An Evaluation of the Robustness of Length Based Indicators using Receiver Operating Characteristics.

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Abstract

Keywords:

1 Introduction

A substantial fraction of world fisheries are conducted on resources for which data are insufficient to conduct formal stock assessments and so status, productivity, and exploitation levels of many stocks and species are largely unknown (Thorson et al., 2015). Such stocks include by-caught, threatened, endangered, and protected species and are termed data-poor, data-limited, or information-poor. The adoption of the precautionary approach (PA, Garcia, 1996), however, still requires management plans and biological reference points for all stocks not just for the main commercial stocks where analytical assessments are available (Sainsbury and Sumaila, 2003).

Reference points are used in management plans as targets to maximise surplus production and as limits to minimise the risk of depleting a resource to a level where productivity is compromised. They must integrate dynamic processes such as growth, recruitment, mortality and connectivity into indices for exploitation level and spawning reproductive potential (Kell et al., 2015). In data poor situations life history parameters, such as maximum size and size at first maturity have been used as proxies for productivity (Roff, 1984; Jensen, 1996; Caddy, 1998; Reynolds et al., 2001; Denney et al., 2002). For example ICES uses indicators and proxy maximum sustainable yield (MSY) reference points based on length (e.g. the von Bertalanffy growth parameter L_∞ and length at maturity L_{mat}) as part of a Precautionary Approach for stocks where only trends in mean length are available (**?**).

An important characteristic of PA advice is that it should be robust to uncertainty. Where a robust control system is one that still functions correctly despite the presence of uncertainty (Radatz et al., 1990; Zhou et al., 1996), while to be robust an indicator should be both reliable and stable. An indicator has high reliability if despite uncertainty it provides an accurate result, and it is stable if despite random error, similar results are produced across multiple trials. To evaluate the robustness of length based indicators and MSY proxies a simulation and sampling (i.e. sim-sam) procedure was employed where an Operatating Model (OM) was conditioned on life history parameters then psuedo data simulated using an Observation Error Model (OEM), allowing the indicators to be compared to the actual state of the resource.

2 Material and Methods

OMs were conditioned on life histories representing a range of population dynaics, namely turbot, brill, thornback ray, pollack and sprat. Scenarios that represent the main sources of uncertainty were also developed. Resource dynamics were simulated assuming an increasing trend in fishing mortality (F) that led to overfishing, then a recovery plan was implemented to bring fishing back to the F_{MSY} level. Length based indicators were then generates using the OEM and compared to the fishing mortality in the OM, using Reciever Operating Characteristic (ROC) curves (Green et al., 1966). A ROC curve can be thought of as a plot of the power as a function of the Type I Error of the decision rule. If the probability distributions for both detection and false alarm are known, the ROC curve is generated by plotting the cumulative distribution function (area under the probability distribution from to the discrimination threshold) of the detection probability in the y-axis versus the cumulative distribution function of the false-alarm probability on the x-axis. A ROC analysis therefore provides a tool to select the best candidate indicators.

2.1 Methods

For each species the life history parameters (**Table ??**) were used to parameterise a Von Bertalanffy (1957) growth curve, proportion mature-at-age, natural mortality (Lorenzen and Enberg, 2002) and a Beverton and Holt (1993) stock recruit relationship. Spawning stock biomass (SSB) was was used as a proxy for stock reproductive potential (SRP Trippel, 1999). This assumes that fecundity is proportional to the mass-at-age of the sexually mature portion of the population irrespective of the demographic composition of adults (Murawski et al., 2001) and that processes such as sexual maturity are simple functions of age (Matsuda et al., 1996) and independent of gender.

These processes allow an equilibrium per-recruit model to be parameterised, which when combined with a stock recruitment relationship Sissenwine and Shepherd (1987) is then used to condition a forward projection to simulate the time series.

2.1.1 Scenarios

Even for data-rich stock assessments there is often large uncertainty about the dynamics (i.e. model uncertainty; Punt, 2008). This means that estimates of stock status are highly sensitive to assumptions about natural mortality-at-age (Jiao et al., 2012), vulnerability of age classes to the fisheries (Brooks et al., 2009), and the relationship between stock and recruitment which is difficult to estimate in practice (e.g. Vert-pre et al., 2013; Szuwalski et al., 2014; Cury et al., 2014; Kell et al., 2015; Pepin and Marshall, 2015). Therefore scenarios (Ono et al., 2015; Kell et al., 2015; Boorman and Sefton, 1997) representing these sources of uncertainty were developed for selection pattern, natural mortality, steepness of the stock recruitment relationship, recruitment variablility and sample size (**Table ??**)

- Selection pattern: **same as matirity ogive**; dome shaped; constant across all ages.
- Natural Mortality: **varies by age**; 0.2
- Steepness of the stock recruitment: **0.7**; 0.9
- Recruitment CV: **30%**; **50%**; **AR**
- Sample Size:**500**, **250**

2.1.2 Indicators

Simple catch rules have been developed for data poor stock, for example the 2 over 3 rule of ICES (2012) which aims to keep stocks at their current level by multiplying recent catches by the trend in a biomass index. Catch rules that make use of more data sources have subsequently been developed (e.g. Fischer et al., submitted), using a rule of the form

$$C_{y+1} = C_{y-1} r f b \tag{1}$$

The advised catch is based on the previous catch C_{y-1}, multiplied by three components r, f and b, each representing a particular stock characteristic. Component r corresponds to the trend in a biomass index, component f uses a proxy for the rateio $F : F_{MSY}$ based on length, and b is a safeguard which protects the stock by not allowing catch to increase unlimitedly once the biomass index drops below a threshold. In this study we focus on the f component, although the same approach can be used to screen any data source or even outputs from data rich assessments.

Empirical indicators based on length, used as proxies for exploitation rate, include

- $L_{max5\%}$ mean length of largest 5%
- $L_{95\%}$ 95^{th} percentile
- P_{mega} Proportion of individuals above $L_{opt} + 10\%$
- $L_{25\%}$ 25^{th} percentile of length distribution
- L_c Length at 50% of modal abundance
- L_{mean} Mean length of individuals $> L_c$
- L_{max_y} Length class with maximum biomass in catch
- L_{mean} Meanlength of individuals $> L$

and potential reference points include

- L_∞
- L_{mat}
- $L_{opt} = L_\infty \frac{3}{3+\frac{M}{K}}$, assuming $M/K = 1.5$ gives $\frac{2}{3} L_\infty$
- $L_{F=M} = 0,75 l_c + 0.25 l_\infty$

2.1.3 Receiver Operating Characteristics

Indicators and reference point may be biased and have poor precision due to uncertainty about life history parameters, lags between size distribution and exploitation levels, variability in recruitment and resonant cohort effects that can produce long term fluctuation in the time series (**??**). This means that the reference level that can best identify the system state is unlikely to be $L_{mean}/L_{F=M}$ but a multiple of it, i.e. the discrimination threshold. The discrimination threshold is the value of $L_{mean}/L_{F=M}$ at which the a stock is said to be undergoing overfishing. A ROC curve plots the true positive rate (TPR) against the false positive rate (FPR) at various threshold settings. Risks are asymmetric, i.e. the risk of indicating overfishing is occurring when the stock is sustainably exploited is not the same as the risk of failing to identify overfishing, and so it may be desirable to adjust the threshold to increase or decrease the sensitivity to false positives.

The ROC curve is constructed by sorting the observed outcomes from the OM by their predicted scores (from the OEM) with the highest scores first. The cumulative True Positive Rate (TPR) and True Negative Rate (TNR) are then calculated for the ordered observed outcomes. The ROC curve can also be thought of as a plot of the power as a function of the Type I Error of the decision rule. If the probability distributions for both detection and false alarm are known, the ROC curve can be generated by plotting the cumulative distribution function (area under the probability distribution from to the discrimination threshold) of the detection probability in the y-axis versus the cumulative distribution function of the false-alarm probability on the x-axis. A ROC analysis therefore provides a tool to select the best candidate indicators.

3 Results

Figure 1 Life history parameters

Figure 2 shows the simulated exploitation history relative to MSY reference points for each of the stocks for the base case. Fishing was initially low then increased to twice F_{MSY}, following which a recovery plan was implemented in order to reduce F to F_{MSY}.

The coloured regions indicate exploitation levels.

Figure 3 Example simulated length samples

Figure 4 indicators

Figure 5 ROC curves

Figure 6 discrimination thresholds for each indicator.

4 Discussion

Uncertainty

Risk

Management Frameworks

Robustness

Lessons for data poor case studies

Lessons for data rich case studies

5 Conclusions

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6 Acknowledgement

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7 Figures

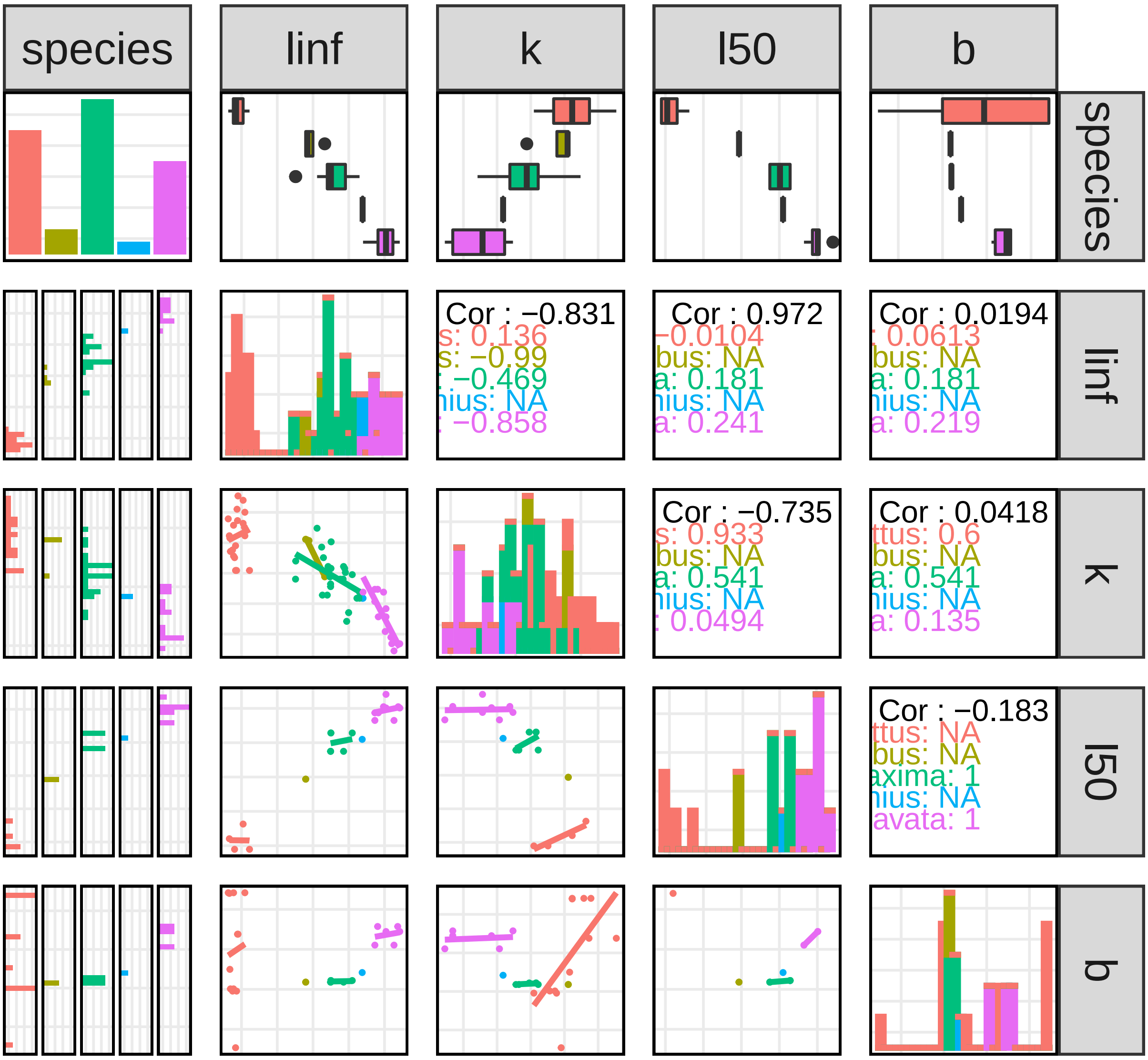


Figure 1: Life history parameters.

Figure 2: Operating Models, showing exploitation history relative to MSY reference points; fishing was initially low then increased to twice F_{MSY} following which a recovery plan was implemented in order to reduce F to F_{MSY}.

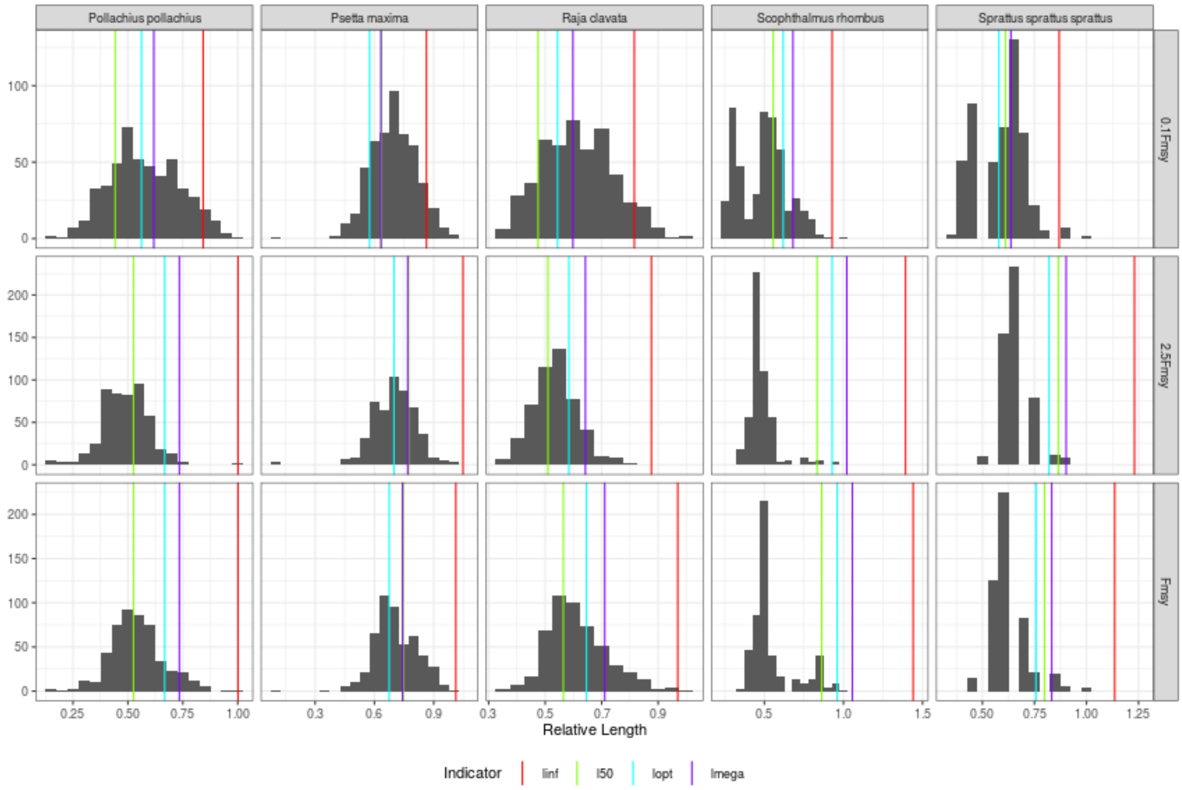
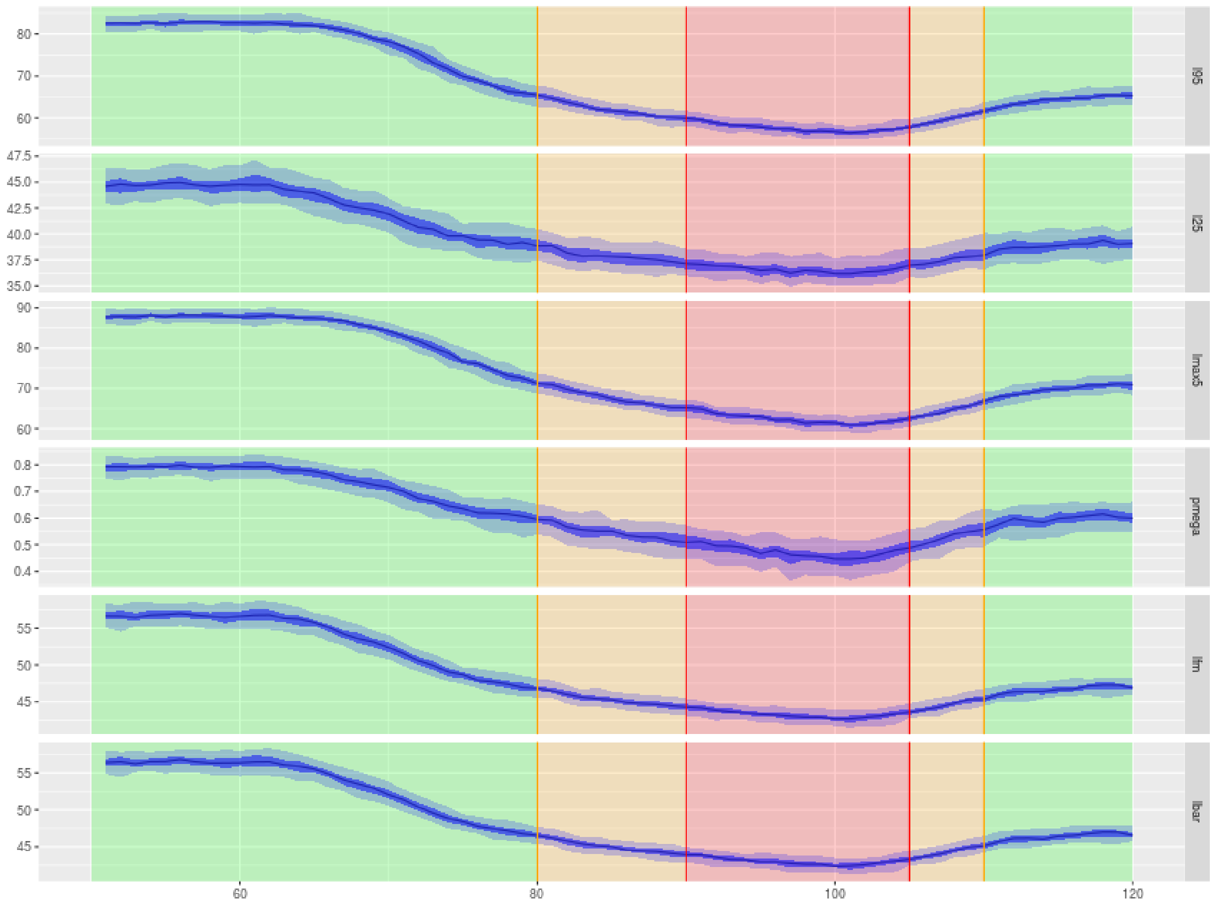


Figure 3: Simulated length samples.

Figure 4: Examples of indicators for the turbot base case; the coloured regions indicate exploitation levels relative to F_{MSY}, $F < F_{MSY}$ (green), $F_{MSY} < F < 1.5F_{MSY}$ (yellow), and $F \geq 1.5F_{MSY}$ (red).



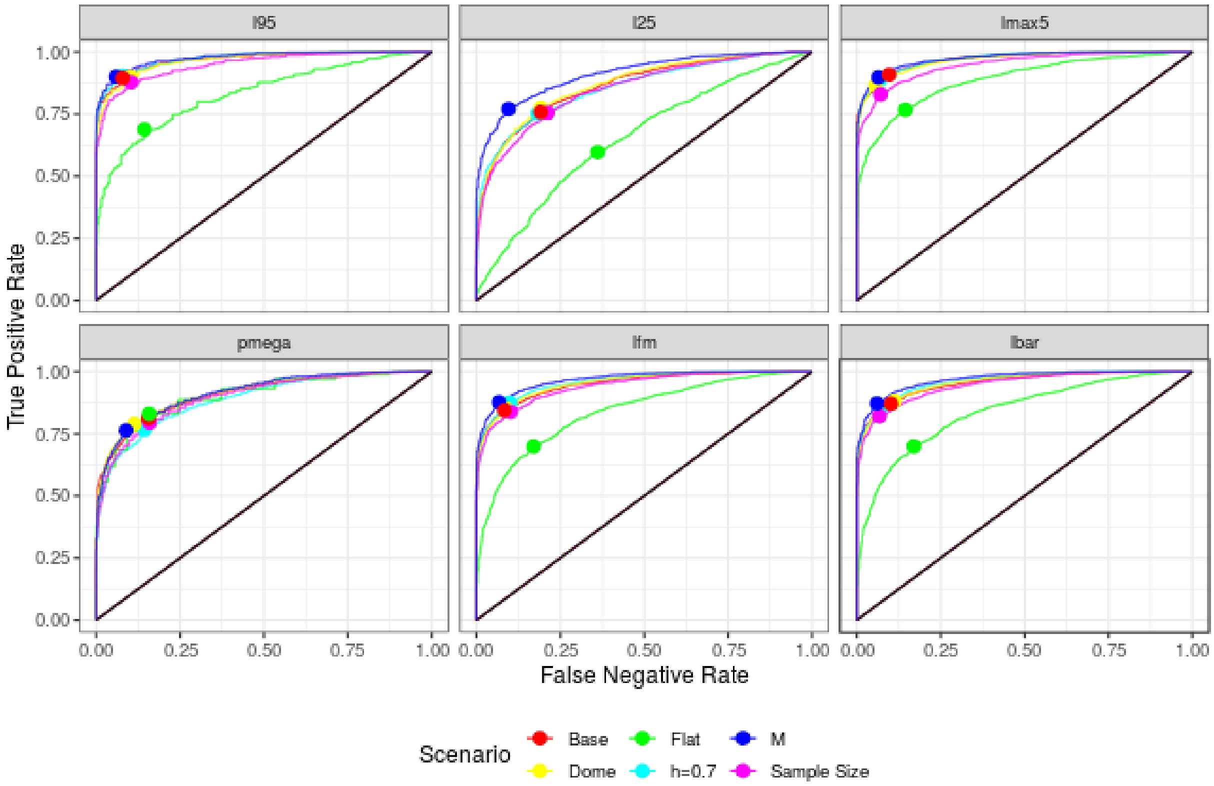


Figure 5: Receiver Operating Characteristic curves.

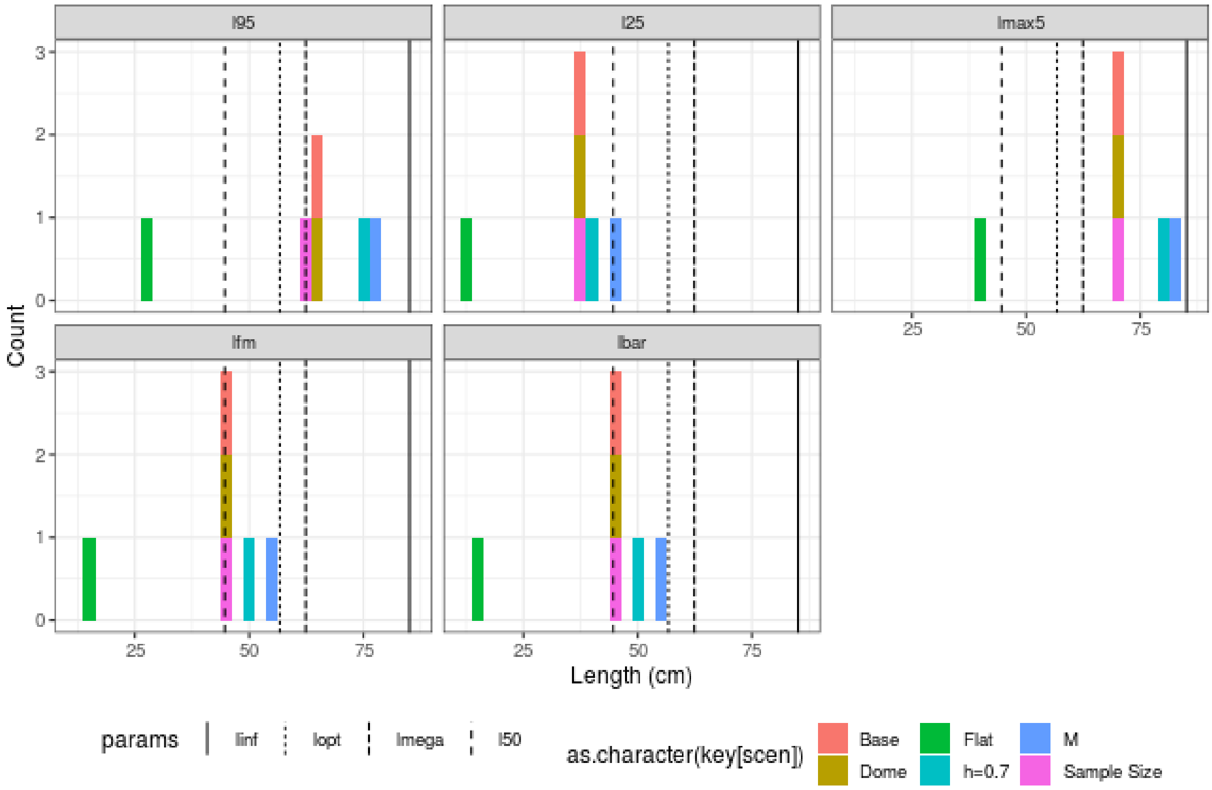


Figure 6: Descrimnation thresholds.

8 Appendix

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