

Unnecessarily Complicated Research Title

John Smith

California, United States

Abstract

Keywords: Science, Publication, Complicated

1. Introduction

- Risk and uncertainty
- One rule for all?
- Impact of life histories
- Comparison of constant catch v changing catch based on trends in an empirical index.
- catch only - need good catch data if you havent got this how can you set catch limits

Sustainability and risks to non target exploited marine fish stock populations requires both estimates of current stock status, the effects of fishing pressure (catchability and fishing effort) and the effects of management measures on target populations, however these data are often lacking. Subsequently there is increasing concern and a growing need for the development of innovative approaches so that management of all marine stocks not just those of high commercial value can be included into the Common Fisheries Policy (CFP [1]) framework. Under the CFP management objectives are to recover stocks and to maintain stocks within safe biological limits to levels that can produce Maximum Sustainable Yield (MSY), including by-catch species by 2015 (Implementation Plan adopted at the World Summit on Sustainable Development, Johannesburg in 2002) and no later than 2020. These conservation objectives are currently being achieved by introducing

biological target (can fluctuate around targets) and limit (i.e must not be exceeded) reference points e.g. population size (stock biomass) and/or yields (catches) and/or long-term yields and fishing mortality against which the preservation of stocks within such limits are assessed. These targets or limit reference points are often referred to as harvesting strategies which include an operational component called a harvest control rule (HCR) that are based on indicators (e.g. monitoring data or models) of stock status and to prevent overfishing.

The International Council for the Exploration of the Sea (ICES) categorises stocks in to classes *data-rich*, (categories 1 and 2) i.e those that have a quantitative assessment based on conventional methods that require large amounts of data that include a long historical time series of catches and sound biological information [2]; or *data-limited* [3](categories 3 and 4) (often called data poor) those without assessment, forecasts and have limited funding for research. For data-rich stocks ICES uses two types of reference points for providing fisheries advice;

1. Precautionary Approach (PA) reference points (those relating to stock status and exploitation relative to precautionary objectives) and
2. MSY reference points (those relating to achieving MSY)

In contrast for data limited stocks MSY *proxy* reference points are used to estimate stock status and exploitation. Often many of the methods used to estimate MSY proxy reference points require length based inputs as they are cheap, easy to collect [4] and are related to life history parameters such as fish size, mortality and fecundity as well as fishery selectivity. For example many methods are being developed to estimate MSY, but currently only 4 are approved by ICES, these include, Surplus Production model in Continuous Time (catch based) (SPiCT; [5], Mean Length Z (MLZ; [6]), Length Based Spawner Per Recruit (LBSPR; [7]) and Length Based Indicators (LBI; e.g. [8]). The aforementioned data limited procedures have differing data requirements, intended uses and obviously have their own strengths and weaknesses.

To test the performance of candidate management procedures often requires evaluation of alternative hypothesis about the dynamics of the system e.g. population dynamics (life history dynamics such as growth parameters which are an indication of fishery exploitation levels and management) and the behaviour of the fishery (e.g range contraction and density dependence) etc.. Due to the nature of conflicting objectives, stakeholder interests and the uncertainty in the dynamics of the resource and/or the plausibility of alter-

native hypotheses can lead to poor decision making and can be problematic when defining management policy.

An intense area of work being researched over the last 2 decades is Management Strategy Evaluation (MSE), which focuses on the broader aspects of fishing (the Ecosystem) whereby different management options are tested against a range of objectives (see [9]). The approach is not to come up with a definitive answer, but to lay-bare the trade offs associated with each management objective, along with identifying and incorporating uncertainties in the evaluation and communicating the results effectively to client groups and decision-makers. MSE is not intended to be complex but to provide a robust framework that account for conflicting poorly defined objectives and uncertainties that have been absent in conventional management [9].

To assess case specific harvest strategies (via simulation) within the MSE, we will implement a management procedure based on a empirical HCR that adjusts yield depending on stock status for a given set of tunable parameters for each of the harvest strategies and to test their robustness to uncertainty. This approach could also help identify similar conditions across species where particular advice rules are likely to work well, and where they perform poorly for a given a set of parameters.

Often empirical harvest control rules require extensive exhaustive parameter searches to tune or optimise 'hyper-parameters' (external parameters to a model) that aren't directly learnt from estimators. This requires a technique known as a grid search that extensively searches for all combinations of all parameters. In contrast, and some what less time consuming alternative and efficient parameter search strategies can be considered for a given range of parameter space and a known distribution. As such a random sample can be obtained and used to perform the different experiments for parameter optimisation. This approach differs from the simplest constant catch HCR strategy whereby catches are kept constant and low to ensure no lasting damage is done in periods of low stock productivity or whereby the stock is highly variable year on year, therefore the empirical approach can help optimise catch by setting a precautionary Total Allowable Catch (TAC).

Here we describe methods to assess the performance of each empirical HCR via a set of utilities and show the benefits compared to a constant catch strategy across a spectrum of different species: safety ($B/B_{MSY} > 1$), yield ($yield/MSY$), kobe proportion (proportion of years that stay in the green zone of kobe plot ($B/B_{MSY} > 1$), and Yield Annual Variation (yield changes by 10% year on year).

2. Material and Methods

2.1. Materials

Life history parameters for growth, natural mortality and maturity were used to develop an age-based Operating Model. To do this the parameters were first used to parameterise functional forms for mass (W), proportion mature (Q), natural mortality (M) and fishing mortality (F) at age. These were then used to calculate the spawner (S/R) and yield-per-recruit (Y/R) which were then combined with a stock recruitment relationship [10] to calculate the equilibrium stock size as a function of fishing mortality (F).

This analysis allows a variety of reference points such as those based on Maximum Sustainable Yield (MSY), i.e. B_{MSY} the spawning stock biomass (S) and F_{MSY} the fishing mortality that produces MSY at equilibrium to be estimated. Other reference points are $F_{0.1}$ the fishing mortality on the yield per recruit curve where the slope is 10% of that at the origin, a conservative proxy for F_{MSY} ; and F_{Crash} which is the fishing mortality that will drive the stock to extinction since it is equivalent to a R/S greater than the slope at the origin of the stock recruitment relationship, i.e. recruitment can not replace removals for a fishing mortality equal to F_{Crash} .

The equilibrium relationships can then be turned into a forward dynamic model and projected forward.

A variety of functional forms can be assumed for all of the various process, i.e. growth, mortality, maturity, the selection pattern of the fisheries and the stock recruitment relationship. Commonly processes such as growth and maturity-at-age are well known while those for natural mortality and the stock recruitment relationship are poorly known [11]. In the later case assumptions have to be made and to evaluate the sensitivity of any analysis to those assumptions a variety of scenarios are considered.

2.2. Methods

Individual Growth

Growth in length is modelled by the Von Bertalanffy growth equation [12]

$$L = L_{\infty}(1 - \exp(-k(t - t_0))) \quad (1)$$

where k is the rate at which the rate of growth in length declines as length approaches the asymptotic length L_{∞} and t_0 is the hypothetical time at which an individual is of zero length.

130 Length is converted to mass using the length-weight relationship

$$W = aL_t^b \quad (2)$$

131 where a is the condition factor and b is the allometric growth coefficient.

132 Maturity-at-age

133 Proportion mature-at-age is modelled by the logistic equation with 2 pa-
134 rameters: age at 50% (a_{50}) and 95% (a_{95}) mature.

$$f(x) = \begin{cases} 0 & \text{if } (a_{50} - x)/a_{95} > 5 \\ a_{\infty} & \text{if } (a_{50} - x)/a_{95} < -5 \\ \frac{m_{\infty}}{1.0 + 19.0^{(a_{50} - x)/95}} & \text{otherwise} \end{cases} \quad (3)$$

135 Selection Pattern

136 By default the fishery is assumed to catch mature fish and so the selection
137 pattern is based on the maturity ogive. It is modelled by a double normal
138 curve, however, to allow scenarios to be implemented where older fish are
139 less vulnerable to the fisheries.

140 The double normal has three parameters that describe the age at maxi-
141 mum selection ($a1$), the rate at which the left-hand limb increases (sl) and
142 the right-hand limb decreases (sr) which allows flat topped or domed shaped
143 selection patterns to be chosen, i.e.

$$f(x) = \begin{cases} 0 & \text{if } (a_{50} - x)/a_{95} > 5 \\ a_{\infty} & \text{if } (a_{50} - x)/a_{95} < -5 \\ \frac{m_{\infty}}{1.0 + 19.0^{(a_{50} - x)/95}} & \text{otherwise} \end{cases} \quad (4)$$

144 Stock Recruitment Relationship By default a Beverton and Holt stock
145 recruitment relationship [13] was assumed, This relationship is derived from
146 a simple density dependent mortality model where the more survivors there
147 are the higher the mortality. It is assumed that the number of recruits (R)
148 increases towards an asymptotic level (R_{max}) as egg production increases i.e.

$$R = Sa/(b + S) \quad (5)$$

149 The relationship between stock and recruitment was modelled by a Bev-
150 erton and Holt stock-recruitment relationship [13] reformulated in terms of
151 steepness (h), virgin biomass (v) and $S/R_{F=0}$. Where steepness is the propor-
152 tion of the expected recruitment produced at 20% of virgin biomass relative
153 to virgin recruitment (R_0). However, there is often insufficient information

154 to allow its estimation from stock assessment [14] and so by default a value
 155 of 0.8 was assumed. Virgin biomass was set at 1000 Mt to allow comparisons
 156 to be made across scenarios.

$$R = \frac{0.8R_0h}{0.2S/R_{F=0}R_0(1-h) + (h-0.2)S} \quad (6)$$

157 S the spawning stock biomass, is the sum of the products of the numbers
 158 of females, N , proportion mature-at-age, Q and their mean fecundity-at-age,
 159 G , which is taken to be proportional to their weight-at-age i.e.

$$S = \sum_{i=0}^p N_i Q_i W_i \quad (7)$$

160 where fecundity-at-age is assumed proportional to biomass and the sex
 161 ratio to be 1:1. Proportion mature is 50% at the age that attains a length of
 162 150, 0% below this age and 100% above.

163 2.2.1. Operating Model

164 Age based Equilibrium Analysis

165 [10], estimated surplus production using an age-based analysis using an
 166 equilibrium analysis that by combining a stock-recruitment relationship, a
 167 spawning-stock-biomass-per-recruit analysis, and a yield-per-recruit analysis.
 168 For any specified rate of fishing mortality, an associated value of spawning
 169 stock biomass (S) per recruit (R) is S/R is defined, based on the assumed
 170 processes for growth, natural mortality and selection pattern-at-age detailed
 171 in the previous sections.

$$S/R = \sum_{i=0}^{p-1} e^{\sum_{j=0}^{i-1} -F_j - M_j} W_i Q_i + e^{\sum_{i=0}^{p-1} -F_i - M_i} \frac{W_p Q_p}{1 - e^{-F_p - M_p}} \quad (8)$$

172 When the value of S/R obtained is inverted and superimposed on the
 173 stock-recruitment function as a slope (R/S), the intersection of this slope
 174 with the stock-recruitment function defines an equilibrium level of recruit-
 175 ment. When this value of recruitment is multiplied by the yield per recruit
 176 calculated for the same fishing mortality rate, the equilibrium yield associ-
 177 ated with the fishing mortality rate emerges [15].

$$Y/R = \sum_{a=r}^{n-1} e^{\sum_{i=r}^{a-1} -F_i - M_i} W_a \frac{F_a}{F_a + M_a} (1 - e^{-F_i - M_i}) + e^{\sum_{i=r}^{n-1} -F_i - M_i} W_n \frac{F_n}{F_n + M_n} \quad (9)$$

178 The second term is the plus-group, i.e. the summation of all ages from
179 the last age to infinity.

180 Forward Projection

181 The stock recruitment relationship and the vectors of weight, natural
182 mortality, maturity and selectivity-at-age allow a forward projection model
183 to be created, which forms the basis of the Operating Model.

$$N_{t,a} = \begin{cases} R_t, & \text{if } a = 0, \\ N_{t-1,a-1} e^{-Z_{t-1,a-1}}, & \text{if } 1 \leq a \leq A-1, \\ N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}}, & \text{if } a = A, \end{cases} \quad (10)$$

184 where $N_{t,a}$ is the number of fish of age a at the beginning of year t , R_t
185 is the total number of recruits born in year t . Here, A is the so-called plus
186 group age, which is an aggregated age greater than or equal to the actual
187 age A .

188 2.2.2. Management Procedure

189 The management procedure was based on an empirical MP, where an
190 increase in an index of abundance resulted in an increase in the TAC, while
191 a decrease in the index results in a decrease in the TAC.

192 2.2.3. Random Search

193 When running an MSE commonly a set of MP scenarios are run to tune
194 the MP, this requires running the MSE for each OM scenario for a range of
195 fixed values in the HCR and then choosing the rule that best meets manage-
196 ment objectives. If there are a lot of parameters to tune then a grid search
197 may become unfeasible. An alternative is random search [16] as randomly
198 chosen trials are more efficient for parameter optimisation than trials based
199 on a grid.

200 3. Results

201 Estimates of the simulated life history parameters obtained from Fishbase
 202 (<http://www.fishbase.org>) are presented in Fig.1. These show that for fast
 203 growing species which are small in size l_{∞} (asymptotic length parameter)
 204 species such as sprat, the growth parameter k is high. The sprats age-at-
 205 50%-maturity a_{50} are low, in contrast to a slower growing larger longer lived
 206 species l_{∞} such as rays or pollack.

207 Observations in Fig.2 shows the relationship of maturity in the OM to
 208 selectivity and that the faster growing species are more susceptible to fishing,
 209 although the slower growing larger (by mass and length) species (e.g. pollack
 210 has a higher natural mortality rate at lower ages) with the most significant
 211 natural mortality rate increases associated with turbot. A levelling off in the
 212 mortality rate is evident for ray just prior to age 4.5. In contrast, there have
 213 been less steep declines in natural mortality estimates for brill, but most
 214 notably for sprat.

215 Fig.3 displays the equilibrium relationships of the operating model. Com-
 216 parisons of reference points estimates can be made across species. The m/k
 217 plot shows interesting trends with lower values for sprat where the growth
 218 rate k is considerably higher than the natural mortality rate with little un-
 219 certainty around the estimate. In contrast to a slower growing species such as
 220 pollack where natural mortality is higher, as is the uncertainty around the es-
 221 timate. The relationships when compared the proxy for fishing pressure f/m
 222 show that the estimate is considerably higher in sprat than pollack, how-
 223 ever the intrinsic population growth rate r shows that sprats reproductive
 224 capacity is higher and thus its surplus production.

225 **[EXAMPLES TO BE UPDATED]**

- 226 • Figure 3 shows the life history parameters
- 227 • Figure 2 shows the vectors
- 228 • Figure 4 shows the time series relative to reference points
 - 229 1.
 - 230 2.
 - 231 3.
 - 232 4.
 - 233 5. Figure 5 shows the utility functions for the seven study stocks
 - 234 points area

- 235 1.
236 2.
237 3.
238 4.

239 4. Discussion

240 Fisheries management is often faced with multiple conflicting objectives
241 e.g social, biological and economic, and it is widely recognised that there is
242 a need to incorporate these objectives into management plans. However
243 such an experiment on large scale fish stocks is nearly impossible to perform.
244 Therefore performing computer simulations to develop robust management
245 procedures is particularly valuable in data poor situations where knowledge
246 and data are limited, but also in data rich situations as simulation testing an
247 assessment procedure using a model conditioned on the same assumptions is
248 not necessarily a true test of robustness.

249 The main ICES MSY objectives for category 3 and 4 stocks are to max-
250 imise long-term yield, in a manner that is consistent with precautionary prin-
251 ciples; i.e. having a low probability of falling outside biologically sustainable
252 limits. This paper has shown that the desired performance measures can
253 be met via tweaking of the management procedure by adjusting a particular
254 HCR, a specific management objective can be achieved. Here a simplistic
255 utility function was used to evaluate visually how well each HCR performed
256 and the uncertainties associated with the specific combinations.

- 257 • Bullet point one
258 • Bullet point two

259 5. Conclusions

- 260 • Bullet point one
261 • Bullet point two

6. References

References

- [1] E. Commission, Regulation (eu) no 1380/2013 of the european parliament and of the council of 11 december 2013 on the common fisheries policy, amending council regulations (ec) no 1954/2003 and (ec) no 1224/2009, and repealing council regulations (ec) no 2371/2002 and (ec) no 639/2004, and council decision 2004/585/ec (2013).
- [2] N. Bentley, Data and time poverty in fisheries estimation: potential approaches and solutions, *ICES J. Mar. Sci.* 72 (2015) 186–193.
- [3] C. Costello, D. Ovando, R. Hilborn, S. D. Gaines, O. Deschenes, S. E. Lester, Status and solutions for the world’s unassessed fisheries, *Science* (2012) 1224768.
- [4] T. J. Quinn, R. B. Deriso, Quantitative fish dynamics, Oxford University Press, 1999.
- [5] M. W. Pedersen, C. W. Berg, A stochastic surplus production model in continuous time, *Fish and Fisheries* 18 (2017) 226–243.
- [6] T. Gedamke, J. M. Hoenig, Estimating mortality from mean length data in nonequilibrium situations, with application to the assessment of goosfish, *Transactions of the American Fisheries Society* 135 (2006) 476–487.
- [7] A. Hordyk, K. Ono, K. Sainsbury, N. Loneragan, J. Prince, Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio, *ICES Journal of Marine Science* 72 (2014) 204–216.
- [8] W. N. Probst, M. Kloppmann, G. Kraus, Indicator-based status assessment of commercial fish species in the north sea according to the eu marine strategy framework directive (msfd), *ICES Journal of Marine Science* 70 (2013) 694–706.
- [9] L. Kell, I. Mosqueira, P. Grosjean, J. Fromentin, D. Garcia, R. Hillary, E. Jardim, S. Mardle, M. Pastoors, J. Poos, et al., FLR: an open-source framework for the evaluation and development of management strategies, *ICES J. Mar. Sci.* 64 (2007) 640.

- 294 [10] M. Sissenwine, J. Shepherd, An alternative perspective on recruitment
295 overfishing and biological reference points, *Can. J. Fish. Aquat. Sci.* 44
296 (1987) 913–918.
- 297 [11] C. G. Michielsens, M. K. McAllister, A bayesian hierarchical analysis of
298 stock recruit data: quantifying structural and parameter uncertainties,
299 *Can. J. Fish. Aquat. Sci.* 61 (2004) 1032–1047.
- 300 [12] L. Von Bertalanffy, Quantitative laws in metabolism and growth, *Quar-*
301 *terly Review of Biology* (1957) 217–231.
- 302 [13] R. Beverton, S. Holt, On the dynamics of exploited fish populations,
303 volume 11, Springer, 1993.
- 304 [14] P. Pepin, C. T. Marshall, Reconsidering the impossible???linking envi-
305 ronmental drivers to growth, mortality, and recruitment of fish 1, *Canad-*
306 *ian Journal of Fisheries and Aquatic Sciences* 72 (2015) 1–11.
- 307 [15] W. Gabriel, P. Mace, A review of biological reference points in the
308 context of the precautionary approach, in: *Proceedings of the fifth*
309 *national NMFS stock assessment workshop: providing scientific advice*
310 *to implement the precautionary approach under the Magnuson-Stevens*
311 *fishery conservation and management act*. NOAA Tech Memo NMFS-
312 F/SPO-40, pp. 34–45.
- 313 [16] J. Bergstra, Y. Bengio, Random search for hyper-parameter optimiza-
314 tion, *Journal of Machine Learning Research* 13 (2012) 281–305.

315 7. Figures

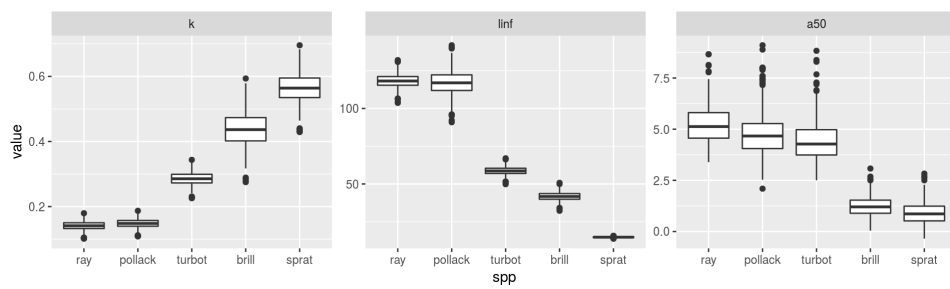


Figure 1:

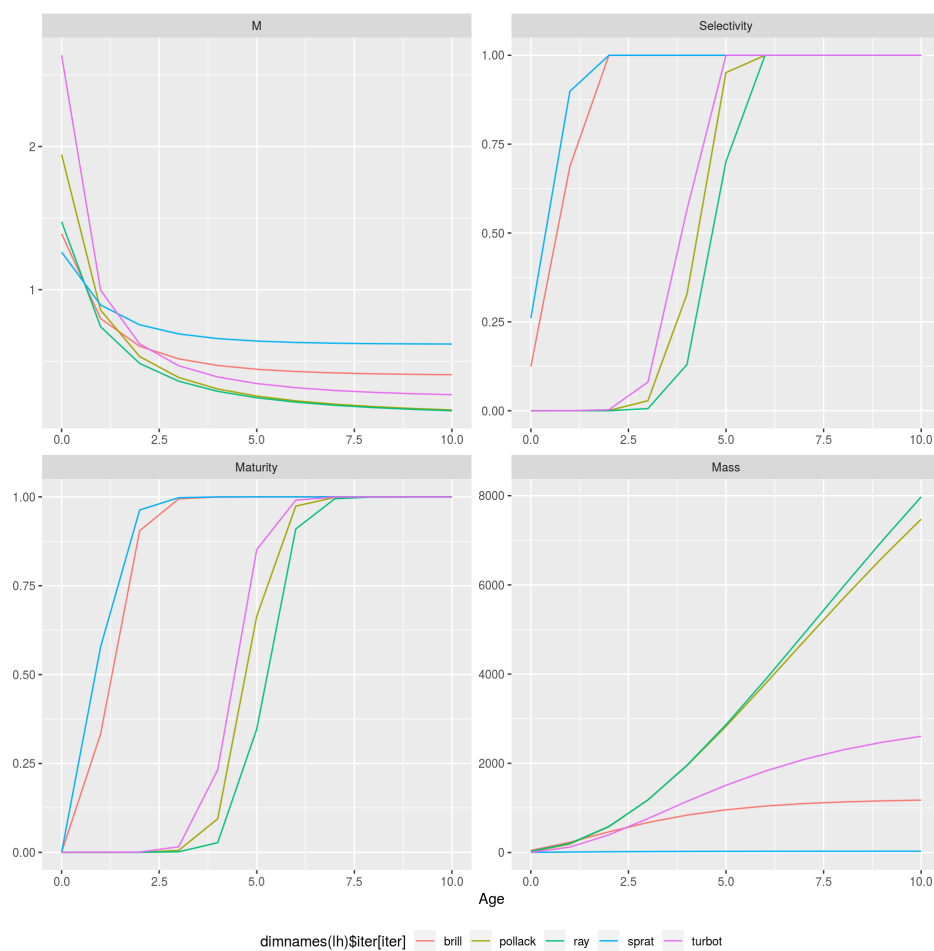


Figure 2:

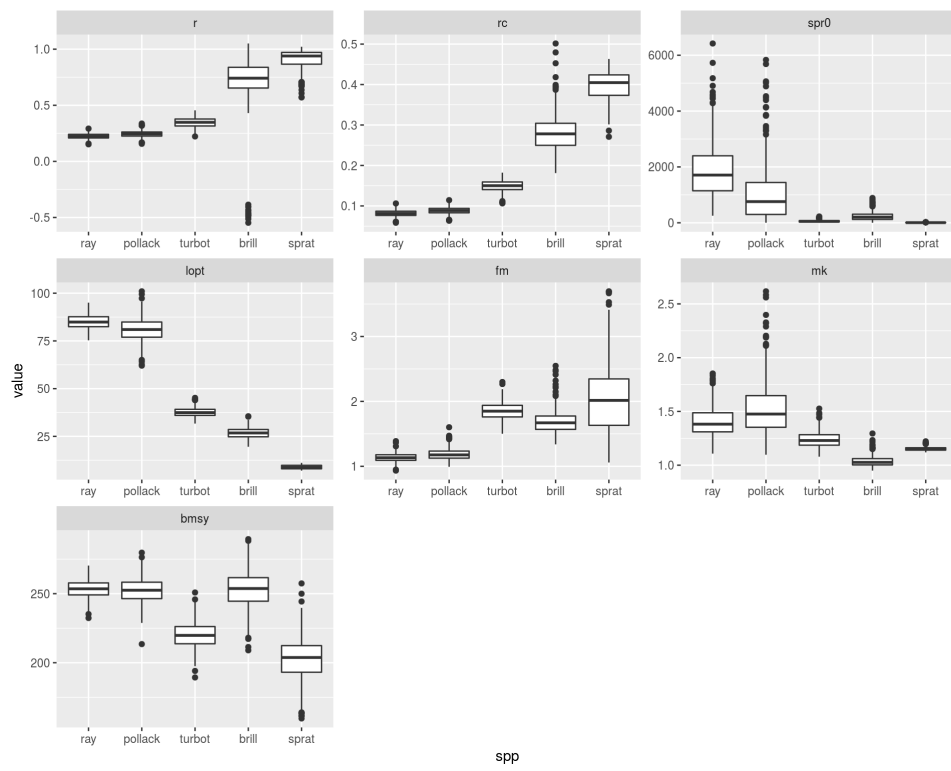


Figure 3:

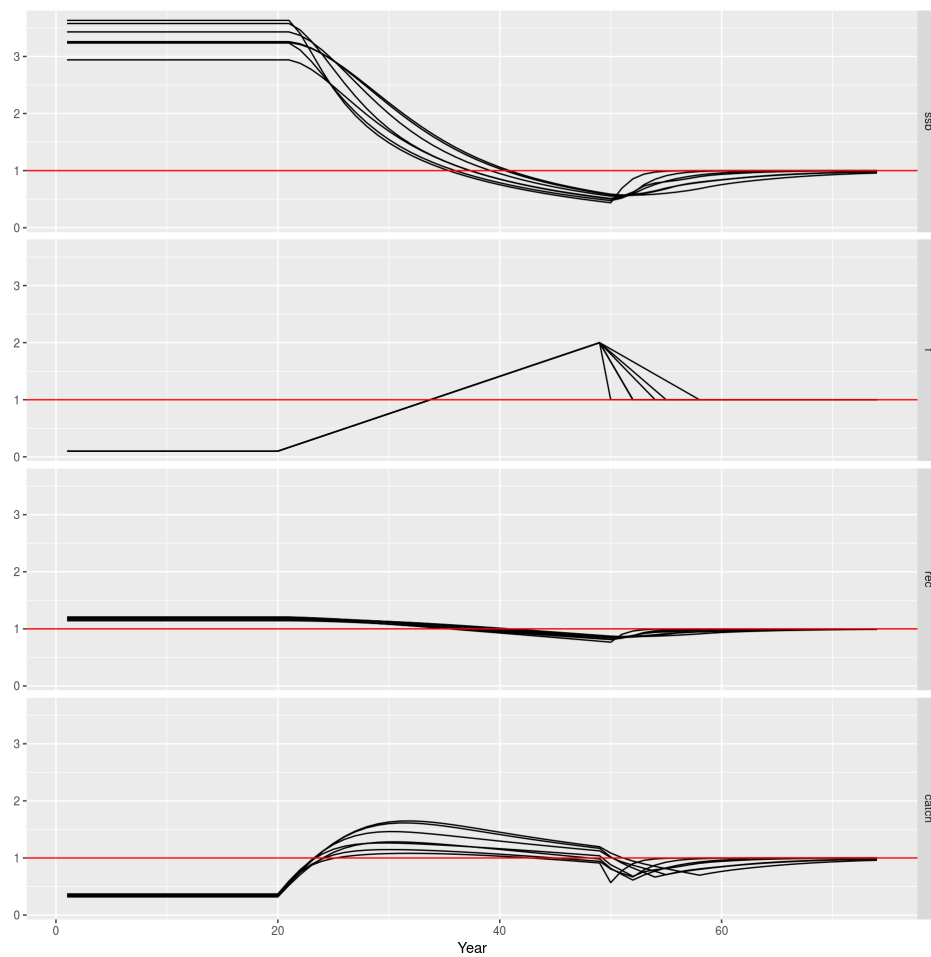


Figure 4:

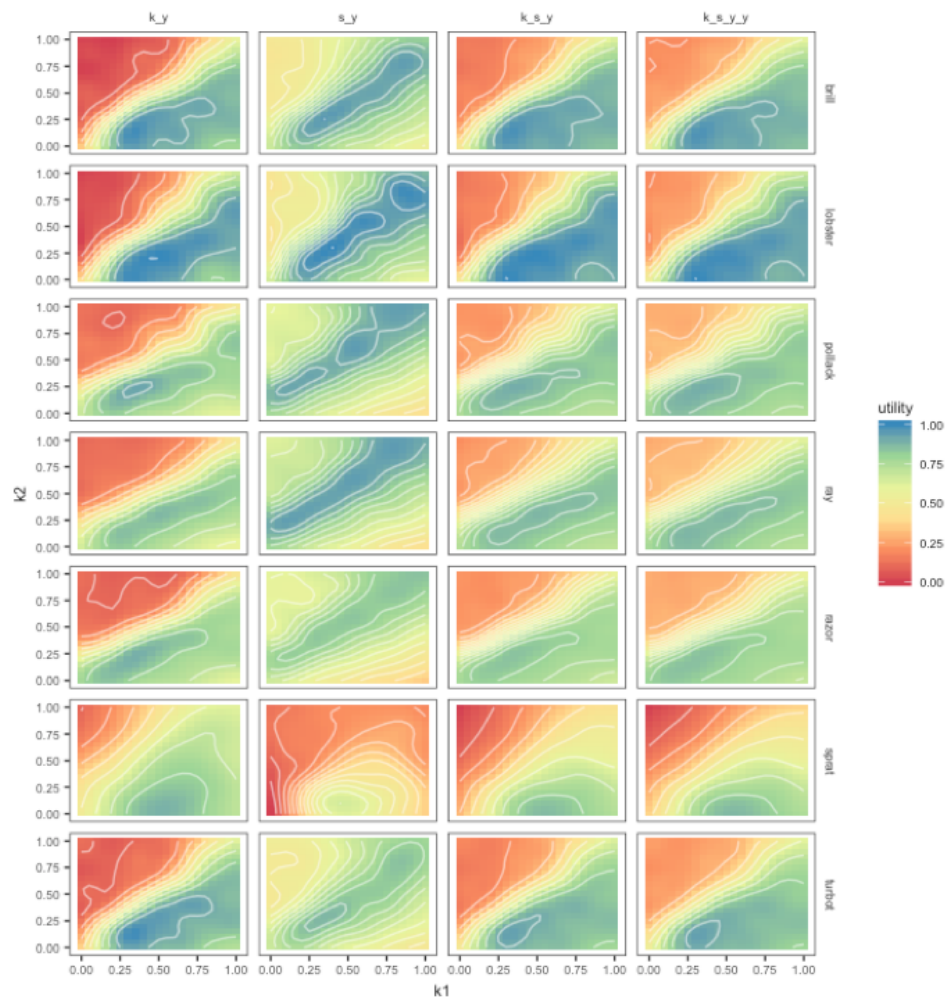


Figure 5: