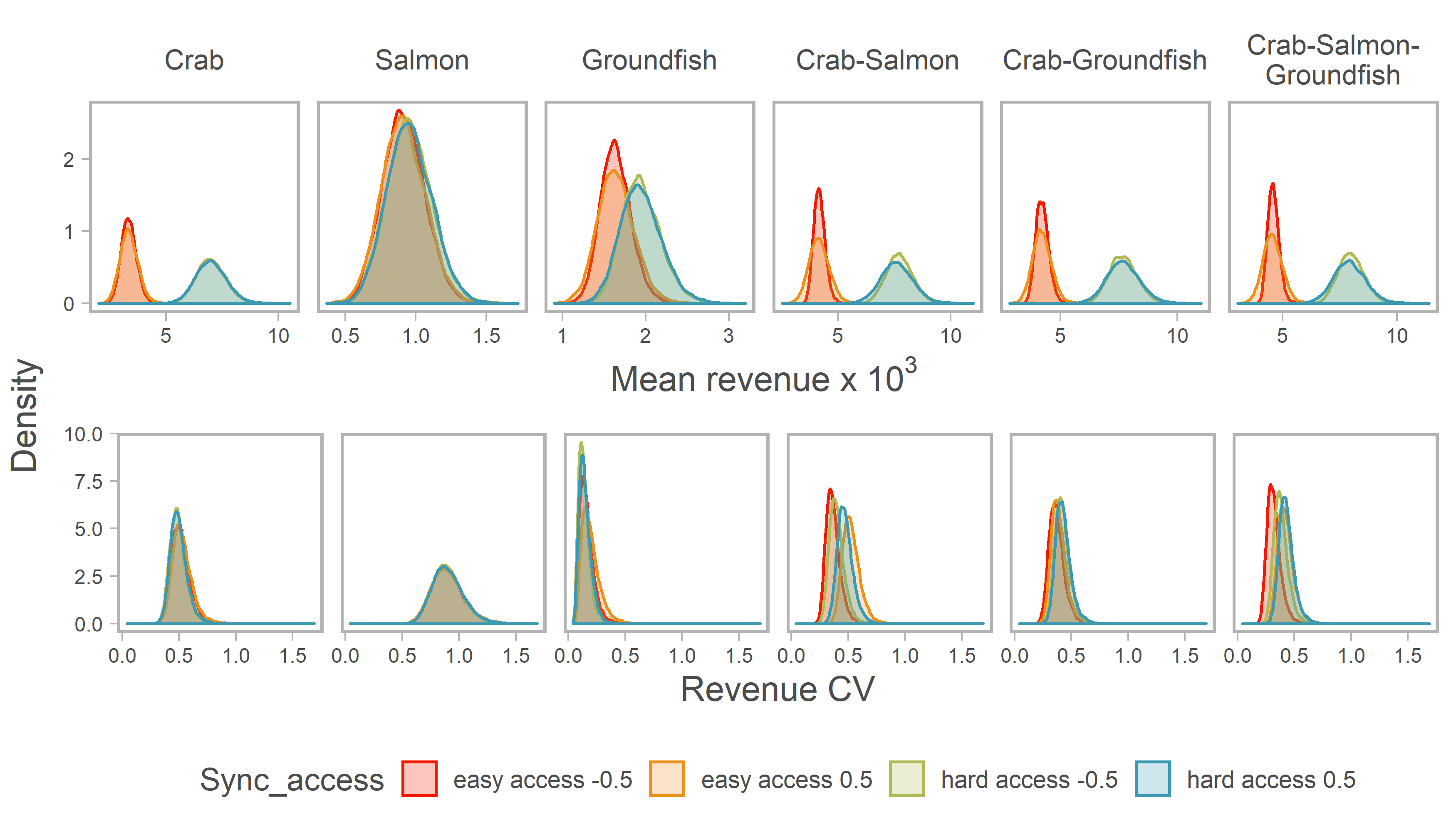


Fig. S4 Distribution of mean and standard deviation of profit and standard deviation of revenue for individual vessels holding six possible permit portfolios for synchrony scenarios. Mean and SD are calculated over time for each vessel in each simulation, and then averaged across vessels within a simulation. Distributions show variability across simulations.

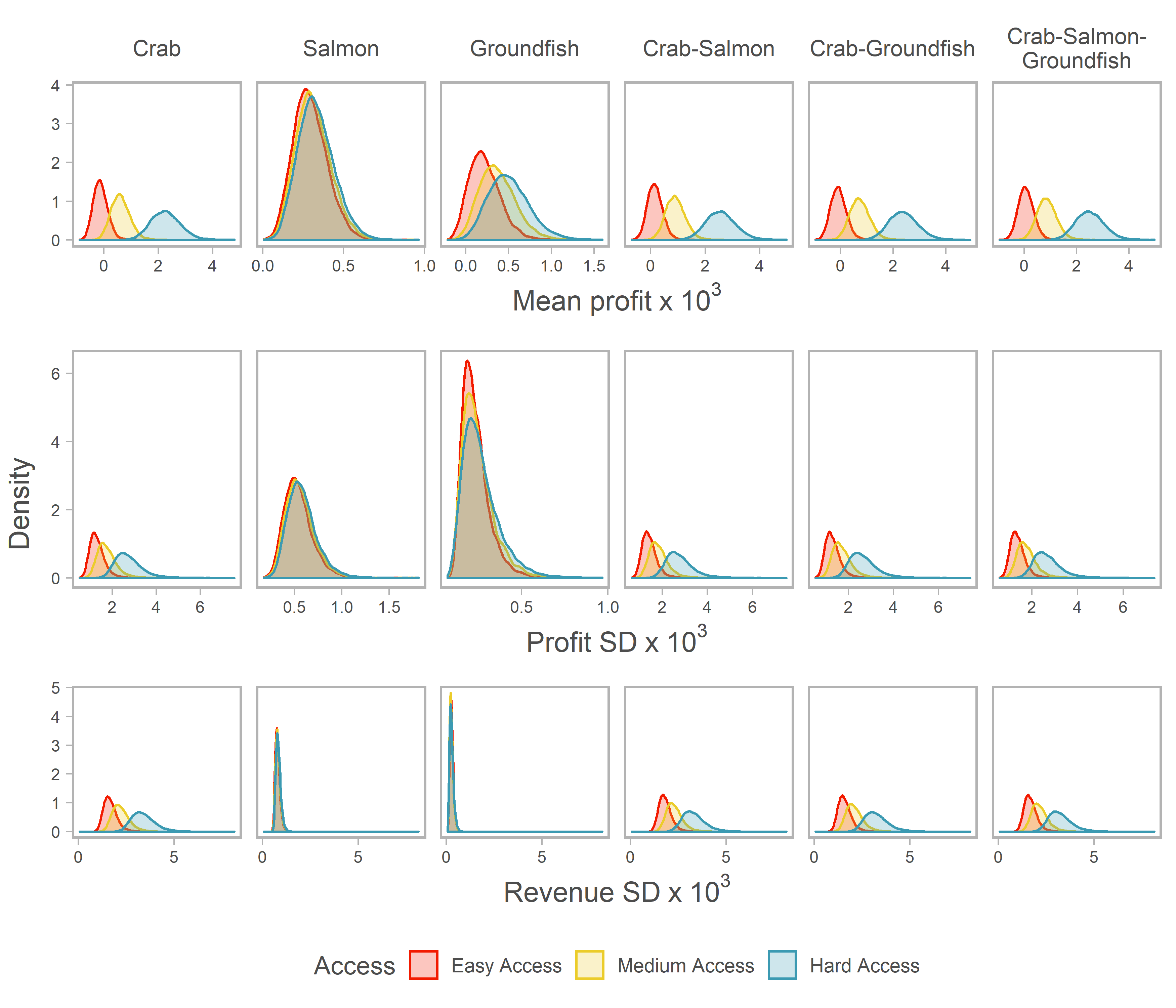


Fig. S5 Distribution of mean and standard deviation of profit and standard deviation of revenue for individual vessels holding six possible permit portfolios for access scenarios. Mean and SD are calculated over time for each vessel in each simulation, and then averaged across vessels within a simulation. Distributions show variability across simulations.

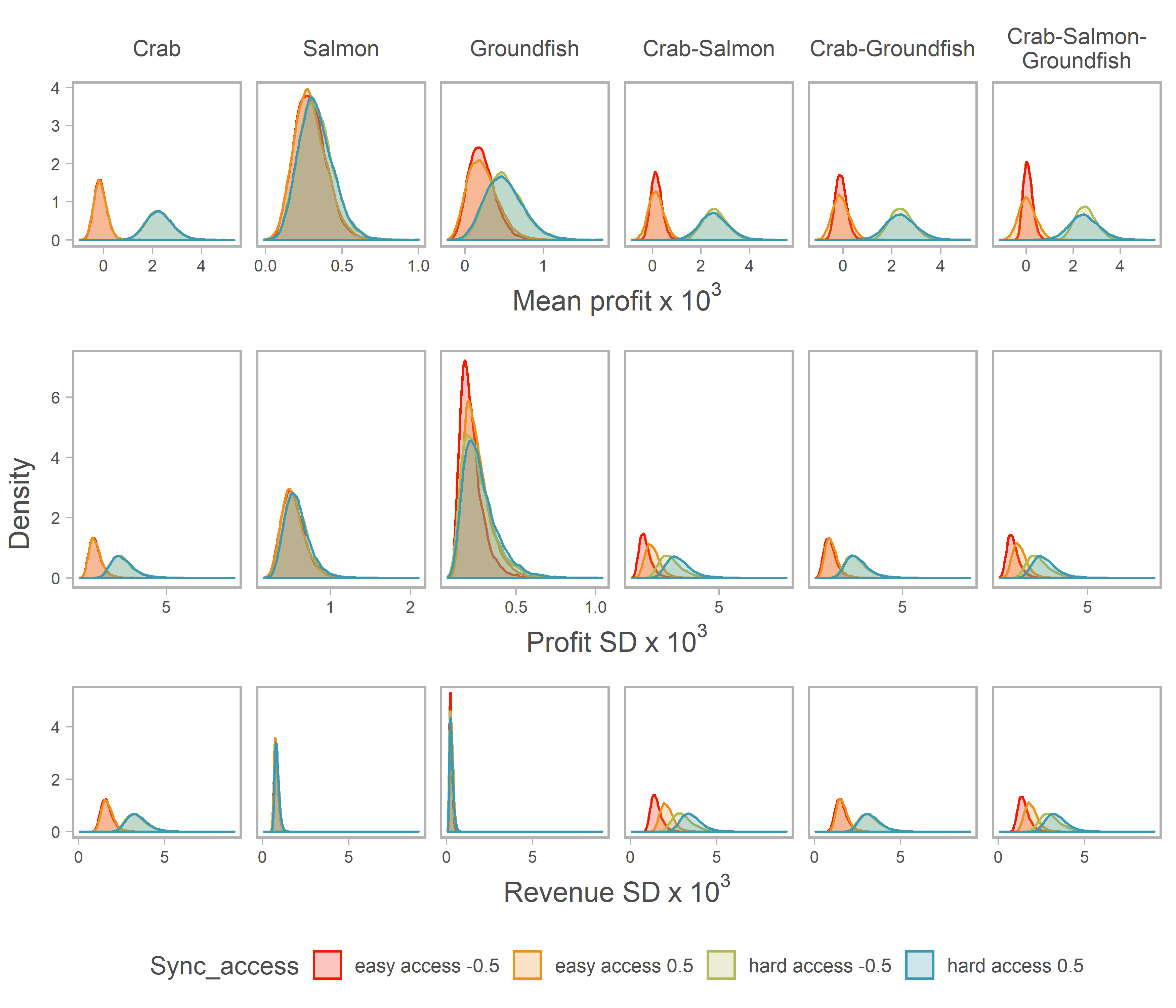


Fig. S6 Distribution of mean and standard deviation of profit and standard deviation of revenue for individual vessels holding six possible permit portfolios under different synchrony and access scenarios. Mean and SD are calculated over time for each vessel in each simulation, and then averaged across vessels within a simulation. Distributions show variability across simulations.