

Appendix B: Code for analysis comparing to historical data

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Section 1: Model estimates from data

Computes model parameter estimates for selected stocks in RAM using NIMBLE.

```
# devtools::install_github("boettiger-lab/sarsop") ## install package first if necessary.
library(tidyverse)
library(sarsop)
library(nimble)
library(parallel)
library(gridExtra)

if(!file.exists("ramlegacy.zip")){
download.file(paste0(
  "https://depts.washington.edu/ramlegac/wordpress/databaseVersions/",
  "RLSADB_v3.0_(assessment_data_only)_excel.zip"),
  "ramlegacy.zip")
}

path <- unzip("ramlegacy.zip")
sheets <- readxl::excel_sheets(path)
ram <- lapply(sheets, readxl::read_excel, path = path)
names(ram) <- sheets
unlink("ramlegacy.zip")
unlink("RLSADB v3.0 (assessment data only).xlsx")
ramlegacy <-
  ram$timeseries_values_views %>%
  select(assessid, stockid, stocklong, year, SSB, TC) %>%
  left_join(ram$stock) %>%
  left_join(ram$area) %>%
  select(assessid, stockid, scientificname,
         commonname, areaname, country, year,
         SSB, TC) %>%
  left_join(ram$timeseries_units_views %>%
            rename(TC_units = TC, SSB_units = SSB)) %>%
  select(scientificname, commonname,
         stockid, areaname, country, year,
         SSB, TC, SSB_units, TC_units)
```

Let's filter out missing data, non-matching units, and obvious reporting errors (catch exceeding total spawning biomass), then we rescale each series into the 0,1 by appropriate choice of units:

```
df2 <- ramlegacy %>%
  filter(!is.na(SSB), !is.na(TC)) %>%
  filter(SSB_units == "MT", TC_units=="MT") %>%
  filter(SSB > TC) %>%
  select(-SSB_units, -TC_units) %>%
  group_by(stockid) %>%
```

```

mutate(scaled_catch = TC / max(SSB),
       scaled_biomass = SSB / max(SSB))

stock_ids <- c("PLAICNS", "ARGHAKENARG")
examples <- df2 %>%
  filter(stockid %in% stock_ids) %>%
  ungroup() %>%
  group_by(commonname)

## Model does not estimate sigma_m; data is insufficient to do so.
gs_code <- nimble::nimbleCode({
  r ~ dunif(0, 2)
  K ~ dunif(0, 2)
  sigma ~ dunif(0, 1)

  x[1] <- x0
  for(t in 1:(N-1)){
    mu[t] <- x[t] + x[t] * r * (1 - x[t] / K) - min(a[t], x[t])
    x[t+1] ~ dnorm(mu[t], sd = sigma)
  }
})

fit_models <- function(fish, code){
  # fish <- examples %>% filter(stockid == stock_ids[1])

  ## Rescale data
  N <- dim(fish)[1]
  scaled_data <- data.frame(t = 1:N, y = fish$scaled_biomass, a = fish$scaled_catch)
  data = data.frame(x = scaled_data$y)

  ## Compile model
  constants <- list(N = N, a = scaled_data$a)
  inits <- list(r = 0.5, K = 0.5, sigma = 0.02, x0 = scaled_data$y[1])
  model <- nimbleModel(code, constants, data, inits)
  C_model <- compileNimble(model)

  mcmcspec <- configureMCMC(model, thin = 1e2)
  mcmc <- buildMCMC(mcmcspec)
  Ccmc <- compileNimble(mcmc, project = model)
  Ccmc$run(1e6)

  samples <- as.data.frame(as.matrix(Ccmc$mvSamples))
  burnin <- 1:(0.05 * dim(samples)[1]) # drop first 5%
  samples <- samples[-burnin, 1:(length(inits) - 1)] # drop raised vars, burnin
  #gather(samples) %>% ggplot() + geom_density(aes(value)) + facet_wrap(~key, scale='free')

  ## Return fit
  data.frame(stockid = fish$stockid[1],
             commonname = fish$commonname[1],
             r = mean(samples$r),
             K = mean(samples$K),
             sigma_g = mean(samples$sigma),
             r_sd = sd(samples$r),

```

```

      K_sd = sd(samples$K),
      sigma_g_sd = sd(samples$sigma),
      stringsAsFactors = FALSE)
}

set.seed(123)
fits <- examples %>% do(fit_models(., code=gs_code))

|-----|-----|-----|-----|
|-----|-----|-----|-----|
|-----|-----|-----|-----|
|-----|-----|-----|-----|

fits

# A tibble: 2 x 8
# Groups:   commonname [2]
  stockid commonname      r      K sigma_g  r_sd K_sd sigma_g_sd
  <chr>    <chr>      <dbl> <dbl>   <dbl> <dbl> <dbl>   <dbl>
1 ARGHAKENARG Argentine hake  1.04  1.20  0.112 0.177 0.188  0.0263
2 PLAICNS    European Plaice 0.906  1.78  0.128 0.0734 0.155  0.0130

pars <- fits %>% ungroup() %>% select(commonname, r, K, sigma_g)
pars

```

| commonname | r | K | sigma_g |
|-----------------|-----------|----------|-----------|
| Argentine hake | 1.0387783 | 1.196112 | 0.1118370 |
| European Plaice | 0.9055933 | 1.778186 | 0.1275455 |

Calculations of the Decision Policies for Historical Data

```

options(mc.cores = parallel::detectCores()) # Reserve ~ 10 GB per core
log_dir <- "../data/ram_ex"

## Classic Graham-Schaefer. Note that recruitment occurs *before* harvest
gs <- function(r,K){
  function(x, h){
    x + x * r * (1 - x / K) - pmin(x,h)
  }
}
reward_fn <- function(x,h) pmin(x,h)
discount <- .95

```

Discretize space

Note that the large values of K require we carry the numerical grid out further.

```
states <- seq(0,4, length=150)
actions <- states
observations <- states
```

Consider all parameter values combinations for which we want solutions (both species at each of three possible levels of measurement uncertainty; though we will focus on the 0.1 level for simplicity as overall pattern is the same at 0.15):

```
meta <- expand.grid(commonname = pars$commonname,
                   sigma_m = c(0, 0.1, 0.15),
                   stringsAsFactors = FALSE) %>%
  left_join(pars) %>%
  mutate(scenario = as.character(1:length(sigma_m)))
```

```
meta
```

| commonname | sigma_m | r | K | sigma_g | scenario |
|-----------------|---------|-----------|----------|-----------|----------|
| Argentine hake | 0.00 | 1.0387783 | 1.196112 | 0.1118370 | 1 |
| European Plaice | 0.00 | 0.9055933 | 1.778186 | 0.1275455 | 2 |
| Argentine hake | 0.10 | 1.0387783 | 1.196112 | 0.1118370 | 3 |
| European Plaice | 0.10 | 0.9055933 | 1.778186 | 0.1275455 | 4 |
| Argentine hake | 0.15 | 1.0387783 | 1.196112 | 0.1118370 | 5 |
| European Plaice | 0.15 | 0.9055933 | 1.778186 | 0.1275455 | 6 |

Create the model matrices (transition, observation, and reward matrix):

```
models <-
  parallel::mclapply(1:dim(meta)[1],
    function(i){
      fisheries_matrices(
        states = states,
        actions = actions,
        observed_states = observations,
        reward_fn = reward_fn,
        f = gs(meta[i, "r"][[1]], meta[i, "K"][[1]]),
        sigma_g = meta[i, "sigma_g"][[1]],
        sigma_m = meta[i, "sigma_m"][[1]],
        noise = "normal")
    })
```

Here's the slowest part: computing POMDP alpha vectors.

```
dir.create(log_dir)
options(mc.cores = 1)

## POMDP solution (slow, >20,000 seconds per loop memory intensive)
system.time(
  alphas <-
    parallel::mclapply(1:length(models),
      function(i){
        log_data <- data.frame(model = "gs",
                                r = meta[i, "r"][[1]],
                                K = meta[i, "K"][[1]],
                                sigma_g = meta[i, "sigma_g"][[1]],
```

```

        sigma_m = meta[i, "sigma_m"][[1]],
        noise = "normal",
        commonname = meta[i, "commonname"][[1]],
        scenario = meta[i, "scenario"][[1]])

    sarsop(models[[i]]$transition,
           models[[i]]$observation,
           models[[i]]$reward,
           discount = discount,
           precision = 2e-6,
           timeout = 25000,
           log_dir = log_dir,
           log_data = log_data)
  })
)

meta <- meta_from_log(data.frame(model="gs"), log_dir) %>%
  mutate(scenario = as.character(scenario)) %>%
  left_join(
    select(meta, sigma_m, commonname, scenario),
    by = c("scenario", "sigma_m", "commonname")) %>%
  arrange(scenario)
alphas <- alphas_from_log(meta, log_dir)
#models <- models_from_log(meta)

```

Comparison to the static models

```

pars <- examples %>%
  group_by(commonname) %>%
  summarise(N = max(SSB)) %>%
  right_join(
    meta %>%
      select(commonname, r, K) %>%
      distinct())

```

Add corresponding static policy levels on:

```

statics <- function(P){
  f <- gs(P$r, P$K)
  S_star <- optimize(function(x) -f(x,0) + x / discount, c(0, 2* P$K))$minimum
  B_MSY <- S_star
  MSY <- f(B_MSY,0) - B_MSY

  tibble(S_star, F_MSY = MSY / B_MSY, F_TAC = 0.8 * F_MSY,
         commonname = P$commonname, N = P$N)
}

policy_pars <-
  pars %>%
  rowwise() %>%
  do(statics(.))

```

Convert example data into discrete index space.

```

index <- function(x, grid) map_int(x, ~ which.min(abs(.x - grid)))
## repeats each series for each static model
ex <- examples %>%
  mutate(biomass = index(scaled_biomass, states),
         catch = index(scaled_catch, actions)) %>%
  left_join(policy_pars) %>%
  left_join(pars) %>%
  ungroup()

```

Static policy calculations:

```

CE_f <- function(S_star, r, K, i)
  index(pmax(gs(r[[1]],K[[1]])(states,0) - S_star[[1]],0), actions)[i]
MSY_f <- function(F_MSY, i) index(states * F_MSY[[1]], actions)[i]
TAC_f <- function(F_TAC, i) index(states * F_TAC[[1]], actions)[i]
rescale <- function(x, N) states[x]*N

historical <- ex %>%
  group_by(commonname) %>%
  mutate(CE = CE_f(S_star, r, K, biomass),
         MSY = MSY_f(F_MSY, biomass),
         TAC = TAC_f(F_TAC, biomass)) %>%
  select(year, biomass, catch, CE, MSY, TAC, commonname, N) %>%
  gather(model, stock, -year, -commonname, -N) %>%
  mutate(stock = states[stock] * N) %>%
  select(-N)

```

Compute POMDP policy for historical data:

```

set.seed(123456)
pomdp_sims <-
  pmap_dfr(list(models, alphas, 1:dim(meta)[[1]]),
    function(.x, .y, .z){

      ## avoid NSE
      who <- (ex$commonname == meta[.z,"commonname"])
      df <- ex[who,]

      hindcast_pomdp(.x$transition, .x$observation, .x$reward, discount,
                     obs = index(df$scaled_biomass, states),
                     action = index(df$scaled_catch, states),
                     alpha = .y)$df %>%
        mutate(method = "pomdp") %>% # include a column labeling method
        mutate(year = ex[who, "year"][[1]])
    },
    .id = "scenario")

```

Join records:

```

pomdp_sims <-
  meta %>%
  select(scenario, commonname, sigma_m) %>%
  left_join(pars) %>%
  right_join(pomdp_sims)

```

```

sims <- pomdp_sims %>%
  mutate(optimal = states[optimal] * N) %>% # original scale
  select(year, optimal, commonname, sigma_m) %>%
  rename(stock = optimal) %>%
  ## treat each sigma_m value as separate 'model'
  mutate(sigma_m = as.factor(sigma_m)) %>%
  mutate(model = recode(sigma_m,
                        "0" = "CE",
                        "0.1" = "POMDP",
                        "0.15" = "POMDP_0.15")) %>%

  select(-sigma_m) %>%
  bind_rows(historical)

write_csv(sims, file.path(log_dir, "ram_ex.csv"))

```

Final plot, as in paper but including MSY:

```

ram_ex <- read_csv(file.path(log_dir, "ram_ex.csv"))
ram_ex %>%
  filter(model %in% c("biomass", "catch", "POMDP", "CE", "TAC", "MSY")) %>%
  ggplot(aes(year, stock, col=model)) +
  geom_line(lwd=1) +
  scale_color_manual(values = colors) +
  facet_wrap(~commonname, scales = "free", ncol=1)

```

