R Package: Metafolio

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What does the package do?

Metafolio simulates meta populations and applies **financial portfolio optimization concepts** to those metapopulations. **This is a package that optimizes spatial conservation strategies.**

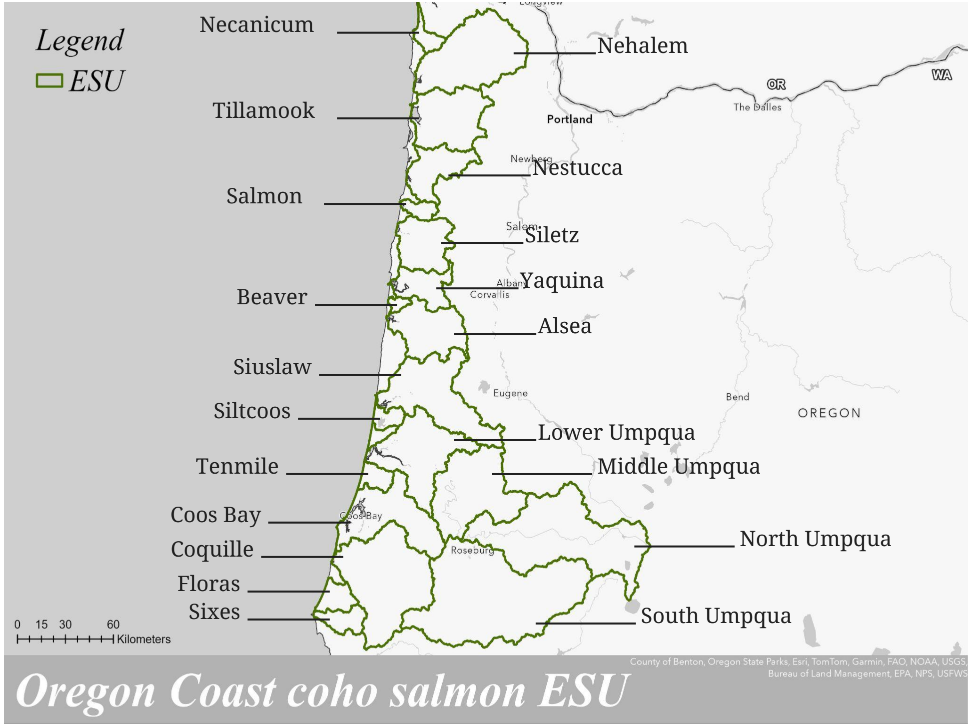
Goal of portfolio optimization is to **increase the return** on investment from portfolios and **minimize variance** on the returning portfolios.

Metafolio is best suited for salmon populations, but can be applied to other species potentially.

Background: What is a metapopulation?

Metapopulation is a **group of spatially separated populations** that **interact or exchange genetic material at some level.**

The Oregon Coast coho salmon has **21 individual populations.**



What type of problems can metafolio address?

Metafolio can help us understand:

1. How to make **optimal investments** to the metapopulations for spatial recovery planning

2. How to **choose optimal portfolios** that promote population stability (**reduce variance and increase population abundance by quantifying carrying capacity and productivity**)

3. How to identify optimal vs non optimal portfolios

4. What are the impacts of restorative actions on fish populations?

A (very) brief overview of Portfolio Theory

The overall goal of portfolio theory is to maximize returns for a given level of variance.

Three variables need to be defined: the portfolio, the assets, and the weights. In the context of metafolio, they are defined as:

Portfolio: Metapopulation
Assets: Individual populations that make up the metapopulation
Weights: Capacity of the population

Model Overview

Ricker Model: Spawner-Returner Relationship

$$R_{i(t+1)} = S_{i(t)} e^{a_{i(t)}\left(1 - \frac{S_{i(t)}}{b_i}\right) + w_{i(t)}}$$

Where:

R = Fish Return
S = Stock Abundance
a = Productivity
b = Carrying Capacity
w = weight
i = population

Model Overview

(2) Main functions within the package:

meta_sim() :Runs a single iteration simulation. Can be baseline scenario prior to conservation intervention

run_cons_plans() : Used to run meta_sim() for several iterations across multiple conservation strategies

(2) Optimization functions:

create_asset_weights() :Creates a matrix of asset weights for optimization

monte_carlo_portfolios() :Runs the optimization using the weights created from create_asset_weights()

(3) Plotting functions:

plot_sim_ts()

plot_cons_plans()

plot_efficient_frontier()

Type of Data Needed?

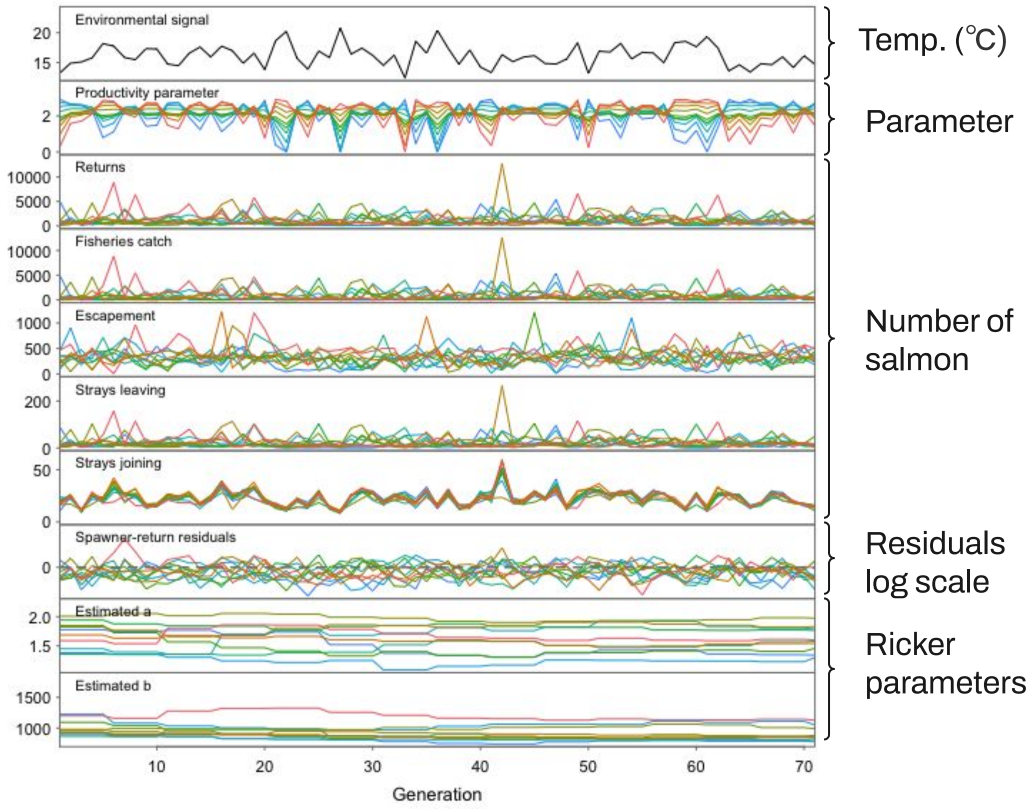
1. Matrix of population abundances over time

2. Environmental parameters specific to a given spatial strategy of conservation
   a. Thermal Tolerance

Example Code continued...

Starting with a base scenario:

```
## Example simulation - create environmental parameters
```{r}
arma_env_params <- list(mean_value = 16, # mean
                        ar = 0.1, # auto regressive parameter
                        sigma_env = 2, # std deviation of env signal
                        ma = 0) # moving average parameter
```

Run base simulation
```{r}
## define base simulation:
base1 <- meta_sim(n_pop = 10, # simulate 10 population
                  env_params = arma_env_params,
                  env_type = "arma",
                  assess_freq = 5) # reassess the fishery every 5 years

# plot base simulation
plot_sim_ts(base1, years_to_show = 70, burn = 30)
```
```

Example Code Continued…

Plot base scenario:

Baseline scenario at stationary environmental stochasticity and parameter values



Example Code Continued…

Using the baseline scenario, we can explore different conservation strategies by creating weights

```
## Exploring prioritization strategies
```{r}
## create conservation plans
# balanced: conserve response diversity from across all possible responses
# one half: conserve one half of the response diversity

w_plans <- list()
w_plans[["balanced"]] <- c(5, 1000, 5, 1000, 5, 5, 1000, 5, 1000, 5)
w_plans[["one_half"]] <- c(rep(1000, 4), rep(5, 6))
```
```

w_plans	list [2]	List of length 2
balanced	double [10]	5 1000 5 1000 5 5 ...
one_half	double [10]	1000 1000 1000 1000 5 5 ...

Weight of 5: no investment in population; weight of 1000: investment in population

```
```{r}
# create list of weights
w <- list()
for(i in 1:2) { # loop over plans
w[[i]] <- list()
for(j in 1:80) { # loop over iterations
w[[i]][[j]] <- matrix(w_plans[[i]], nrow = 1)
}
}
```
```

w	list [2]	List of length 2
[[1]]	list [80]	List of length 80
[[2]]	list [80]	List of length 80

Example Code Continued...

Using our weights, we can run simulations to explore different prioritization strategies for conservation

```
# run simulation with conservation plans
```{r}
set.seed(1)

# run the conservation plan with our weights
arma_sp <- run_cons_plans(w,
                          env_type = "arma", # same as base scenario
                          env_params = arma_env_params) # same as base scenario

plot_cons_plans(arma_sp$plans_mv,
                plans_name = c("Balanced", "One half"),
                cols = c("#EE7C11", "#377EB8"), xlab = "Variance of growth rate",
                ylab = "Mean growth rate")
```
```

Results

prioritizing populations for investment

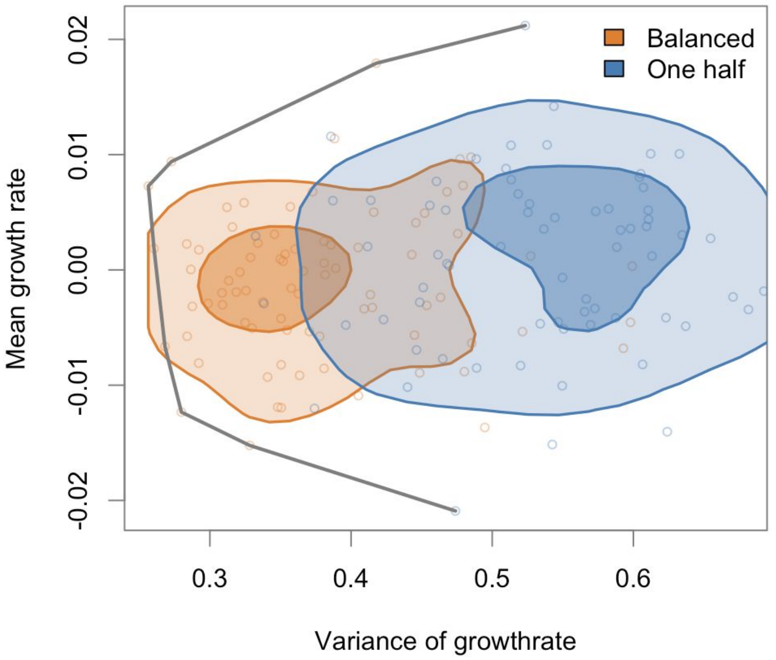
Figure shows **two spatial conservation strategies** in a risk–return space with stationary environmental stochasticity.

1. *All populations (10) are conserved (orange)*
2. *Half of the populations are conserved (blue)*

Grey line is the **efficient frontier** that represents the **minimum expected mean growth rate** for a given expected **variance in populations.**

An efficient portfolio will maximize returns, while minimizing variance.

Dots show **meta-populations** across all simulated meta populations (80 simulations).

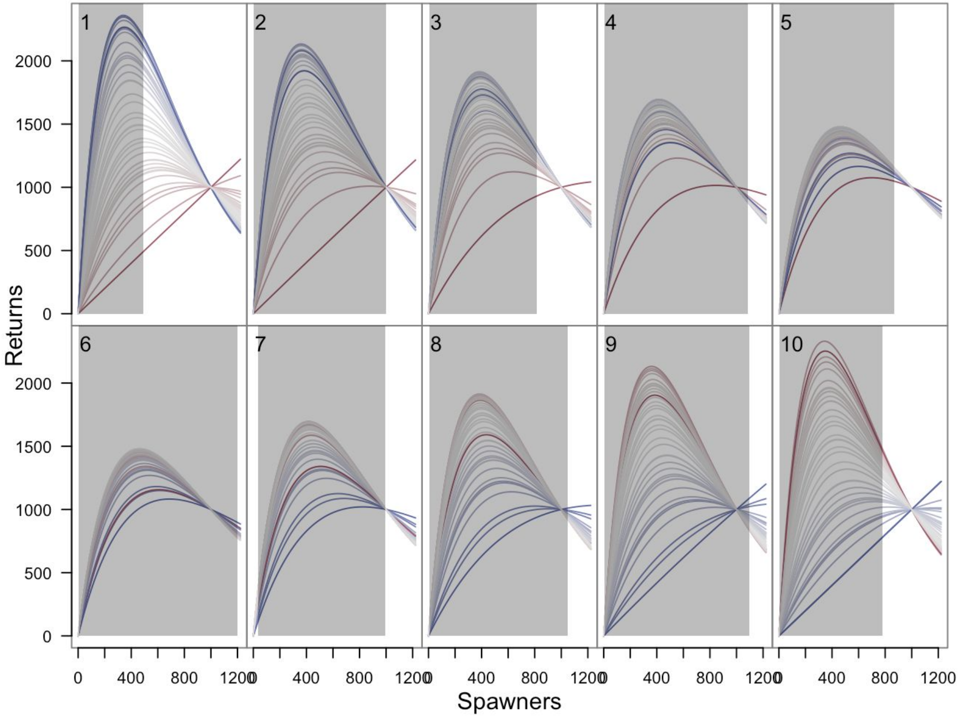


Results

Plotting additional functions

```{r}
# visualize variability in Ricker alpha parameter
plot_rickers(base1, pal = rep("black", 10))
```

Each panel represents a different stream population. Population 1 is more productive in cool conditions and population 10 is more productive in warm conditions.



Results

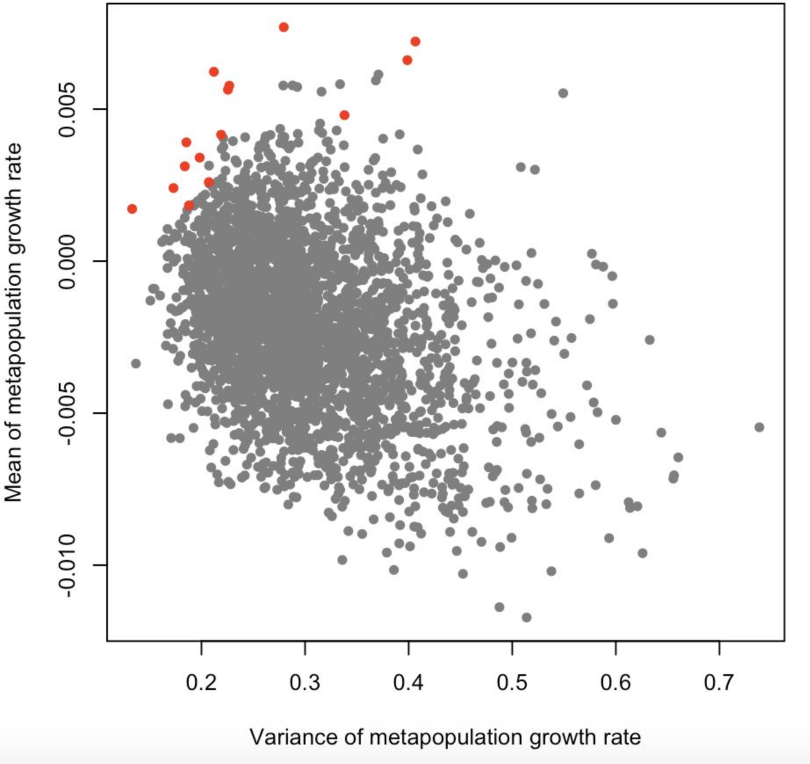
We can select the optimized portfolios by determining the efficient frontier

````
## Optimizing metapopulation portfolios
```{r}
set.seed(1)

weights_matrix <- create_asset_weights(n_pop = 6, n_sims = 3000,
  weight_lower_limit = 0.001)

mc_ports <- monte_carlo_portfolios(weights_matrix = weights_matrix,
  n_sims = 3000, mean_b = 1000)
```

```{r}
ef_dat <- plot_efficient_portfolios(port_vals = mc_ports$port_vals)
```
````

Results

visualizing thermal tolerance conditions and efficient frontier showing meta populations

Red dots are efficient portfolios that **maximize return of salmon for a given level of variance.**



Advantages and Limitations of Metafolio

Advantages:

- Metapopulation analysis
- Allows for the direct comparison of returns and variance from different conservation scenarios
- The results can aid in which type of conservation scenario is optimal
    - For example, should we conserve all thermal tolerances or just one type of thermal tolerance?
- In this example, the results can be used to help build metapopulation resilience in the face of climate change

Limitations:

- Largely limited to salmon simulations
- Analysis requires a metapopulation
- Requires different forms of environmental data for a given conservation scenario
- Uses a single life-stage population model (Ricker model)

Unique Insight

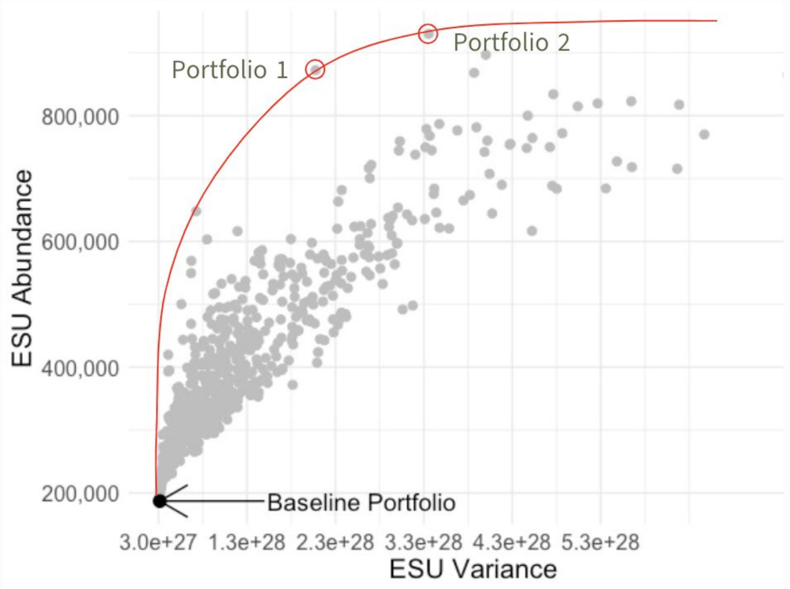
Portfolio theory can be applied in many different ways: salmon conservation, fishery management...etc.

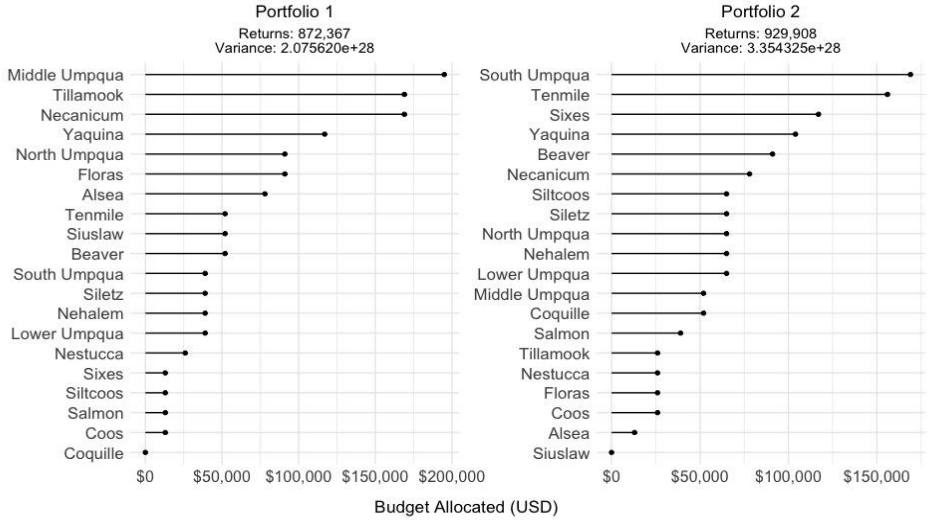
A new application of MPT that our group developed as part of our Group Project with the Wild Salmon Center is: ***Applying an endogenous application of portfolio theory for spatial recovery planning for Oregon Coast coho salmon.***

Our research question is: ***How can we differentially allocate a fixed budget across a metapopulation to maximize salmon returns for a given level of variance?***

- ***Portfolio:*** Oregon Coast coho salmon
- ***Assets:*** 21 Individual populations
- ***Weights:*** Conservation Dollars

Unique Insight





Resources

[Vignette]

An introduction to the metafolio R package

Sean C. Anderson[1*], Jonathan W. Moore[1,2], Michelle M. McClure[3], Nicholas K. Dulvy[1] Andrew B. Cooper[2]

[Metafolio Manual]

Package 'metafolio'

October 20, 2023

Type Package

Title Metapopulation Simulations for Conserving Salmon Through Portfolio Optimization

Version 0.1.2

Description A tool to simulate salmon metapopulations and apply financial portfolio optimization concepts. The package accompanies the paper Anderson et al. (2015) <doi:10.1101/2022.03.24.485545>.

License GPL-2

URL https://github.com/seananderson/metafolio

BugReports https://github.com/seananderson/metafolio/issues

VignetteBuilder knitr

Depends R (>= 3.5.0)

LinkingTo Rcpp, RcppArmadillo

Imports Rcpp (>= 0.11.2), plyr, colorspace, MASS

Suggests knitr, TeachingDemos, RColorBrewer, reshape2

RoxygenNote 7.2.3

Encoding UTF-8

[Literature]

Portfolio conservation of metapopulations under climate change

Sean C. Anderson[1*] Jonathan W. Moore[1,2] Michelle M. McClure[3] Nicholas K. Dulvy[1] Andrew B. Cooper[2]

MPT Related Resources

- ➔ *Identifying the Potential of anadromous salmonid habitat restoration with life cycle models:*
- ➔ *Optimizing provisions of ecosystem services suring modern portfolio theory*
- ➔ *Optimal Portfolio Design to reduce climate-related conservation uncertainty in the Prairie Pothole Region.*

Portfolio Assignment

1. We evaluated 10 individual populations as our baseline meta population. **Change the number of populations in the baseline scenario within the meta_sim() function and plot the results.**
   ➔ *How does this affect the base simulation plot (plot_sim_ts)?*

2. **Change the weight allocation for the 'balanced' conservation strategy so that all 10 populations receive a maximum investment (i.e. 1000) and plot the results.**
   ➔ *How does the variance and mean of the growth rate shift?*
   ➔ *Does it shift the efficiency frontier?*
   ➔ *Of the two conservation plans, which portfolio is optimal? Why?*

3. **What are some other examples of environmental conditions for salmonids that would be beneficial to model using this package?**

Thanks! Questions?