Graphical Abstract

Risk-calibrated HCR under productivity shifts

Question: Can a single transparent HCR remain robust when steepness changes?

Approach: Two steepness regimes (h = 0.6, 0.9) in a pollock-like model; calibrate one Ftarget so mean risk P(SSB < 0.2 B0) = 0.05 across scenarios.

```r
scenario_low <- create_scenario(h = 0.6, "Low, h=0.6")
scenario_high <- create_scenario(h = 0.9, "High, h=0.9")
scenarios <- list(scenario_low, scenario_high)

ref_low <- scenario_low$ref_points
ref_high <- scenario_high$ref_points

# Yield curves
p_yield <- plot_yield_comparison(scenarios, colors = c("blue", "red")) +
  labs(title = "Productivity shifts move Fmsy and yield")

# Risk calibration (small table rendered as text)
target_risk <- 0.05
b0_frac <- 0.2
n_sims_risk <- 200
seed_low <- 2200
seed_high <- 3200

calc_terminal_b0_risk <- function(scenario, F_target, B0, n_sims, seed_base, b0_frac) {
  params <- scenario$params
  n_years <- params$n_years
  below <- logical(n_sims)

  for (i in 1:n_sims) {
    sim <- run_simulation_hcr(
      params,
      F_target = F_target,
      B0 = B0,
      catch_cap = NULL,
```

```
      seed = seed_base + i
    )
    below[i] <- sim$SSB[n_years] < (b0_frac * B0)
  }

  mean(below)
}

combined_b0_risk <- function(F_target) {
  risk_low <- calc_terminal_b0_risk(
    scenario_low,
    F_target,
    ref_low$SSB0,
    n_sims_risk,
    seed_low,
    b0_frac
  )
  risk_high <- calc_terminal_b0_risk(
    scenario_high,
    F_target,
    ref_high$SSB0,
    n_sims_risk,
    seed_high,
    b0_frac
  )

  mean(c(risk_low, risk_high))
}

F_grid <- seq(0.05, 1.0, by = 0.05)
risk_grid <- sapply(F_grid, combined_b0_risk)

if (target_risk <= min(risk_grid)) {
  Ftarget <- F_grid[which.min(risk_grid)]
} else if (target_risk >= max(risk_grid)) {
  Ftarget <- F_grid[which.max(risk_grid)]
} else {
  ordered <- data.frame(F_grid, risk_grid)[order(risk_grid), ]
  Ftarget <- approx(ordered$risk_grid, ordered$F_grid, xout = target_risk)$y
}

risk_label <- paste0("Calibrated Ftarget = ", round(Ftarget, 3))

p_yield
```
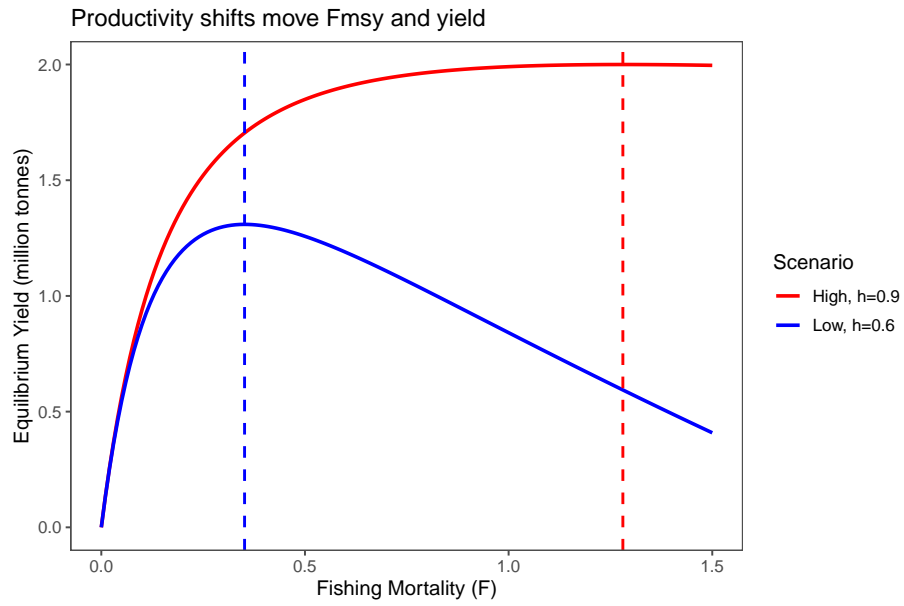
Productivity shifts move Fmsy and yield

Result: A single risk-calibrated Ftarget provides consistent biomass protection across steepness regimes while preserving catch potential in high productivity states.

Implication: A transparent, SPR-based HCR can be made robust without time-varying covariates.