

Unnecessary hyperparameter search

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Abstract

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1. Introduction

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 [1]. Subsequently there is increasing concern and a growing need for the development of effective more holistic approaches so that management of all marine stocks not just those of high commercial value can be included into the Common Fisheries Policy framework (CFP [2]). 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 [3] [4]. 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

18 the preservation of stocks within such limits are assessed. These targets or
19 limit reference points are often referred to as harvesting strategies which in-
20 clude an operational component called a harvest control rule (HCR) that are
21 based on indicators (e.g. monitoring data or models) of stock status and to
22 prevent overfishing.

23 The International Council for the Exploration of the Sea (ICES) cate-
24 gorises stocks in to classes *data-rich*, (categories 1 and 2) i.e those that have
25 a quantitative assessment based on conventional methods that require large
26 amounts of data that include a long historical time series of catches and
27 sound biological information [5]; or *data-limited* [6](categories 3 and 4) (of-
28 ten called data poor) those without assessment, forecasts and have limited
29 funding for research. For data-rich stocks ICES uses two types of reference
30 points for providing fisheries advice;

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

34 In contrast for data limited stocks MSY *proxy* reference points are used
35 to estimate stock status and exploitation. Often many of the methods used
36 to estimate MSY proxy reference points require length based inputs as they
37 are cheap, easy to collect [7] and are related to life history parameters such as
38 fish size, mortality and fecundity as well as fishery selectivity. For example
39 many methods are being developed to estimate MSY, but currently only 4 are
40 approved by ICES, these include, Surplus Production model in Continuous
41 Time (catch based) (SPiCT; [8], Mean Length Z (MLZ; [9]), Length Based
42 Spawner Per Recruit (LBSPR; [10]) and Length Based Indicators (LBI; e.g.

43 [11]). The aforementioned data limited procedures have differing data requirements,
44 intended uses and obviously have their own strengths and weaknesses.

45 To test the performance of candidate management procedures often requires evaluation of alternative hypothesis about the dynamics of the system
46 e.g. population dynamics (life history dynamics such as growth parameters
47 which are an indication of fishery exploitation levels and management) and
48 the behaviour of the fishery (e.g range contraction and density dependence)
49 etc.. Due to the nature of conflicting objectives, stakeholder interests and the
50 uncertainty in the dynamics of the resource and/or the plausibility of alter-
51 native hypotheses can lead to poor decision making and can be problematic
52 when defining management policy.

53 An intense area of work being researched over the last 2 decades is Management Strategy Evaluation (MSE), which focuses on the broader aspects
54 of fishing (the Ecosystem) whereby different management options are tested
55 against a range of multiple and conflicting biological (i.e. mixed fisheries
56 multispecies interactions [12]), economic (i.e. variability in yield [13], and
57 social objectives (i.e. full vs part time employment [14])). For instance the
58 approach is not to come up with a definitive answer, but to lay-bare the trade
59 offs associated with each management objective, along with identifying and
60 incorporating uncertainties in the evaluation and communicating the results
61 effectively to client groups and decision-makers (see [15]; [16]). MSE is not
62 intended to be complex but to provide a robust framework that account for
63 conflicting poorly defined objectives and uncertainties that have been absent
64 in conventional management [15].

65 MSE methods rely on simulation testing to assess the consequences of

68 a range of management options and to evaluate each performance measure
69 across a range of objectives, requiring the use of an operating model (OM)
70 to simulate the actual system (observation model) which are then fed into an
71 management procedure (MP) to provide catch advice. To assess case specific
72 harvest strategies (via simulation) within the MSE, we will implement a man-
73 agement procedure based on a empirical HCR that adjusts yield depending
74 on stock status for a given set of tunable parameters for each of the harvest
75 strategies and to test their robustness to uncertainty. This approach could
76 also help identify similar conditions across species where particular advice
77 rules are likely to work well, and where they perform poorly for a given a set
78 of parameters.

79 Often empirical harvest control rules require extensive exhaustive param-
80 eter searches to tune or optimise 'hyper-parameters' (external parameters to
81 a model) that aren't directly learnt from estimators. This requires a tech-
82 nique known as a grid search that extensively searches for all combinations of
83 all parameters. In contrast, and some what less time consuming alternative
84 and efficient parameter search strategies can be considered for a given range
85 of parameter space and a known distribution. As such a random sample
86 can be obtained and used to perform the different experiments for parameter
87 optimisation [17].

88 This paper describes a generic method to simulate differing life history pa-
89 rameters for 5 commercially important european fish species (sprat; *Sprattus*
90 *pprattus*, ray; *Rajidae*, pollack; *Pollachius pollachius*, turbot; *Psetta maxima*
91 and brill; *Scophthalmus rhombus* and to simulation test the performance of
92 each empirical HCRs. Asessment is made via a set of utility functions that

93 indicate where the stock is in relation to ICES limit reference points, target
94 reference points and economics. Our approach is to show the benefits and
95 advance management procedures by using an empirical approach for data lim-
96 ited stocks in comparison to a constant catch HCR strategy i.e one where
97 catches are kept constant and low to ensure no lasting damage is done in
98 periods of low stock productivity or whereby the stock is highly variable year
99 on year, therefore the empirical approach can help optimise catch by setting
100 a precautionary TAC.

101 2. Material and Methods

102 2.1. Materials

103 Life history parameters were obtained from Fishbase (<http://www.fishbase.org>)
104 for growth, natural mortality and maturity were used to develop an age-based
105 Operating Model. To do this the parameters were first used to parameterise
106 functional forms for mass (W), proportion mature (Q), natural mortality
107 (M) and fishing mortality (F) at age. These were then used to calculate the
108 spawner (S/R) and yield-per-recruit (Y/R) which were then combined with
109 a stock recruitment relationship [18] to calculate the equilibrium stock size
110 as a function of fishing mortality (F).

111 This analysis allows a variety of reference points such as those based on
112 Maximum Sustainable Yield (MSY), i.e. B_{MSY} the spawning stock biomass
113 (S) and F_{MSY} the fishing mortality that produces MSY at equilibrium to be
114 estimated. Other reference points are $F_{0.1}$ the fishing mortality on the yield
115 per recruit curve where the slope is 10% of that at the origin, a conservative
116 proxy for F_{MSY} ; and F_{Crash} which is the fishing mortality that will drive

₁₁₇ the stock to extinction since it is equivalent to a R/S greater than the slope
₁₁₈ at the origin of the stock recruitment relationship, i.e. recruitment can not
₁₁₉ replace removals for a fishing mortality equal to F_{Crash} .

₁₂₀ The equilibrium relationships can then be turned into a forward dynamic
₁₂₁ model and projected forward.

₁₂₂ A variety of functional forms can be assumed for all of the various pro-
₁₂₃ cess, i.e. growth, mortality, maturity, the selection pattern of the fisheries
₁₂₄ and the stock recruitment relationship. Commonly processes such as growth
₁₂₅ an maturity-at-age are well known while those for natural mortality and the
₁₂₆ stock recruitment relationship are poorly known [19]. In the later case as-
₁₂₇ sumptions have to be made and to evaluate the sensitivity of any analysis to
₁₂₈ those assumptions a variety of scenarios are considered.

₁₂₉ *2.2. Methods*

₁₃₀ Individual Growth

₁₃₁ Growth in length is modelled by the Von Bertalanffy growth equation [20]

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

₁₃₂ where k is the rate at which the rate of growth in length declines as
₁₃₃ length approaches the asymptotic length L_∞ and t_0 is the hypothetical time
₁₃₄ at which an individual is of zero length.

₁₃₅ Length is converted to mass using the length-weight relationship

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

₁₃₆ where a is the condition factor and b is the allometric growth coefficient.

₁₃₇ Maturity-at-age

₁₃₈ Proportion mature-at-age is modelled by the logistic equation with 2 pa-
₁₃₉ rameters: age at 50% (a_{50}) and 95% (a_{95}) mature.

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

₁₄₀ Selection Pattern

₁₄₁ By default the fishery is assumed to catch mature fish and so the selection
₁₄₂ pattern is based on the maturity ogive. It is modelled by a double normal
₁₄₃ curve, however, to allow scenarios to be implemented where older fish are
₁₄₄ less vulnerable to the fisheries.

₁₄₅ The double normal has three parameters that describe the age at maxi-
₁₄₆ mum selection (a_1), the rate at which the left-hand limb increases (sl) and
₁₄₇ the right-hand limb decreases (sr) which allows flat topped or domed shaped
₁₄₈ selection patterns to be chosen, i.e.

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

₁₄₉ Stock Recruitment Relationship By default a Beverton and Holt stock
₁₅₀ recruitment relationship [21] was assumed, This relationship is derived from
₁₅₁ a simple density dependent mortality model where the more survivors there
₁₅₂ are the higher the mortality. It is assumed that the number of recruits (R)
₁₅₃ increases towards an asymptotic level (R_{max}) as egg production increases i.e.

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

154 The relationship between stock and recruitment was modelled by a Bev-
 155 erton and Holt stock-recruitment relationship [21] reformulated in terms of
 156 steepness (h), virgin biomass (v) and $S/R_{F=0}$. Where steepness is the propor-
 157 tion of the expected recruitment produced at 20% of virgin biomass relative
 158 to virgin recruitment (R_0). However, there is often insufficient information
 159 to allow its estimation from stock assessment [22] and so by default a value
 160 of 0.8 was assumed. Virgin biomass was set at 1000 Mt to allow comparisons
 161 to be made across scenarios.

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

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

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

165 where fecundity-at-age is assumed proportional to biomass and the sex
 166 ratio to be 1:1. Proportion mature is 50% at the age that attains a length of
 167 l_{50} , 0% below this age and 100% above.

168 2.2.1. Operating Model

169 Age based Equilibrium Analysis

170 [18], estimated surplus production using an age-based analysis using an
 171 equilibrium analysis that by combining a stock-recruitment relationship, a

172 spawning-stock-biomass-per-recruit analysis, and a yield-per-recruit analysis.
 173 For any specified rate of fishing mortality, an associated value of spawning
 174 stock biomass (S) per recruit (R) is S/R is defined, based on the assumed
 175 processes for growth, natural mortality and selection pattern-at-age detailed
 176 in the previous sections.

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

177 When the value of S/R obtained is inverted and superimposed on the
 178 stock-recruitment function as a slope (R/S), the intersection of this slope
 179 with the stock-recruitment function defines an equilibrium level of recruit-
 180 ment. When this value of recruitment is multiplied by the yield per recruit
 181 calculated for the same fishing mortality rate, the equilibrium yield associ-
 182 ated with the fishing mortality rate emerges [23].

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

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

185 Forward Projection

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

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

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

193 *2.2.2. Management Procedure*

194 The management procedure was based on an empirical MP, where an in-
 195 crease in an index of abundance resulted in an increase in the TAC, while a
 196 decrease in the index results in a decrease in the TAC. This process is per-
 197 formed via a derivative control rule (D), and is so called as the control signal
 198 is derived from the trend in the signal (abundance), i.e. to the derivative of
 199 the error.

$$TAC_{y+1}^1 = TAC_y \times \begin{cases} 1 - k_1|\lambda|^\gamma & \text{for } \lambda < 0 \\ 1 + k_2\lambda & \text{for } \lambda \geq 0 \end{cases} \quad (11)$$

200 where λ is the slope in the regression of $\ln I_y$ against year for the most
 201 recent n years and k_1 and k_2 are *gain* parameters and γ actions asymmetry
 202 so that decreases in the index do not result in the same relative change as as
 203 an increase.

204 The TAC is then the average of the last TAC and the value output by
 205 the HCR.

$$TAC_{y+1} = 0.5 \times (TAC_y + C_y^{\text{targ}}) \quad (12)$$

206 *2.2.3. Random Search*

207 When running an MSE commonly a set of MP scenarios are run to tune
 208 the MP, this requires running the MSE for each OM scenario for a range of
 209 fixed values in the HCR and then choosing the rule that best meets manage-
 210 ment objectives. If there are a lot of parameters to tune then a grid search
 211 may become unfeasible. An alternative is random search [17] as randomly
 212 chosen trials are more efficient for parameter optimisation than trials based
 213 on a grid. The random parameter search is performed where random combi-
 214 nations of hyperparameters k1 and k2 are used to find the optimal solutions
 215 for the MSE model in terms of performance measures: a) safety, (recruit-
 216 ment in relation to virgin recruitment), b) yield (catch/MSY), c) proportion
 217 of years in the kobe green zone i.e $B/B_{MSY} > 1$ and $F/F_{MSY} < 1$ and d)
 218 Average annual variation in a TAC from one year to the next (expressed as
 219 a proportion of the average annual catch). For instance as the process is
 220 random at each iteration its likely that the whole of the grid space would be
 221 covered in the simulation providing that there are enough iterations, there is
 222 a greater chance of finding the optimal parameter pairs.

223 *2.2.4. Utility function*

224 Utility is based on economic theory and as such a decision-maker is faced
 225 with making a choice among a number of alternative options, obtaining dif-
 226 fering levels of utility from each alternative option, and tending to choose one
 227 that maximizes utility. To evaluate the HCRs from the range of performance

measures described above it is possible to collectively group the measures to indicate potentially conflicting trade-offs to inform different stakeholders and/or objectives. Here we provide visual isopleths as decision support tools to show the net benefit of making one decision over another with the inclusion of the sources of uncertainty with the objective of showing where the stock is in relation to ICES limit reference points, target reference points and economics.

3. Results

Results from our simulated life histories illustrate the diversity in relation to growth, size and maturity and are presented in Fig.1. These plots show that for fast growing species which are small in size l_∞ (asymtopic length parameter - maximum attainable length) species such as sprat, the growth parameter k is high. There are also inherent relationships between length at maturity and the maximum attainable length. For instance sprats length-at-50%-maturity l_{50} are low, in contrast to a slower growing larger species l_∞ such as ray or pollack.

Observations in Fig.2 shows the resulting trends of the vectors from the OM for natural mortality, selectivity, maturity and length in relation to age. Selectivity is derived from maturity and results show that the faster growing species (Fig.1 i.e. sprat) are more selective to fishing, have a high natural mortality at lower ages and thus length. However for the slower growing larger (here represented by length) species (e.g. pollack or ray) have a higher natural mortality rate at lower ages, are more selective/mature with age increases. Interestingly the most significant natural mortality rate increases

252 are associated with turbot at lower ages, however in contrast for the similar
253 flatfish brill, the rate isn't as steep.

254 Fig.3 displays the equilibrium relationships of the OM. Comparisons of
255 reference points estimates can be made across species. The m/k plot shows
256 interesting trends with lower values for sprat where the growth rate k is
257 considerably higher than the natural mortality rate m with little uncertainty
258 around the estimate. In contrast to a slower growing species such as pollack
259 where natural mortality is higher, as is the uncertainty around the estimate.
260 The aforementioned relationships when compared with the proxy for fishing
261 pressure f/m show that the estimate is considerably higher in sprat than
262 pollack.

263 The intrinsic population growth rate r shows that sprats reproductive
264 capacity is higher than all of the species. However the long term average
265 biomass (if fishing at f_{MSY}) to deliver MSY b_{MSY} is slightly less in comparison
266 to all other species although has a higher MSY. Nevertheless the catch size
267 relative to the stock size f_{MSY} is > 1 thus suggesting this species is susceptible
268 to overfishing.

269 The dynamics of the forward projection to go from equilibrium (Fig.3)
270 to time series dynamics are presented in Fig.4. As an example we show
271 that by changing the fishing mortality F time series so that it represents a
272 time series where the stock was originally lightly exploited and then increase
273 F until the stock was overfished, and show by reducing fishing pressure to
274 ensure spawning stock biomass was greater than b_{MSY} .

275 The outputs from the MSE and hyperparameters relative to performance
276 measures are displayed in Fig.5. For the proportion of years where $B/B_{MSY} >$

277 1 and $F/F_{MSY} < 1$ here represented by "kobe.p" it is evident that if the de-
278 sired objective is to increase the proportion of years of staying in the kobe
279 green zone then the hyperparameter k_1 must be increased while k_2 must be
280 decreased for all species. Observations for safety (recruitment relative to
281 virgin recruitment) expectedly show the same patterns as for kobe.p. In con-
282 trast, for yield it has an opposite trend especially pronounced for brill and
283 ray, i.e. by decreasing k_1 and increasing k_2 the yield would increase. While
284 for sprat, turbot and pollack the relationship is particularly different in that
285 the dynamics are highly variable, more so for sprat. Turbot and pollack show
286 similar relationships whereby keeping k_2 high solely increases yield and that
287 k_1 has very little effect when the parameter is decreased/increased. In con-
288 trast sprats isopleths depict that the best yields are obtained when k_2 are at
289 25% when k_1 is at zero or both k_1 and k_2 are at 100%. The variable repre-
290 senting variation in year on year yield, YieldAav, shows that if k_1 is reduced
291 to a 50% and k_2 reduced to 25% the variability in catch is at its lowest.

292 To indicate specific trade-offs when combining performance measures util-
293 ity functions were considered primarily on the basis of meeting ICES limit
294 reference points, target reference points and economics:

295 4. Discussion

296 Fisheries management is often faced with multiple conflicting objectives
297 e.g. social, biological and economic, and it is widely recognised that there is a
298 need to incorporate these objectives into management plans [24]. However
299 such an experiment on large scale fish stocks is nearly impossible to perform.
300 Therefore performing computer simulations to develop robust management

301 procedures is particularly valuable in data poor situations where knowledge
302 and data are limited, but also in data rich situations as simulation testing an
303 assessment procedure using a model conditioned on the same assumptions is
304 not necessarily a true test of robustness [25].

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

313 **5. Conclusions**

314 **6. References**

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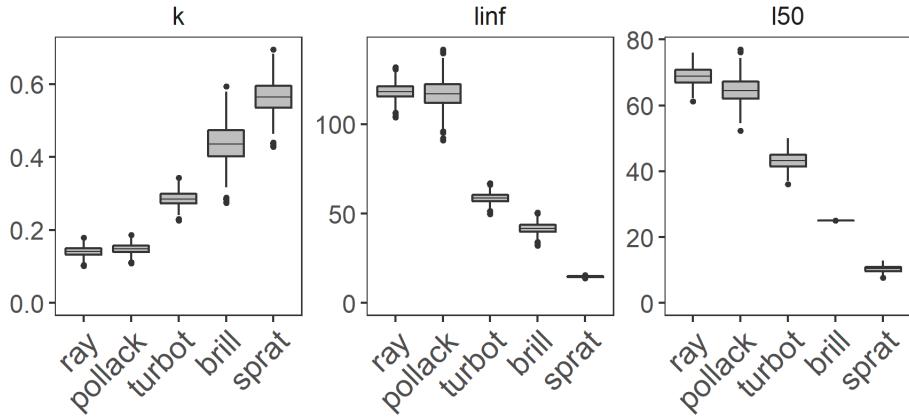


Figure 1:

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397 **7. Figures**

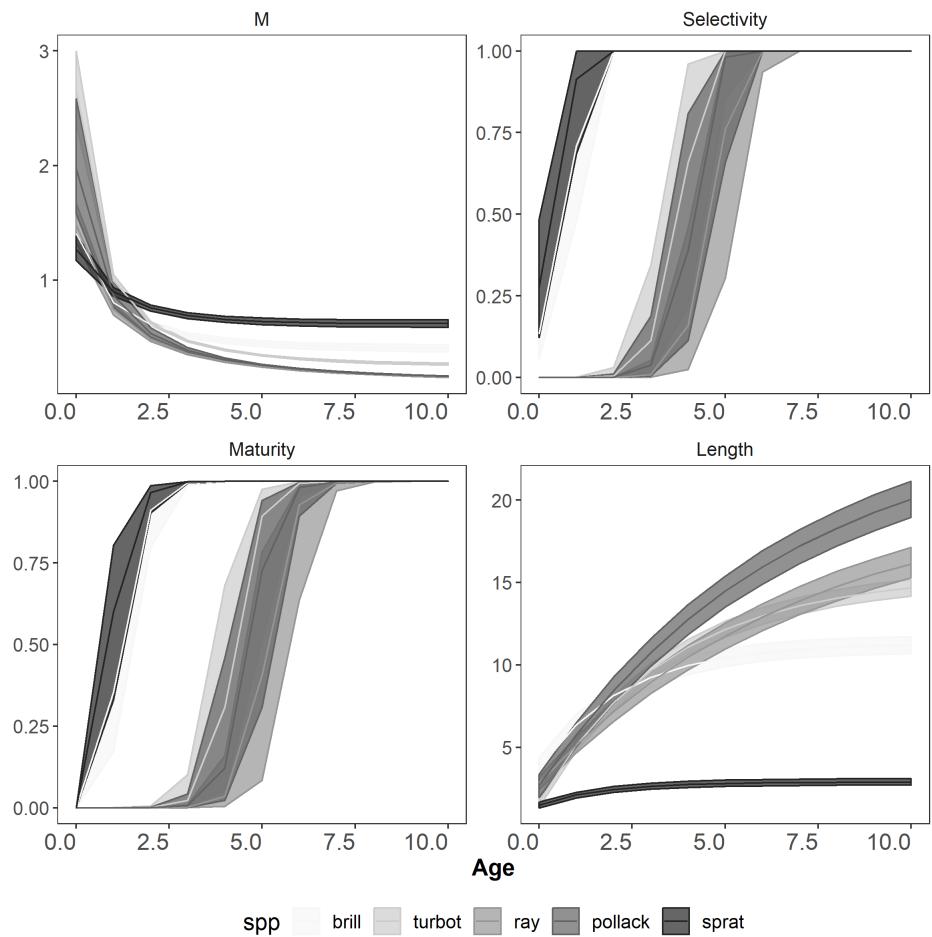


Figure 2:

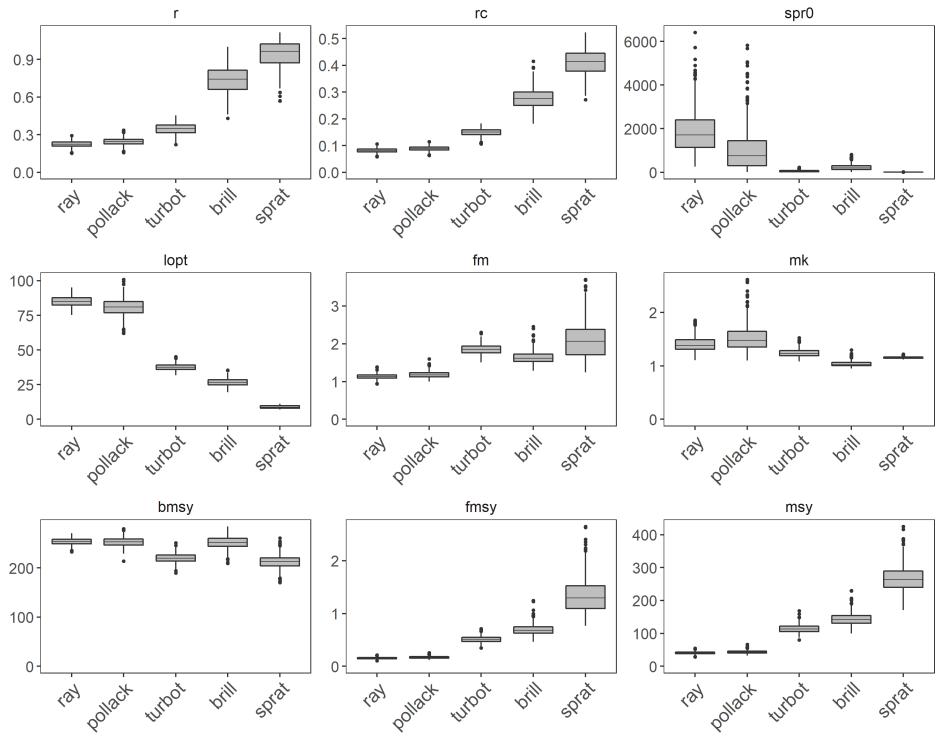


Figure 3:

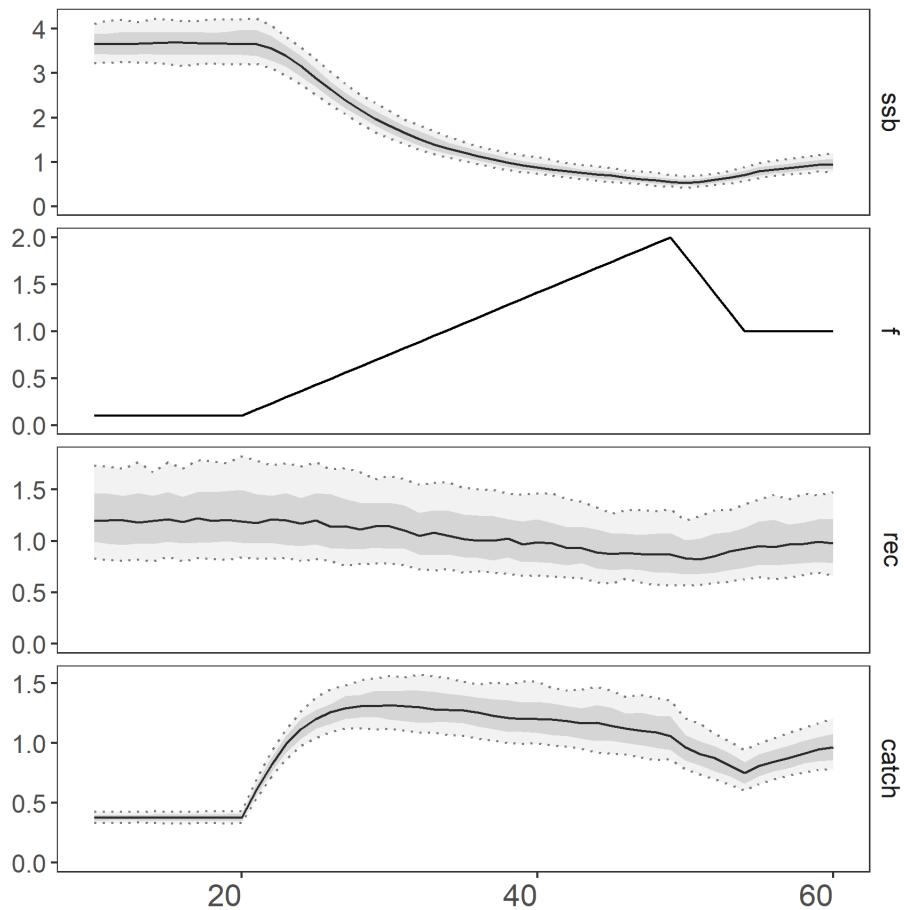


Figure 4:

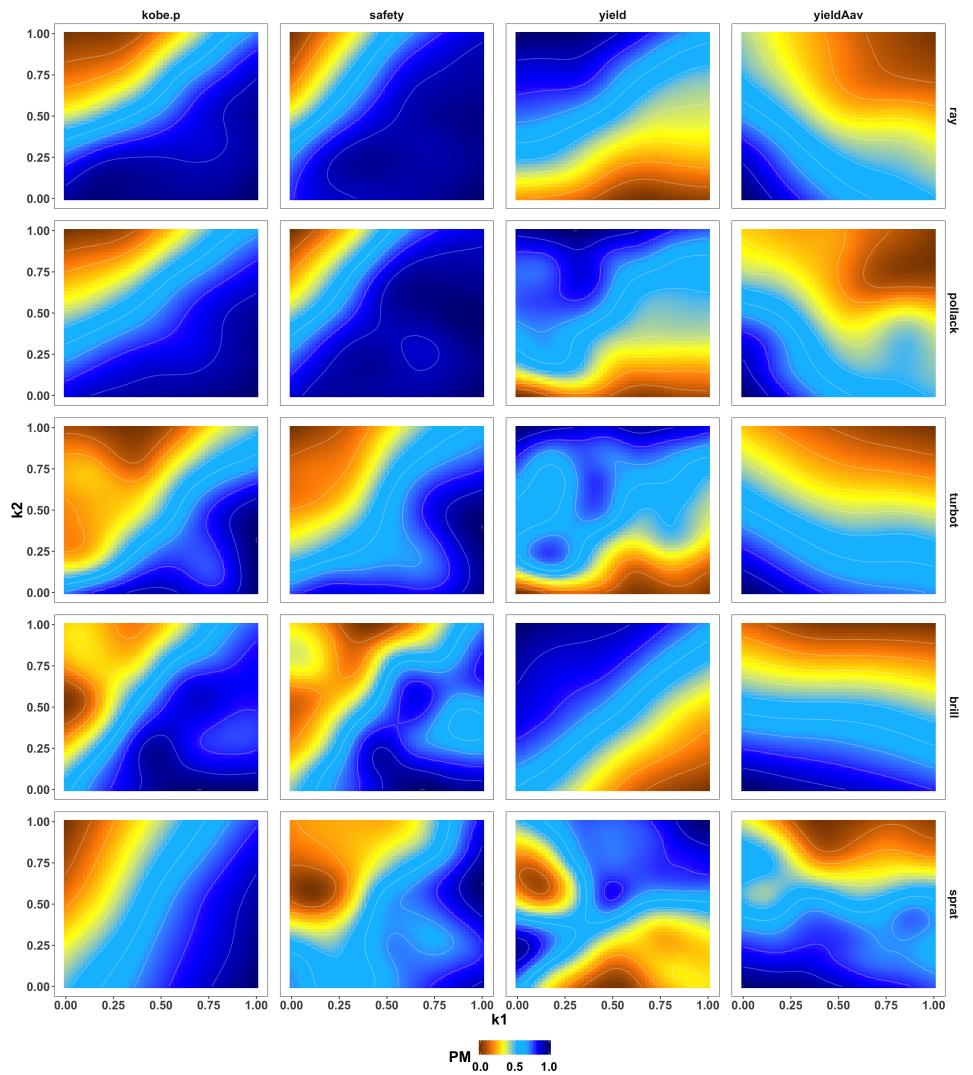


Figure 5:

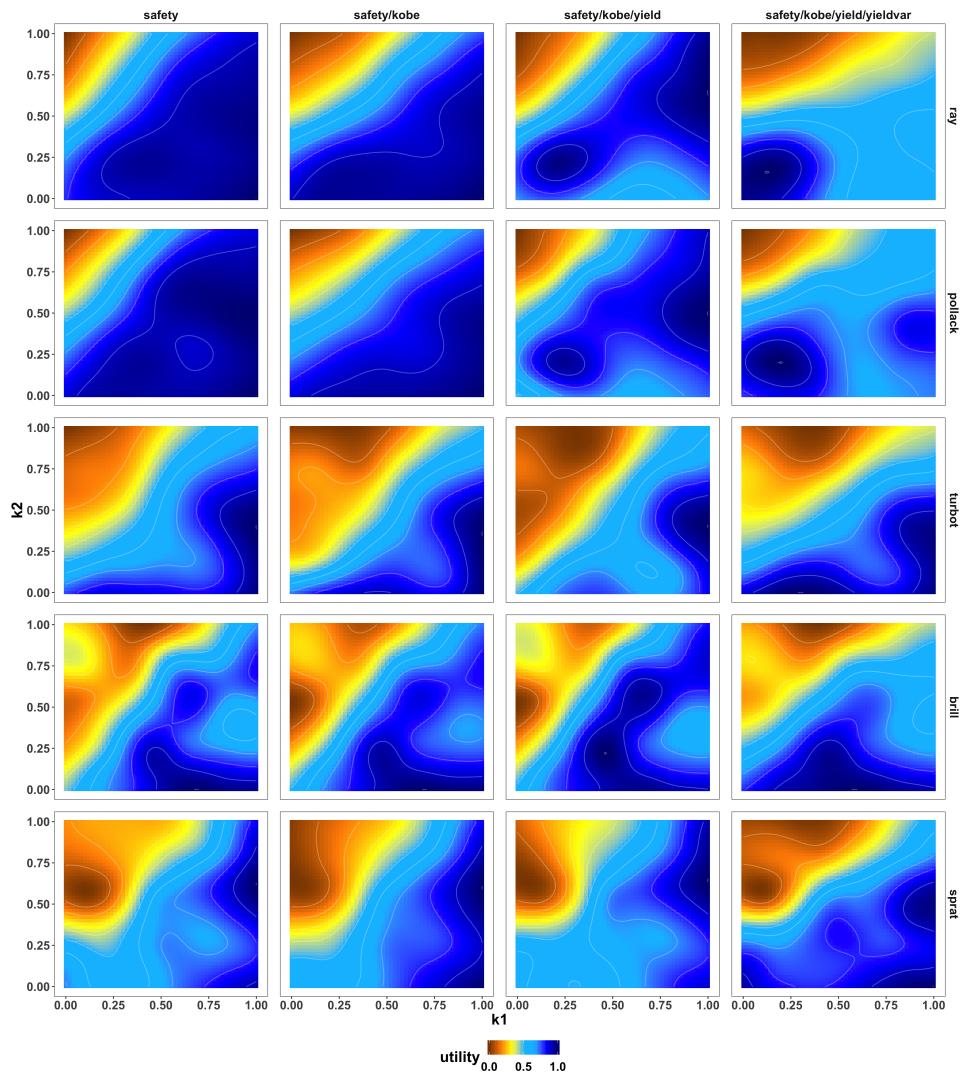


Figure 6: