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
- Comparision 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 quantitive assessment based on conventional mehods that require large amounts of data that include a long historical time series of catches and sound biological information [2]; or *data-limted* [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 paramters 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 aforementoned 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 alternative 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 (recruitment relative to virgin recruitment), yield ($yield/MSY$), kobe proportion (proportion of years that stay in the green zone of kobe plot ($B/B_{MSY} > 1$ and $F/F_{MSY} < 1$), and Yield Annual Variation (Average annual variation in a TAC from one year to the next (expressed as a proportion of the average annual catch).

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 an 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]

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

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.

Length is converted to mass using the length-weight relationship

$$W = aL_t^b \tag{2}$$

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

Maturity-at-age

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

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

Selection Pattern

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

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

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

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

$$R = Sa/(b + S) \tag{5}$$

The relationship between stock and recruitment was modelled by a Beverton and Holt stock-recruitment relationship [13] reformulated in terms of steepness (h), virgin biomass (v) and $S/R_{F=0}$. Where steepness is the proportion of the expected recruitment produced at 20% of virgin biomass relative to virgin recruitment (R_0). However, there is often insufficient information to allow its estimation from stock assessment [14] and so by default a value of 0.8 was assumed. Virgin biomass was set at 1000 Mt to allow comparisons to be made across scenarios.

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

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

$$S = \sum_{i=0}^{p} N_i Q_i W_i \tag{7}$$

where fecundity-at-age is assumed proportional to biomass and the sex ratio to be 1:1. Proportion mature is 50% at the age that attains a length of $l50$, 0% below this age and 100% above.

2.2.1. Operating Model

Age based Equilibrium Analysis

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

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

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

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

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

Forward Projection

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

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

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

2.2.2. Management Procedure

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

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

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

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

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

2.2.3. Random Search

When running an MSE commonly a set of MP scenarios are run to tune the MP, this requires running the MSE for each OM scenario for a range of fixed values in the HCR and then choosing the rule that best meets management objectives. If there are a lot of parameters to tune then a grid search may become unfeasible. An alternative is random search [16] as randomly chosen trials are more efficient for parameter optimisation than trials based on a grid. The random parameter search is performed where random combinations of hyperparameters k1 and k2 are used to find the optimal solutions for the MSE model in terms of a) safety, (recruitment in relation to virgin recruitment), b) yield (catch/MSY), c) proportion of years in the kobe green zone i.e $B/B_{MSY} > 1$ and $F/F_{MSY} < 1$ and d) Average annual variation in a TAC from one year to the next (expressed as a proportion of the average annual catch). For instance as the process is random at each iteration its likely that the whole of the grid space would be covered in the simulation providing that there enough iterations, there is a greater chance of finding the optimal parameter pairs.

3. Results

Estimates of the simulated life history parameters obtained from Fishbase (http://www.fishbase.org) are presented in Fig.1. These show that for fast growing species which are small in size l_∞ (asymtopic length parameter) species such as sprat, the growth parameter k is high. The sprats age-at-50%-maturity *a50* are low, in contrast to a slower growing larger longer lived species l_∞ such as rays or pollack.

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

Fig.3 displays the equilibrium relationships of the operating model. Comparisons of reference points estimates can be made across species. The m/k plot shows interesting trends with lower values for sprat where the growth rate k is considerably higher than the natural mortality rate with little uncertainty around the estimate. In contrast to a slower growing species such as pollack where natural mortality is higher, as is the uncertainty around the estimate. The relationships when compared the proxy for fishing pressure f/m show that the estimate is considerably higher in sprat than pollack, however the intrinsinc population growth rate r shows that sprats reproductive capacity is higher and thus its surplus production.

[EXAMPLES TO BE UPDATED]

- Figure 1 shows the life history parameters
- Figure 2 shows the vectors
- Figure 3 shows the time series relative to reference points

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5. Figure **??** shows the utility functions for the seven study stocks points area

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4. Discussion

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

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

- Bullet point one
- Bullet point two

5. Conclusions

- Bullet point one
- Bullet point two

6. References

References

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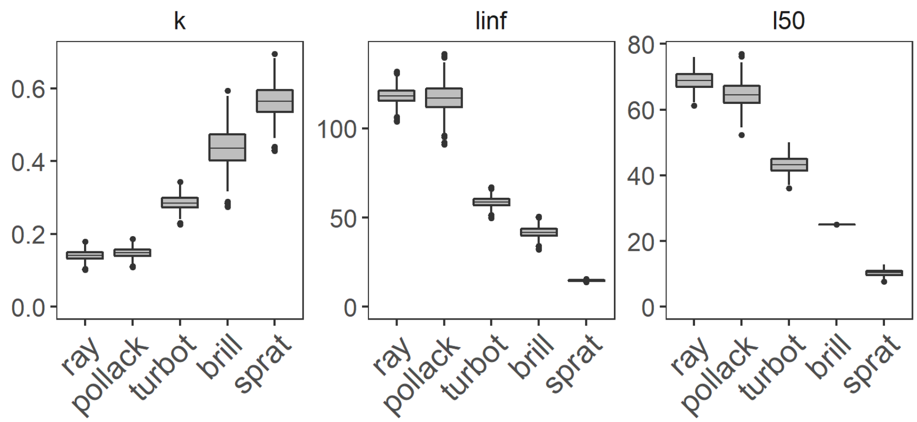

Figure 1:

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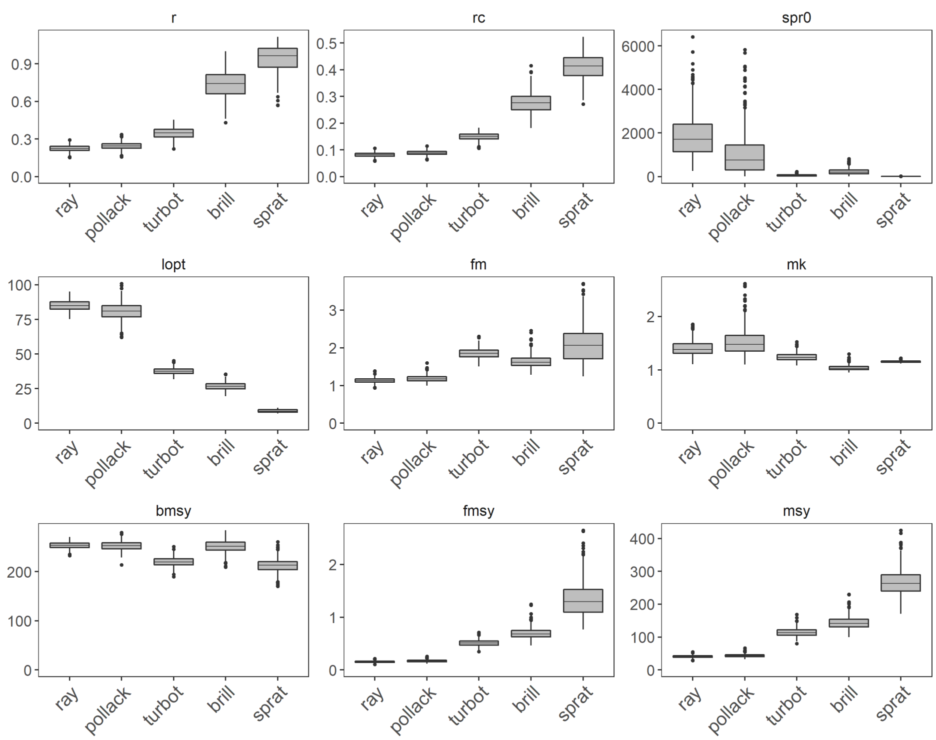
7. Figures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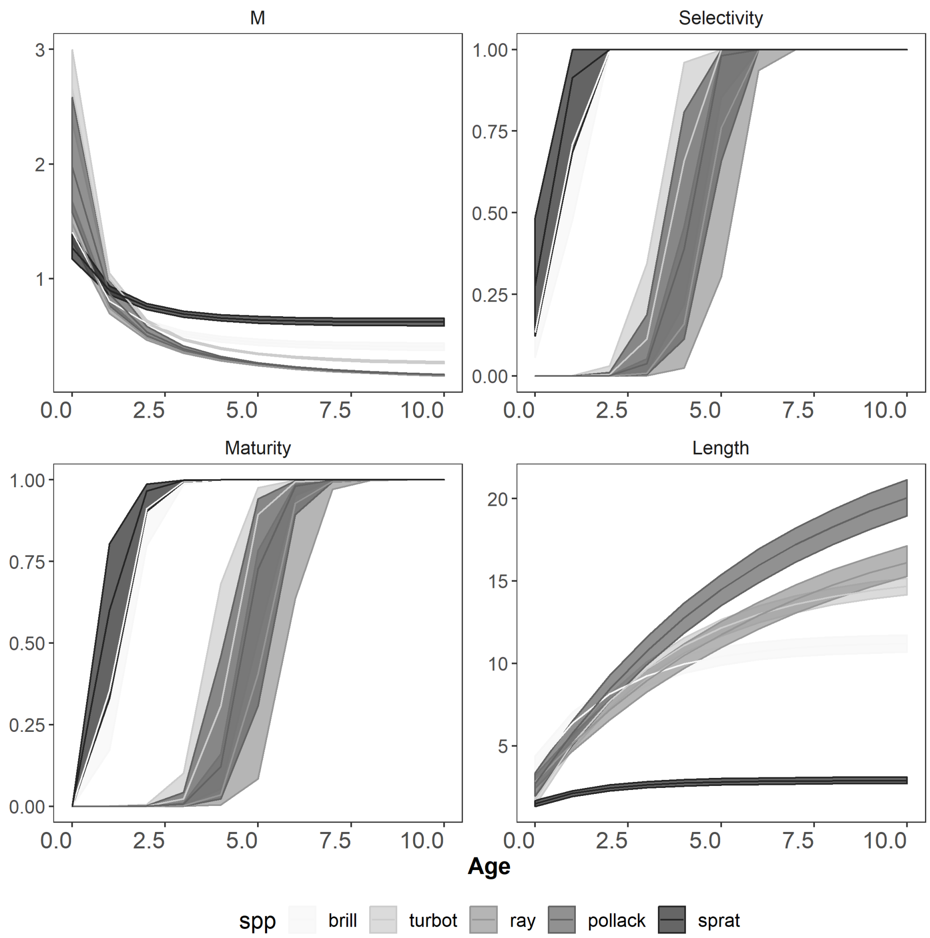

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Figure 3:

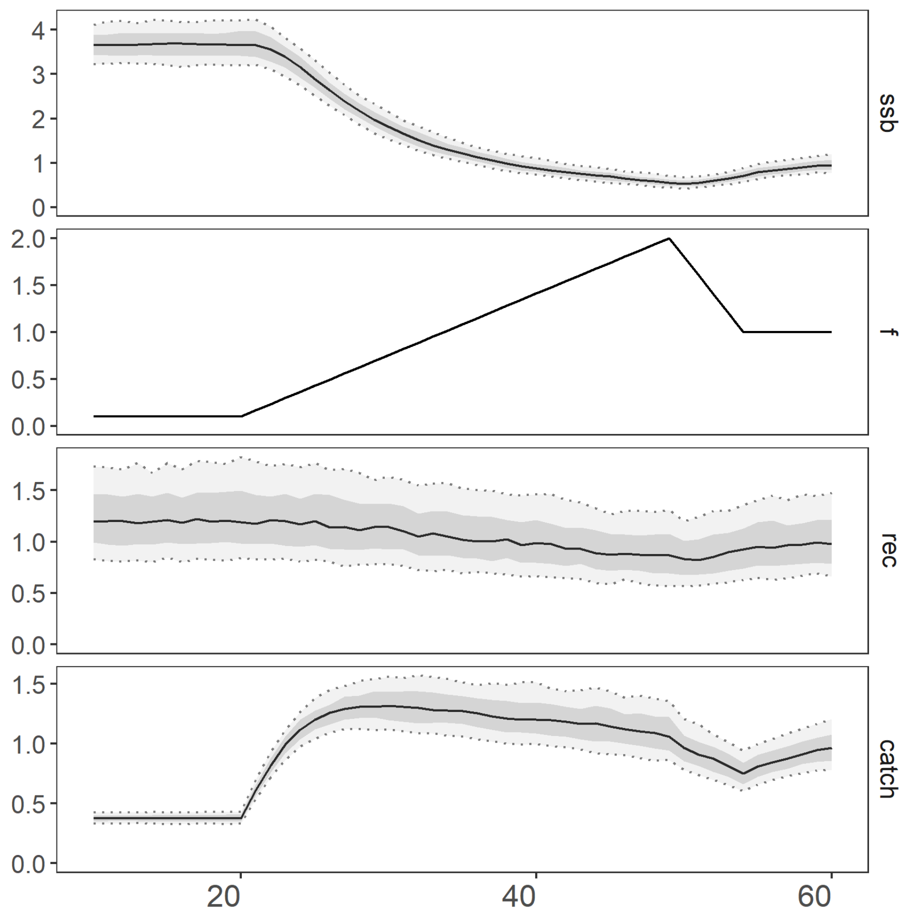

Figure 4:

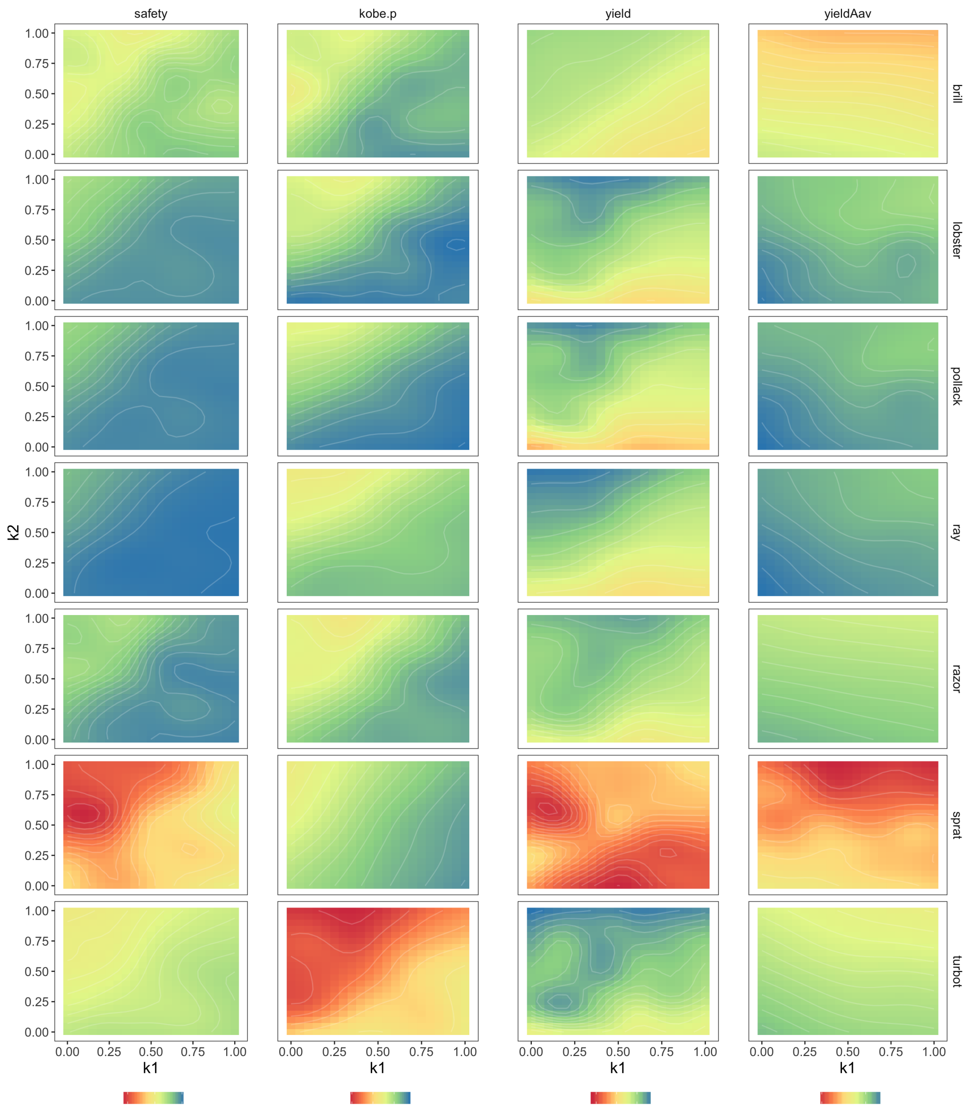
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Figure 5:

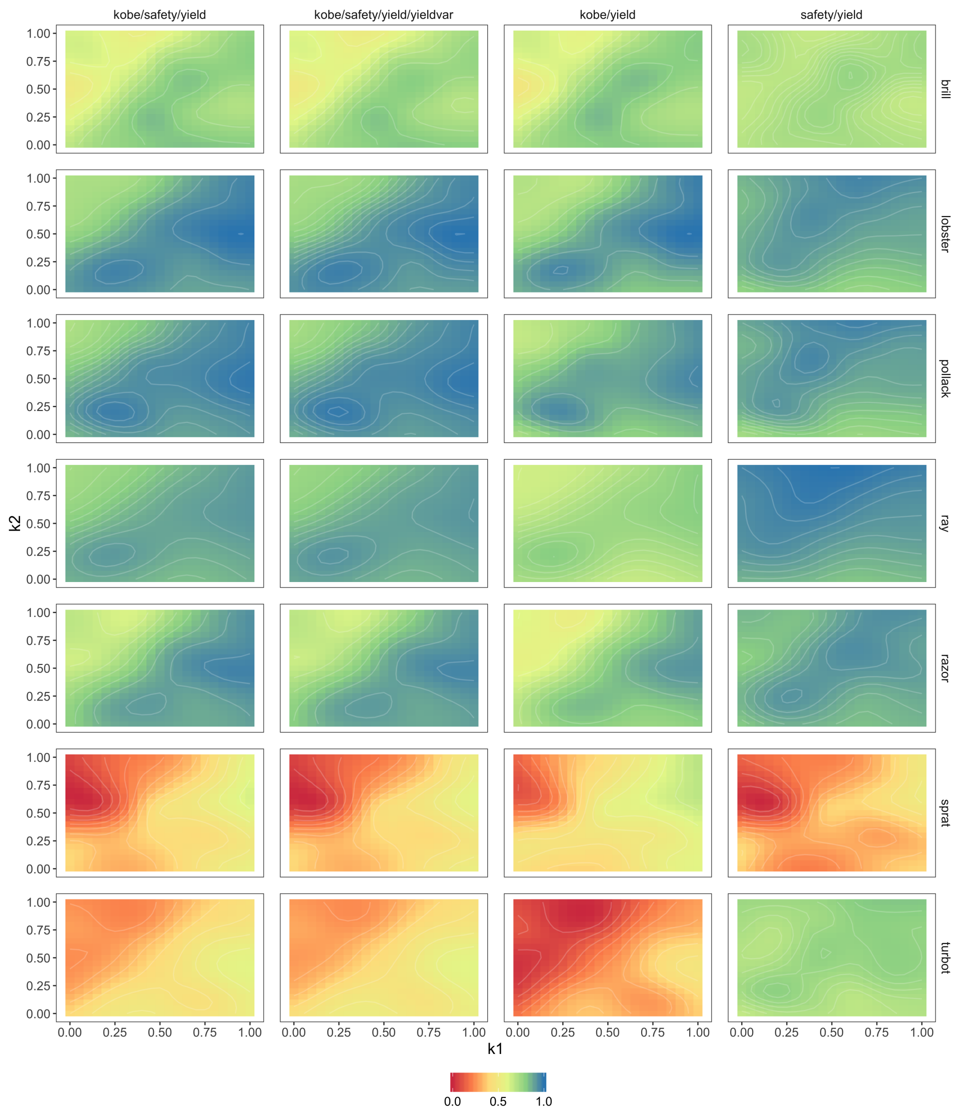

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Figure 6: