DATA LIMITED ANALYSIS METHODS: INPUTS, OUTPUTS, AND MAJOR ASSUMPTIONS

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# Life History and Expert Knowledge

**Productivity Susceptibility Analysis**

This method provides guidance on the risk of overfishing a stock by using generally available life history data and expert knowledge to estimate the stock’s productivity and vulnerability to fishing.

Inputs:

* life history information: length at maturity, growth rate, maximum length, aggregation behavior
* fishery information: gear, fishing practices
* expert knowledge of fish biology and behavior
* expert knowledge of how the fishery operates, especially with respect to characteristics that affect catchability of target species

Outputs:

* Productivity score - the biological capacity of the target population to produce its maximum sustainable yield and to recover if the population is depleted
* Susceptibility to fishing score - potential for the target to be impacted by the fishery through direct capture as well as indirect impacts, such as bycatch
* Vulnerability score – the overall vulnerability of the stock to overfishing

Assumptions

* life history parameters are known, or can be borrowed from similar species in a similar geographic location
* scoring of productivity and susceptibility attributes is accurate and standard across species

Reference points:

* no reference point; provides risk of overfishing useful for prioritizing species for precautionary management, monitoring, and assessment. Also useful for creating management categories of stocks within multispecies fisheries to simplify management.

Recommendations:

* use Productivity Susceptibility Analysis (PSA) to prioritize data collection, assessment and management for targets with relative high vulnerability (low productivity and high susceptibility) scores

# Fishery Independent Data

## Catch Trends

Catch trends uses fishery dependent catch data to compare total catch, average catch, CPUE, and/or abundance between years of interests.  Comparisons can be derived for sequential years, or as a running average between historical trends. Additionally, comparisons can be made across all species or by species of interest.

**Inputs:**

* Total catch for more than one year
* Catch-Per-Unit-Effort (CPUE) for more than one year
* Abundance of the catch for more than one year
* Length-frequency of the catch for more than one year

**Outputs:**

* Total catch and trends in total catch
* CPUE and trends in CPUE
* Abundance and trends in abundance
* Average length and trends in average length

**Input Sensitivities:**

It can be difficult to attribute a change in catch to a corresponding increase or decrease in biomass. Therefore, seeing an increase in catch could provide a false sense of security. Inferring stock status from catch statistics

**Caveats:**

* This method depends on reliably tracking the total catch
* For example, raw CPUE is seldom proportional to abundance over a whole exploitation history and an entire geographic range, because numerous factors affect catch rates.

**Recommendations:**

* Catch trends can support the interpretation of other analyses, for example of fishing morality of spawning potential ratio (SPR).
* Understanding how the trends in catch fluctuate from one year to next or in comparison to the historic trends is essential to use catch trends for management.

## MPA Density Ratio

This method provides an estimate of stock depletion relative to unfished levels, providing insight into the intensity of fishing pressure, by comparing fish densities on the fishing grounds to fish densities inside Marine Protected Areas (MPAs). In this description, we assume that fishing is banned within the MPA. Often, these types of MPAs are referred to as marine reserves or no-take reserves.

Inputs:

* fish density (fish counts and/or fish lengths plus area sampled), or catch per unit effort (from fishery independent surveys) inside and outside of no-take areas

Outputs:

* ratio of fished to unfished density as a proxy for depletion

Assumptions:

* habitat quality and productivity similar inside and outside of no-take area for sampled areas
* fish density in the MPA represents unfished conditions
* well-designed MPA (i.e., representative habitats inside and outside of the managed area, enforced, large enough for management of targets and is old enough for fish populations to have equilibrated to no-take conditions)
* consistent monitoring program
	+ sites assigned randomly with the same protocol
	+ the same fixed sites

Reference points:

* proxy reference points for stock status, since MSY reference points cannot be calculated using this method
* TRP, above 60% (fished/ reserve); no restrictions
* LRP, between 20 % and 60 % (fished/ reserve), reduce length of open season
* below 20% (fished/ reserve) - close all year

Recommendations:

* effort controls (e.g., season length) can be adjusted in response to changes in MPA density ratio as an indirect way to adjust fishing mortality aimed at moving the MPA density ratio toward targets and away from limits
* For data on fish density inside and outside of MPAs that are not paired:
	+ Calculate average density across fished sites (density.fished)
	+ Calculate average density across reserve sites (density.reserve)
	+ DR=density.fished/density.reserve
* For paired sites inside and outside of MPAs
	+ Calculate density.fished/density.reserve for each pair and take the mean
* May need to divide by the density ratio observed during the year the MPA was established to account for differences in habitat between fished and reserve sites.
* Combined with methods that estimate F or a reference value for F, effort can be adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far the MPA density ratio is from the proxy reference points

## MPA Catch Curve

This method utilizes length-frequency data (fish lengths) from inside and outside a Marine Protected Area (MPA, here assumed to be a no-take zone) to compare the slope of the right-hand side of the log transformed age-frequency histogram from inside the no-take zone (an estimate of natural mortality (*M*)) to the slope of the log transformed age-frequency histogram outside the no-take zone (an estimate of total mortality (*Z*)). Fishing mortality (*F*) can then be calculated based on the difference between these two (*F* = *Z* – *M*).

Inputs:

* length-frequency data inside and outside MPA (preferably collected in the same manner)
* life history parameters (growth parameters)
* number of years that the MPA has been well-enforced
* information on the sizes of fish preferred by the fishery

Input Sensitivities:

* accuracy of individual fish length measurements
* accuracy of length-at-age relationships (Von Bertalanffy growth parameters
* correcting fitting of the curve (sensitive to estimates of MPA age, preferred fish size)

Outputs

* an estimate of fishing mortality (F)

Assumptions:

* assumes that a MPA has been sited appropriately, well-enforced, and been in place long enough for the population living inside the MPA to be a proxy for an un-fished population
	+ - *Implication*: May be less accurate for highly-mobile species that do not remain exclusively inside the MPA, such as snapper, tuna and mackerel
		- This method depends on reliably tracking population size structure changes, thus may be less accurate with small, fast-growing species

Reference points:

* stock status based reference points for F
* TRP: M=F
* LRP: F=2M

Recommendations:

* Target F/M is compared with F/M from assessment
* Combined with methods that estimate F or a reference value for F, effort can be adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far apart these values are from target F.

# Fishery Dependent Data

## Froese Length-based sustainability indicators

This method estimates the proportion of the catch that is made of juveniles, adults, and mega-spawners. These proportions can be used as reasonable representation of growth and recruitment overfishing.

Inputs:

* length-frequency of the catch
* expert knowledge of any biases in the data that would make the length composition of the catch less representative of a random sample (e.g., catchability of different sexes or length classes by the gear; catch coming from nursery grounds)
* theoretical maximum length (Linf)
* theoretical length at age zero (To)
* length at maturity (Lm)

Input Sensitivities:

* Accuracy of individual fish length measurements and how it is measured (e.g., total length, standard length, or fork length)
* Accuracy of length at maturity
* Selectivity of sampling
* Representativeness of sampling

Outputs:

* Three metrics of fisheries sustainability:

 (i) percentage of mature fish in catch;

 (ii) percentage of specimens with optimum length in catch (Lopt);

and (iii) percentage of ‘mega-spawners’ in catch

Assumptions:

* Life history parameters (e.g., maximum length and size frequency) are known
* Length composition of the catch reflects that of the population OR selectivity of catch is accounted for by selecting a portion of the length composition data that is relatively unaffected
* LM = length at sexual maturity
* Length-based proxy for MSY is LMSY = 0.75\*LC + 0.25\*LINFnf (where LC is the length at first capture)
* Length of optimal yield is LOPT = 2/3 of LINF
* LMEGA = LOPT + 10%

Reference points:

* proxy reference points for proportions of catch in different length categories for precautionary management, monitoring, and assessment. Also useful for creating harvest control methods (e.g., size or slots limits to manage both recruitment and growth overfishing) to help with rebuilding a target fishery.

Recommendations:

* (i) percentage of mature fish in catch, with 100% as target;
* (ii) percent of specimens with optimum length in catch (Lopt), with 100% as target;
* and (iii) percentage of ‘mega-spawners’ in catch, with 0% as the target.
* combined with methods that estimate F or a reference value for F, effort can be adjusted through harvest control methods (e.g. catch size limits, seasons, or spatial closures) based on how far apart these values are from sized based recommendations.

## Lbar (or “the Mean Length Assessment”)

This method uses fishery-dependent or independent length-frequency data. *Lbar* uses the minimum and maximum fished sizes, and the average length of the fish within the fished sizes from a fished population, along with growth parameters.

Inputs:

* Fishery-dependent or fishery-independent length-frequency data of fished population
* Theoretical maximum length (L∞)
* Theoretical length at age zero (T0)
* Length at maturity (Lm)
* Natural morality rate (M)
* von Bertalanffy growth parameter (k)
* Average length reported in the catch
* First length at full selectivity to the fishery

Input Sensitivities:

* estimate of natural mortality (M) and growth parameters
* accuracy of individual fish length measurements
* representativeness of sampling

Outputs:

* estimate of fishing mortality (F)

Assumptions:

* Life history parameters are known
* Length is related to age throughout life (i.e., growth is indeterminate – the species just keeps growing longer and longer as it ages until it dies)
* Recruitment is constant (i.e., juveniles are becoming adults at about the same rate each year) – this is a simplifying assumption that probably does not hold for any species
* Mortality is constant – another simplifying assumption that probably does not hold for any species
* Natural mortality (M) is known (this is often not the case)
* FMSY = natural mortality (M)
* System is at equilibrium
* This method depends on reliably tracking population size structure changes, thus may be less accurate for small, fast-growing species
* This method is less reliable when mean fish length is very low

 Reference points:

* stock status based F reference points
* TRP: M=F
* LRP: F=2M

Recommendations

* Fishing mortaltiy is adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far apart these values are from TRP & LRP.

## Mean Weight

This method can use fishery-dependent or independent weight-frequency data to estimate fishing mortality (*F*) when no size structure data is available. This method requires the von Bertalanffy growth function, as well as the length-weight relationship and the natural mortality (*M*). In this method, we construct a Yield-Per-Recruit (YPR) model, which allows us to estimate the theoretical age and weight structure of the population at any size. Similar to Mean Length (*Lbar*), Mean Weight provides an estimate of *F* that can be compared to an estimate of *M*. Intuitively, increasing fishing pressure will often cause decreasing average weight and/ or length.

Inputs:

* fishery-dependent or fishery-independent weight-frequency data
* life history parameters, growth parameters, natural mortality (M)
* information on the sizes of fish preferred by the fishery

Input Sensitivities:

* estimate of M and growth parameters
* accuracy of individual fish weight measurements
* accuracy of length-weight relationship

Outputs:

* estimate of fishing mortality (F)

Assumptions:

* FMSY = natural mortality (M)
* depends on reliably tracking population size structure changes
	+ *Implication*: May be less accurate with small, fast-growing species
* M is assumed to be known, which often it is not
* assumes equilibrium
* less reliable when mean fish length is very low

Reference points:

* stock status based reference points
* TRP: M=F
* LRP: F=2M

Recommendations:

- fishing mortality is adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far apart these values are from TRP & LRP.

## Cope and Punt Length-Based Reference Point

This method is an extension of the Froese Length-based sustainability indicators to also estimate reference points that indicate the stock status. Using the Froese indicators, three simple metrics that describe catch length compositions (i.e., that reflect exclusive take of mature individuals, Pmat; that consist primarily of fish of optimal size, the size at which the highest yield from a cohort occurs, Popt; and that demonstrate the conservation of large, mature individuals, Pmega) to monitor population status relative to exploitation. The metrics (collectively referred to as Px) arw intended to avoid growth and recruitment overfishing. This method uses Pobj (the sum of Pmat, Popt, and Pmega) to distinguish selectivity patterns and construct a decision tree for development of stock status indicators.

Inputs:

* Length-frequency of the catch
* Expert knowledge of any biases in the data that would make the length composition of the catch less representative of a random sample (e.g., catchability of different sexes or length classes by the gear; catch coming from nursery grounds; etc.)
* Theoretical maximum length (L∞)
* Theoretical length at age zero (T0)
* Length at maturity (Lm)
* All length data needs to be measured as Total Length (TL) in order to calculate natural mortality

Input Sensitivities:

* accuracy of individual fish length measurements and how it is measured (e.g., total length, standard length, or fork length)
* accuracy of length at maturity
* selectivity
* representativeness of sampling

Outputs:

Three metrics that describe the catch:

1. Percentage of the catch made up of mature adults (PMAT), with 100% as the target;
2. Percentage of the catch made up of optimum length individuals (POPT), with 100% ast the target;
3. Percentage of "mega-spawners" in the catch (PMEGA).

These metrics are taken together (Px) to determine if growth and/ or recruitment overfishing is occurring, and can be summed to create "POBJ" which describes the selectivity of the fishery. The value of POBJ can be compared with the Cope and Punt Management Decision Tree to inform Harvest Control Rule(s).

Assumptions:

* Life history parameters (e.g., maximum length and size frequency) are known
* Length composition of the catch reflects that of the population OR selectivity of catch is accounted for by selecting a portion of the length composition data that is relatively unaffected
* Lm = length at sexual maturity
* Length-based proxy for MSY is Lmsy = 0.75\*Lc + 0.25\*Linf (where Lc is the length at first capture)
* Length of optimal yield is Lopt = 2/3 of Linf
* Lmega = Lopt + 10%
* Froese's (2004) sustainability recommendations are effective
* Due to the reliance on specific size classes, this method may not be appropriate for stocks that exhibit little difference between mature (small) and optimum-sized (medium) individuals.

Reference points:

* percentage optimum sized individual in catch (Popt) = 1 or 100% as target;
* Pobj (Pmat + Pot+Pmega) = 2

Recommendations:

* Pobj < 1; fishing small sized fish, consider size restrictions
* 1< Pobj < 2;
* combined with methods that estimate F or a reference value for F, effort can be adjusted through harvest control methods (e.g. catch size limits, seasons, or spatial closures) based on how far apart these values are from sized based recommendations.

## Catch Curve

This method utilizes length-frequency data (fish lengths) from the catch to estimate total mortality from the slope of the log transformed age-frequency histogram generated from the length data using information on the relationship between length and weight. Fishing mortality is then estimated by subtracting natural mortality from the estimate of total mortality.

Inputs:

* same as length based sustainability indicators, plus:
* natural mortality rate (M)
* von Bertalanffy growth parameter (k)

Input Sensitivities:

* accuracy of individual fish length measurements
* accuracy of length-at-age relationships (Von Bertalanffy growth parameters)
* Correct fitting of the curve (i.e., preferred fish size)

Outputs:

* estimate of fishing mortality (F)

Assumptions:

* life history parameters are known
* length is related to age throughout life (i.e., growth is indeterminate – the species just keeps growing longer and longer as it ages until it dies)
* depends on reliably tracking population size structure changes, thus may be less accurate for small, fast-growing species
* recruitment is constant (i.e., juveniles are becoming adults at about the same rate each year) – this is a simplifying assumption that probably does not hold for any species
* mortality is constant – another simplifying assumption that probably does not hold for any species

Reference points:

* stock status based reference points for F
* TRP: M=F
* LRP: F=2M

Recommendations:

* combined with methods that estimate F or a reference value for F, fishing mortality can be adjusted through harvest control methods (e.g. catch size limits, seasons, or spatial closures) based on how far apart these values are from TRPs & LRPs.

## Length-Based Spawning Potential Ratio (SPR)

This method estimates the fraction of unfished reproductive potential that a fished stock may be theoretically capable of producing by calculating egg production from each length class sampled in the catch.

Inputs:

* length-frequency data from a fished population
* gear selectivity
* life history parameters (fecundity, Von Bertalanffy life history parameters, natural mortality, age-at-maturity, length at age relationships)
* weight to length parameters (Wa, Wb)
* fecundity at age parameters (fa, fb)

Input Sensitivities:

* accuracy of individual fish length measurements
* representativeness of the length data
* accuracy of life history information, particularly growth and maturity parameter
* sensitive to M

Outputs:

* Spawning Potential Ratio (the ratio of current reproductive capacity to maximum potential reproductive capacity of an unfished population)

Assumptions:

* dependent on reliably tracking changes in population size structure
	+ *Implication*: May be less accurate for small, fast-growing species
* fishery is in equilibrium and that conditions are relatively stable (environmental conditions, fishing pressure, stock status, etc.)
* less accurate if fishing pressures has been changing dramatically year to year

Reference points:

* uses stock status based reference points to estimate sustainable yield and maintain F.
* TRP, for fast growing targets SPR20; slow growing targets. SPR40

Recommendations:

* uses estimates of F and TRP for SPR to see if current F supports sustainable yield. Estimate F prior to using this method.
* fishing mortality is adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far reference value for F and RPs for SPR.

## Surplus Production or Biomass Dynamics

This method estimates stock biomass and fishing mortality using catch, effort, and any available indices of relative abundance without the inclusion of stock age or length structure. This model does not reflect any age structure in a population, and the dynamics of natural mortality, growth, and recruitment are aggregated into a single intrinsic rate of population biomass increase, modified by fishing mortality. Estimated biomass and fishing mortality can be examined relative to reference points to determine stock status.

Inputs:

* total catch, stock biomass (if discards are low, then can be just landings)
* preferably more than 10 years of catch and abundance data
* catchability
* effort
* Index of relative abundance

Input Sensitivities:

* life history phenomena not incorporated (e.g., age of recruitment);
* survival
* growth

Outputs:

* estimate of MSY

Assumptions:

* catch is known without error
* stock is undifferentiated (no age, size, or gender differences)
* catch and/or index is linearly related to the stock abundance
* entire population covered by catch and index

Reference points:

* stock status based reference point for estimating sustainable yield
* FMSY
* F10%B
* F40%B
* BMSY

Recommendations:

* fishing mortality is adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far apart these values are from TRP & LRP.
* surplus production models produce relative estimates of MSY and FMSY, good estimates of q (the parameter that scales abundance indices into biomass estimates) and are scaled to steepness of the recruitment curve increase the certainty.

# More Complex Methods

## Depletion-Corrected Average Catch (DCAC)

DCAC samples depletion over a given period (t), FMSY /M, M, and BMSY /B0 and then uses this information with average catches over the time period in order to calculate the average catches while accounting for the catch that went toward reducing the stock to productive levels. Calculates the average catches accounting for the removal of the “windfall harvest” of less productive biomass that may have occurred as the stock became depleted.

Inputs:

* historical catch data (preferably ten years or more)
	+ average catch
	+ ~ relative change in stock size during the period the catch were taken
* natural mortality rate (preferably 0.2 or smaller)
* FMSY /M

Input Sensitivities:

* assumes that the average catch has been sustainable if abundance has not changed,
* performs poorly with low starting abundance levels, and should be used with caution for targets that are in a rebuilding program

Outputs:

* Sustainable yield (based on average catch), not to be used for Overfishing Levels (OFL, does not account for low stock size)

Assumptions:

* average catch is sustainable if stock abundance has not changed substantially, corrected for the initial depletion in fish abundance
* BMSY = 0.4B0
* FMSY = cM, where c = the tuning adjustment which may have a value of <1
	+ c is generally assumed to equal 1, making FMSY/M = 1, and thus making the assumption that FMSY equals M

Reference points:

* stock status based reference point to estimate sustainable yield, as a reference value to control F.
* FMSY /M
* BMSY /Bo

Recommendations:

* fishing mortality is adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far apart these values are from TRP & LRP for OFL.

## Depletion-Based Stock Reduction Analysis (DB-SRA)

DB-SRA finds a stock reconstruction that matches the input level of depletion and historical catch, to calculate a overfishing level (OFL) by sampling FMSY, depletion, and the reconstructed unfished biomass. The process is stochastic, and samples various values for all four inputs, each sample leading to an estimate of unfished biomass and OFL recommendation. This method is similar to the DCAC with the addition of a stock reduction analysis to estimate MSY-based reference points and relative stock condition.

Inputs:

* complete time series of historic catches
* level of current depletion
* FMSY /M
* M
* the most productive stock size relative to unfished (BMSY/B0)
* estimate of age at recruitment to the fishery
* combines DCAC with stochastic stock reduction analysis

Input Sensitivities: same as DCAC

Outputs:

* probability distributions for biological reference points such as:
	+ unfished biomass, MSY, and the overfishing limit (OFL), and the distributions of stock size over time

Assumptions:

* Same as DCAC

Reference points:

* stock status based reference point to estimate sustainable yield, as a reference value to control F
* FMSY /M
* BMSY /Bo

Recommendations:

* fishing mortality is adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far apart these values are from TRP & LRP for OFL.

## MPA-Based Decision Tree

This method estimates a total allowable catch from data collected inside and outside of no-take reserves. The estimate can be improved by adding length composition data, and is also improved over time by repeated sampling and adjustment.

Inputs:

* life-history characteristics such as size and age at maturity and natural mortality,
* fishery independent monitoring of catch-per-unit effort (CPUE) by size class, OR
* age-length data collected from inside and outside marine reserves
* current catches or running average can be used to set initial Total Allowable Catch for decision tree

Input Sensitivities:

* accuracy of individual fish length measurements
* accuracy of length-at-age relationships
* accuracy of the mean generation time of the target from FishBase

Outputs: Total Allowable Catch

Assumptions:

* habitat quality and productivity similar inside and outside of no-take area for sampled areas
* populations within MPAs are representative of unfished populations (i.e. MPAs are old enough and well-enforced enough for fish populations to have equilibrated to unfished conditions)
* results from relatively small MPAs can be extrapolated to generally much larger fishing areas

Reference points:

* proxy reference point to size-specific catch rate (inside/outside no-take zone), as a reference value to control F
* size-specific CPUE reserve : CPUE fished

Recommendations:

* fishing mortality is adjusted through harvest control methods (e.g. TAC or spatial closures) based on how far apart these values are from TRP & LRP for OFL.

## Catch-MSY

This method estimates Maximum Sustainable Yield from catch time series, estimated unfished stock size, estimated stock size at the end of the time series, and life history information.

Inputs:

* catch time series (catch plus discards),
* estimated ranges of stock size in the first and final years of the catch data (BInitial and Bfinal),
* life history information (r, K)

Input Sensitivities:

* r and K are assumed to be constant
* biomass as a fraction of the carrying capacity at both the beginning and end of the time series, and the growth rate
* based Schaefer surplus production, overall effects of recruitment, growth and mortality are pooled into a single production function

Outputs: Maximum Sustainable Yield estimate

Assumptions:

* population growth and carrying capacity do not change over time
* production is based on the Schafer model
* catch is known without error
* stock is undifferentiated (no age, size, or gender differences)
* only a narrow range of r-K combinations can maintain the population,
* population does not collapse or exceed the carrying capacity
* ignores the age structure of the stock and does not consider individual growth, recruitment or the vulnerability of the fish to the fishing gear

Reference points:

* stock status based reference point to estimate sustainable yield, as a reference value to control F
* MSY is calculated as:
	+ MSY=r\*k/4
	+ BMSY =k/2
	+ FMSY =r/2

Recommendations:

* fishing mortality is adjusted through harvest control methods (e.g. catch limits, seasons, or spatial closures) based on how far apart these values are from TRP & LRP for OFL.

## SPR-Based Decision Tree