THE BAREFOOT ECOLOGIST'S TOOLBOX

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CHAPTER FIVE

LENGTH BASED ASSESSMENT OF SPAWNING POTENTIAL RATIO

Introduction

A central element of the SPS approach involves facilitating local communities to collect the data needed to apply the data-poor assessment methodology called Length Based Spawning Potential Ratio assessment methodology (LBSPR). With this methodology simple snapshot stock assessments of marine stocks can be made. The previous chapters focussed on how collaborating with fishing communities to make LBSPR assessments facilitates change by building a solid understanding of their local overfishing problem and how it can be solved. This chapter turns away from the more sociological aspects of the broader SPS approach to focus on the theoretical basis of the LBSPR methodology. The aim of this chapter is to provide a biological understanding of the concepts on which LBSPR is based that is straightforward enough for almost anyone to understand. Readers interested in the more technical detail of the methodology are directed to the original journal articles by Hordyk et al. (2015a, b, 2016) that established the methodology. Our focus here will remain on ease of reading and broader comprehension. Of course, to control the length of this chapter, and to lay the basis for following chapters, some basic biological concepts are needed, and this chapter will introduce them. The aim, however, will remain to explain them simply enough that people without a background in fisheries assessment can follow and learn.

Part of the intension here is to develop a chapter which can be used as a standalone primer for LBSPR assessment. One that provides useful and practical for any barefoot ecologists trying to make sense of assessing small-scale fish stocks in the field.

For this to be possible we need an understanding of some of the basic biological concepts that underly fisheries assessment, not a comprehensive review of all the biological concepts, just a handful of the most salient to our description and understanding of the LBSPR methodology. The processes that influence the variations, or dynamics of fished populations, or stocks, are mathematically described by 'parameters', which when used within equations define aspects of fish biology and the fishing. The variables that describe the core aspects of fish life cycles (growth, mortality and maturation) are referred to collectively as Life History Parameters (LHP), while those that describe aspects of their exploitation can be called fishery parameters. We will begin this chapter defining the core LHP which are not used individually within the LBSPR methodology, but as ratios of each other, Life History Ratios (LHR), before describing some of the fishery parameters which provide the context for understanding the results of LBSPR assessment. Have laid out the basic conceptual framework the chapter will conclude by explaining how they all come together within LBSPR assessment and its results.

Readers of this chapter can find and download an accompanying powerpoint presentation, entitled an 'Introduction to LBSPR & Life History Ratios', from the 'Data Collection and Analytical Tools' page of the biospherics.com.au website. This chapter basically works through that presentation, and to visually enhance the text you may like to click your way through that presentation as you read this chapter. The figures in this chapter are taken from that presentation, but they have been used relatively sparingly to constrain its size for downloading. To assist in relating this text to the slides in that powerpoint I have cited slide numbers, along with the number of the figures you will find in this text.

The Basics of Fisheries Biology

Von Bertalanffy Growth parameters; L_∞ , K and t_0

We begin this chapter with an explanation of growth parameters, perhaps the most central LHP. The process of growth (figure 1 & slides 3-9) is most commonly (but not exclusively) defined, with the three von Bertalanffy growth parameters (L_∞, K and t_0).

The way to understand these parameters is that:

- L_∞ - is the asymptotic size; the average size individuals would attain if they survived to infinite age. In other words, the average size adults would reach and stop growing at, if they lived forever.

- t_0 - is the theoretical age at which size would be zero. This theoretical value actually defines the size at which von Bertalanffy growth starts, or the length at zero-age (L_0) Biologically speaking, the size at which larval fish settle and start juvenile growth, or the size at which sharks pups are born, or hatch from eggs, and begin external (ex-utero) growth, and

- K – is the annualized instantaneous rate of growth, between t_0 and L_∞. In simple terms K is something like an inverse (opposite) measure of how many years a fish takes to grow between t_0 and L_∞. Speaking (very) roughly K ~ 1.0 suggests it takes about one year to attain L_∞ and K ~ 0.1 suggests it takes about 10 years. My crude extrapolation here is far from exact, because K is what we call an instantaneous, or continuous function, but still my ad-hoc extrapolation gives some idea of how these three LHP combine to describe growth.

Together these 3 LHP describe an initial rapid phase of juvenile growth (figure 1), which begins slowing around the size of maturity as animals begin directing the energy and nutrients obtained from their food, away from bodily growth and maintenance, towards reproduction which inevitably causes growth to slow as their L_∞ is approached. Finally, if the fish lives long enough it gets to a size where all its energy is being used for reproduction and maintenance and growth becomes extremely slow – asymptotic size as been attained.

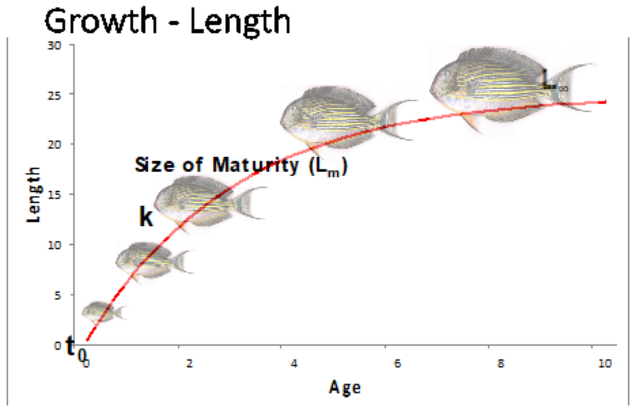

Figure 1. Illustration of Von Bertalanffy Growth model

Size of Maturity (L_m)

Our discussion above has already brought us to the next important LHP, which is the size of maturity, which, on average, marks the beginning of adulthood in a population. We denote this with L_m (figure 1 & slides 7-9), and also L_{50}, because it is commonly defined as the size class in which 50% of the individuals are observed to be functionally adult. The process of maturation actually occurs over a size range which we describe with a typical logistic, or S-shaped curve, which can be defined by the mid-point L_{50} and either a term for slope (r) of the S-curve, or the size at which 95% of individuals are mature (L_{95}). The latter formulation is used by the LBSPR assessment software.

In the finite, real world, energy and nutrients can only be used once, so once animals start using a significant proportion of their resources for producing eggs and sperm (which we refer to collectively as gametes), or for that matter growing young internally, they must divert resources away from their own growth. Consequently, L_m is inevitably around the inflection point of the growth curve, the point at which rapid growth (figure 1& slides 4-6) comes to an end, and the slower growth of adulthood begins (slides 7-9).

Mortality (M)

The final LHP we want to introduce here (slides 10 – 15) is the rate of natural mortality (M). This is the annualized instantaneous rate at which a cohort of fish, having recruited into the population (slide 11) dies off from natural causes; predators, diseases, starvation etc (slides 11 – 15). Natural mortality (M) is the inverse of survival and longevity, and works something like K in the growth curve. The larger M is the shorter the natural life span and the quicker a cohort dies off. So roughly speaking a high M >1 defines a more or less annual species, that dies off within a year of starting life, while a low M ~ 0.2 describes a species with a longevity >20 years.

Optimum Length (L_{opt})

Although not an LHP, another useful biological concept to introduce at this stage is that of optimum length (L_{opt}) or weight (W_{opt}) which is the size at which, in aggregate, a cohort, or age class, of animals reaches its maximum weight or biomass (Beverton & Holt, 1957). Rather than being an LHP, L_{opt} is the product of the LHP defining growth and mortality (slide 17). Through the phase of rapid juvenile growth, each cohort gains weight more quickly than the rate of mortality reduces it. The accumulation of biomass by each cohort continues through until maturity, when growth slows as energy is diverted from growth to reproduction, and the rate of mortality overcomes that of growth, causing the biomass of a cohort to decline as it dies out. Optimal size coincides with maturation into fully functional adults because growth slows as energy is diverted from growth to reproduction.

Variation of Life History Parameters

Although the LHP can be used to describe different species and populations, the actual value of each LHP varies considerable between species and across the range of any species. Within any species systematic variation will be observed across their geographic range. Typically, in cooler higher latitudes species are longer lived, grow more slowly to higher asymptotic sizes and mature at larger sizes.

Size Selectivity

All fishing is, to some extent, selective with respect to the size and age of the fish being caught. There are always some size ranges which are too small to be retained by a certain mesh size or to bite on a certain hook size, or are big enough to out-swim a trawl-net, or too big to enter through a trap entrance etc. The location of fishing can also determine the size of fish being caught, by occurring, or not occurring, at differing depths, in nursery areas, adult feeding grounds, or on spawning aggregations. The term "size selectivity" refers to the size range that is vulnerable to a specific type, or combination of fishing methods (Holt, 2014).

Many types of fishing gear, such as a hook, or a range of mesh sizes used together, have logistic or S-shaped size selectivity curve. With the smallest size-classes being too small to be caught, fish in a middle size range becoming progressively more vulnerable to being caught and, the largest sizes classes being fully selected and unable to escape the fishing gear. An alternative type of selectivity, called dome-shaped selectivity, which is commonly seen in trawl and single mesh-size gillnet fisheries, allows both the relatively small and large fish to escape being caught. The smallest size- classes swimming through the mesh, and the largest size classes either out swimming the trawl-net or bouncing off the gillnet because they are too big to be entangled (Millar & Fryer, 1999).

The inherent size selectivity of a type or combination of fishing gears will interact with the size of the fish vulnerable to being caught on the fishing grounds, to determine the actual size selectivity observed in a sampled catch. So that the catch made with a type of fishing gear with logistic selectivity might produce dome-shaped selectivity if only used in a nursery area.

Adjusting size selectivity in a fishery can be the basis for the simplest effective form of fisheries management (Prince & Hordyk 2018). Many jurisdictions struggle to quantify and control the number of fishers operating in small scale fisheries, let alone the amount of catch. This makes managing fishing pressure extremely challenging or virtually impossible. Managing the size range of fish being caught with minimum legal-size limits, or by regulating the type of fishing gear allowed, may be the only possible way of implementing sustainable management. If the size at which fish are first caught is managed to be sufficiently bigger than the size of maturity, so that >20% SPR is conserved, the sustainability of the fishery can be made independent of the level of fishing pressure, which to some extent can then be left un-managed. In addition to being an essential part of the LBSPR algorithms, the estimation of size selectivity provides a useful means for barefoot ecologists to start thinking explicitly about how size selectivity can be used to manage data-poor fisheries.

The standard LBSPR methodology estimates the size-selectivity displayed by a catch sample assuming it has the logistic, or S-shaped, form which is defined by SL_{50} and SL_{95}, the size at which 50% and 95% of the fish are vulnerable to catching, respectively. Being the simplest form of LBSPR we find this version most versatile and focus on it in this manual, although it also places some limitation on the application of LBSPR which will be discussed in later chapters. There is now also a formulation that has been developed to allow dome shaped selectivity to be specified (Homik et al. 2020) which will be discussed to a much lesser extent.

Fishing Pressure

Fishing pressure (F) is the instantaneous rate of mortality inflicted on a population by fishing, in addition to the rate of mortality due to natural causes (M). Together these differing sources of mortality result in a rate of total mortality (Z) so that F + M = Z. Fishing pressure (F) is a direct and absolute measure of the impact, or intensity of fishing on a stock, and management tends to focus on moderating it to sustainable levels. The level of F that can be sustained by a stock is relative to the natural mortality of a stock (M). Fish stocks evolved to sustain high levels of natural mortality, or turnover, can sustain higher rates of F. As a result the ratio of fishing mortality and natural mortality (F/M) provides a useful measure of fishing pressure relative to the stocks capacity to sustain it.

As a rule-of-thumb for management the range of F/M ~ 0.8 – 1.0 is considered likely to produce a stock size which can produce around the maximum sustainable yield (MSY) possible. It needs to be remembered, however, that unlike M, F only affects the part of the stock that is actually being caught by the fishing gear, the part of the stock larger than the size-selectivity. Fish that are too small to be caught by the fishing gear will only suffer natural rates of mortality. If fishing gears are used that enable a very broad size range to be targeted the impact of any level of fishing pressure will be greater than if a narrow range of size classes are targeted. It is rarely made explicit, that the management rule-of-thumb for MSY referred to above (F/M ~ 0.8 – 1.0), implicitly assumes all adult size classes can be caught, but only adult individuals, which can be expressed in mathematical notation as $L_{50} = SL_{50}$ & $L_{95} = SL_{95}$. If immature fish can also be caught the sustainable level of F/M is lower, but if sufficient adults are protected from being caught stocks can sustain considerably higher levels of F/M.

The LBSPR algorithms uses the shape of the right-hand side of the size composition curve, its steepness and the size of the largest individuals, to estimate F/M, and then with the estimates of size selectivity (SL_{50} & SL_{95}) derived from the shape of the left-hand side, estimates SPR. The relationship between F/M and SPR becomes asymptotic at high levels of relative fishing pressure, so that very small differences in the truncation of a size composition, can produce very different estimates of F/M but extremely similar estimates of SPR. For this reason at high F/M values (> 4) its estimation becomes imprecise, although there will be no doubt that the fishing pressure is very high.

Recruitment

The LHP described above define how populations grow, mature and die-off, a process we call the 'life cycle' of a species, the ultimatum outcome of which is to produce the next, and successive, generations. We fishery biologists refer to the new generation of any population as 'recruitment', because the young animals are recruited into the population. Just a little note of caution here. Different types of marine biologists use the term 'recruitment' a little differently to each other. A marine ecologist focussed on the entire population, uses the term to refer to larval animals settling down to become the youngest cohort of juveniles, while fisheries biologists use it to refer to young fish growing into the youngest cohort caught by the fishery. Fisheries biologists refer to juveniles smaller than those caught by a fishery as 'pre-recruits'. For the marine ecologist those juveniles would already be 'recruits', as long as they were 'post-larvae'. Through this book I will be following the usage of fisheries biologist, not that it will make much difference in this context.

Slides 29 – 35 illustrate one assumed form of the relationship between the biomass (total weight) of adult stock required to produce different amounts of recruitment, or stock-recruitment relationship (SRR). As shown in these slides, it is generally assumed that relatively plentiful recruitment will be produced by a broad ranges of relatively high adult biomass. It is only at relatively low levels of adult stock that the amount of recruitment declines to low levels, which is sometimes referred to as recruitment impairment, collapse, or simply recruitment overfishing. An alternative form of the SRR assumes that very high adult stock levels can also reduce recruitment to some degree, but normally not so severely. That form still shares the assumption that the SRR is relatively steep on the left-hand side, meaning that recruitment failure only occurs at relatively low levels of adult stock.

The aim of fisheries management is to maintain adult stocks at sufficient levels to ensure high levels of recruitment, or expressed the other way, to prevent adult stocks being depleted to a level that reduces, or impairs, recruitment.

The form of a stock's SRR and the parameters defining it are critically important to predicting population dynamics, but in practice rarely known and so largely assumed. The LBSPR methodology avoids this level of complexity by relying on the concept of Spawning Potential Ratio (SPR) which is a form of equilibrium or 'steady-state' modelling which aims to estimate what would happen if fishing pressure was kept constant for long periods of time. Consequently, we are not going to burden the reader by introducing the parameters used to model recruitment, at this stage it is sufficient to define the concept of 'recruitment' and recruitment impairment.

Age-based Assessment Models

Age-based population, or demographic, models which aim to track the dynamics of fished populations are accepted as being fisheries assessment best practice, but they are technically complex and data-intensive. Think national population censuses being conducted annually for each exploited marine population. Trends in catch, fishing effort and some proxy for population abundance are analysed with population models, designed to track the growth, mortality and abundance of successive age classes, of fish. Age based models are created uniquely for each assessed population, specified with the LHP that detail the key aspects of each population's biology, and assumed to be unique for each population. In theory the LHP should be estimated through targeted research on every fish stock which would generally require at least one targeted, well planned, organized and resourced, 2-3 year-long study of fisheries biology. Unfortunately, the reality is that, there are insufficient resources for that sort of basic biological research. In most cases it is only done for the larger industrial scale fisheries. Smaller fisheries must frequently 'borrow' LHP estimates from studies of the same, or similar, species in other localities, or use 'rules-of-thumb' developed to guesstimate' LHP from other aspects of the species (e.g. body size) and the environment they live in (e.g. temperature).

In addition to basic fisheries biology information, complete and comprehensive time-series documenting trends in landed and discarded catch, fishing effort and stock abundance for 2-3 generations of each assessed population are also required. Complex computer models must be constructed by skilled modelers to explain monitored fishery trends in terms of the estimated LHP so as to estimate and predict trends in adult biomass, fishing pressure and the recruitment of young fish. The implication of all this, is that classical stock assessment requires a lengthy, technical and expensive process, beyond the capacity of many nations, jurisdictions and fisheries. A completed age-based assessment model for a single population of fish will generally have a capitalised cost of $100,000s - $1,000,000s and have taken decadal long periods of organization and data collection to become operational.

In the context of small-scale and data-poor fisheries assessment it can normally be assumed that almost none of the information needed to develop an age-based population model are available, neither the time series of catch, effort and population abundance indices, nor the LHP for the population being assessed. World-wide, skilled modelers are in short supply, and especially so in developing and more remote parts of the world. Where their skills do exist in developing countries they are generally better rewarded (monetarily at least) by a range of business professions, rather than a career in fisheries.

Spawning Potential Ratio

Spawning Potential Ratio (SPR) is also called Spawning Per Recruit (SPR), or even Proportion of Lifetime Egg Production (PFLEP). It compares the average reproductive output of individuals in a fished population, with the average level expected in an unfished population. Unfished stocks complete their full natural life spans and so fulfil their natural reproductive potential, which by definition is SPR = 100% or expressed as a proportion 1.0. Fishing reduces the average life span of fish so that they can only fulfil some ratio of their natural spawning potential or SPR < 1.0. In other words, SPR is the proportion of natural unfished reproduction occurring in a fished population (Slides 21- 28).

The SPR concept was developed during the 1970s and 1980s by scientists working with the fish stocks in the North Atlantic as a simple quantitative indicator of the risk of recruitment overfishing (Mace and Sissenwine 1993; Mace et al. 1996; Walters and Martell 2004). This was a period when fisheries modelling was limited by computing power. The revolution brought by personal computing removed that constraint and the more complex age-based biomass modelling, as championed by Hilborn & Walters (1992) became standard during the 1990s displacing simpler concepts like SPR. However, for data-poor and small-scale fisheries the older simpler concept remains a more useful construct for assessing and managing resources.

The SPR concept has two major advantages for data-poor assessment and management:

1. The metric incorporates the effects of both fishing pressure and size selectivity. Measuring the reproductive potential expected of a stock in the equilibrium state with any combination of fishing mortality (F) and size selectivity (SL).

2. Internationally recognised reference points. The level of 20% SPR is internationally recognized as the 'replacement level', akin to the human reproductive capacity of 2.1 children per couple surviving to adulthood. Around this level fish populations are expected to persist at current levels but have little ability to rebuild. Below 20% SPR the supply of young fish (recruitment) is expected to decline over time; 10% SPR is called 'SPR crash' below this level recruitment is expected to decline rapidly and is likely to result eventually in local extinction. The default management targets are 30-40% SPR which is expected to result in maximum sustainable yields (MSY), or ~50% SPR which equates with maximum economic yield (MEY).

Length Based Assessment of Spawning Potential Ratio

Assessment of Spawning Potential Ratio (LBSPR)

The LBSPR methodology has been described as a 'global game changer' by the former vice-chairman of the Marine Stewardship Council (Sainsbury, K. Institute Marine and Antarctic Science, Hobart, Australia personal communication). And a peer review workshop of the developing methodology held at UBC in March 2015, ended with Prof. Carl Walters concluding that; "In terms of the tonnage of fisheries this technique is only going to have a major impact on 20% of the world's fisheries because most of the tonnage is in a few data rich fisheries, but in terms of the conservation of biodiversity, in number of species, this has potential to impact the assessment of 90% of the world's fisheries. And with Dr Alec MacCall, a former top NOAA data-poor stock assessment expert saying: "You are in a position to say to your funder that you now have the tool to go straight at the issue of food security in fisheries."

Previous to our development of LBSPR, different methodologies for SPR assessment were already in common use as a simplified way of assessing stocks with reasonably LHP estimates but insufficient trend data on catch, effort and population abundance to develop standard dynamic age-based models (Walters & Martell 2004). The most commonly applied methodologies parameterized population models using available LHP estimates, and assuming equilibrium conditions (as LBSPR also does) fitted models to observed size or age stock compositions to estimate SPR.

For data-poor and small-scale fisheries assessment, the main break-throughs made possible with the LBSPR methodology are that it provides:

1. a way of making an assessment with a single snap-shot of the size composition of the adult part of the stock, without waiting for a lengthy time-series of data to be developed, and
2. a scientifically rigorous basis for borrowing the biological information needed to assess unstudied species from well-studied species.

Length-Based Analysis

The core input data for LBSPR is the size profile or composition of the fish being caught which it is assumed accurately represents the adult part of a stock. Catch size composition data is perhaps the simplest and cheapest forms of fishery dependent data to collect. For a start you don't normally need to measure every fish caught to get a good estimate of size composition. In the simplest circumstances, when the different size classes of adult fish are well mixed through catches, measuring just 100s to 1,000s can be very informative. On the other hand, if the different size classes of fish segregate, so that they are caught at different times and places, which we refer to as the population being size-structured, getting a good representation of the population from sampling catches can be a lot more challenging. Sampling must be designed and conducted in a way that overcomes the size selectivity of individual catches, to get an accurate portrayal of the adult fish in the population, as you would if every adult fish in the population could be measured. Even so, normally a sample of 2-5% of a landed catch should be sufficient.

LENGTH FREQUENCY HISTOGRAMS

Central to the application of LBSPR is the length frequency histogram that is used to portray size composition data and illustrate the number, or proportion, of each size class observed in a sample. On the bottom, or X-axis, is shown the length of the fish, with the smallest fish on the left and the biggest fish on the right. Up the side on the Y-axis, is shown the number, or proportion, of fish in each size class observed.

FISHING DOWN SIZE COMPOSITIONS

The way fishing changes the size composition of populations, referred to as fishing down the size structure, is well understood and algorithms describing trends in population size structures are widely used in stock assessment methodologies. The previous chapter describes the process, and it is also illustrated with slides 36-38, so that description will not be repeated here.

Catch size composition data and how it changes with fishing pressure is commonly used in stock assessment models, but until our break through, mainly as a time series, alongside catch and effort data and interpreted with the LHP of a population. How quickly the size composition changes over time provides a source of information helping to improve a model's estimation of biomass trends, or the LHP themselves. Size composition data is more informative for stock assessment if, rather than being used to just compare trends, it can be used for a before-and-after comparison. To compare the size composition of a stock before fishing began, with after fishing has occurred. The data collected from the virgin population is much more informative as it provides a baseline against which current data can be compared. The sad truth, however, is that we humans place little priority on collecting information about a renewable resource, before it has been given value in a commercial catch. Fisheries research is a follower of fisheries, so these types of before and after comparisons, have rarely been possible.

With the LBSPR technique it is now possible to hindcast the size composition of unfished populations.

Life History Ratios

DETERMINE THE SHAPE OF GROWTH CURVES AND SIZE COMPOSITIONS

In the summer 2011, my PhD student at the time, Adrian Hordyk, and I were modelling the relationship between the size of a marine organism relative to its size of maturity, and the proportion of its potential life time reproduction completed (SPR). I had previously realized that all abalone populations exhibited the same relationship even though the populations varied wildly in their absolute size on each reef and was using that principal to visually assess abalone reefs (Prince et al. 2008). We were conducting a meta-analysis to test whether all main organisms displayed the same relationship as the theory of Life History Invariants suggested they should (Prince et al. 2015). We had found much more variability than expected and the variation seemed to be related to the ratio between M and K (i.e. M/K). I remember it was during my morning ritual, walking the dog out along the groyne around the local yacht club, I was puzzling about why the ratio M/K should be related to relative size and SPR when it dawned on me with an exciting rush. The ratio between M and K determines the shape of a species' growth curve, and the size composition of populations (Slides 39-48).

An M/K < 1.0 results in a relative square form of growth curve, individuals display relatively rapid juvenile growth to around adult or asymptotic size before maturing, and adults that persist around asymptotic size growing slowly, if at all, while participating in many reproductive seasons. Unfished populations of low M/K species have many adult cohorts with overlapping size ranges which characteristically results in an adult modal size class just smaller than asymptotic size.

An M/K > 1.0 produces a more linear form of growth curve, juvenile growth slows at maturity, but only slightly. Adults continue growing throughout their life cycle and participate in relatively few breeding cycles. Cohorts tend to die out before achieving their asymptotic size which is more of a theoretical construct for these species. With continual relatively rapid growth throughout life, the sizes range of successive adult cohorts overlap relatively little so that even in the absence of fishing, these high M/K populations do not form adult modes.

Initially Adrian and I thought we had been genuinely clever coming up with the connection between the Life History Ratio (LHR) M/K, the shape of size compositions and relationship between SPR and body size. For a couple of months, we walked around feeling as we had discovered something genuinely new! Eventually, however, our newfound knowledge allowed us to begin understanding things that Beverton and Holt had been writing about the LHR in the 1950s and 1960s.

Beverton (1963) wrote that; "all the essential biological characteristics determining responses to fishing pressure are contained in the dimensionless ratios - M/K and L_m/L_∞.

So the individual life history parameters (LHP) are not as important as most fisheries assessment modellers assume … it is actually the ratios of the two LHPs which determine population dynamics and most importantly for this context the shape of size compositions.

LBSPR – STOCK ASSESSMENT AS MENTAL ARITHMETIC.

Armed with this realization it becomes possible to hindcast the original unfished shape of a population's size composition on the basis of a species typical M/K, and to make comparisons with current fished size compositions. And that is what the LBSPR algorithms does for you. Informed about the M/K of a species, and its size with estimates of L_m or L_∞, the algorithm computes the shape and size of the unfished size composition, and on that basis uses the current size composition to estimate the extent to which the unfished size composition has been deformed and truncated by fishing. The extent to which the fished size composition has been fished down is expressed in units of current SPR, and relative fishing pressure (F/M).

Seasoned fisheries biologists have always used a qualitative form of this analysis to make quick judgements from the catches they observe about the degree of overfishing occurring. Wherever I travel I somehow seem to find myself walking around local fish markets taking in the size of fish on display, thinking about how big they are compared to what I suspect would be their maximum size, or size of maturity. The logic is simple, if few individuals reach the size of maturity fishing pressure is so heavy that little reproductive potential is left in the stock, whereas, if I am seeing individuals around the maximum I have previously seen for that species, I infer fishing pressure to be relatively light.

In essence the LBSPR technique enables this qualitative evaluation, to be turned into a simple quantitative snap-shot assessment of size composition data, based partially on comparing the shape of size composition data, and the size of the biggest fish in the sample with the L_m and L_∞ of the population being assessed.

Cost-effective Snapshot Assessments

The realization that M/K defines the shape of adult size compositions eliminates the need to have sampled populations prior to fishing commencing, or to compare long time series of size composition data with trends in catch and effort. It makes possible immediate snapshot assessments by comparing current size composition with unfished compositions that have been hind-caste with M/K and, either L_m or L_∞.

The simple beauty of LBSPR is that it enables assessment in terms of SPR an internationally recognized reference point of management that indicates the risk of recruitment over-fishing.

In essence the LBSPR methodology simply compares the catch size composition, with the local size of maturity to infer how much breeding or spawning potential ratio (SPR) is being allowed by the fishing pressure. If no fish survive to reach maturity there will be very little spawning potential (SPR~0%) and if all the fish survive to live out their natural lives and attain full size, there will be 100% of the natural (unfished) level of spawning potential (SPR~100%) and breeding occurring.

The types of information required are extremely simple:

1. Estimates of the life history ratios (LHR) which are typical for a species, genus or family
2. Local estimates of either L_m or L_∞.
3. the current size composition of the adult part of a fished stock

The LBSPR methodology makes possible simple snapshot assessments of most marine stocks simply by measuring the size 200-2000 fish sampled from catches. In some situations, the LBSPR methodology can take just one or two days to apply,

The results from LBSPR translate easily into advice about minimum size limits, the size of mesh in nets, hooks, or escape gaps in traps, and levels of fishing pressure.

The Assumption of Equilibrium

Before moving on it is worth saying a little more about the assumption of equilibrium that underlies the algorithms of LBSPR used to assess the shape of size compositions, and which also underlies many other forms of data-poor assessment. This assumption is that a population has been under something like the existing level of fishing pressure (F or F/M and SL) and rates of recruitment for several generations so that the population being assessed has come to some sort of 'steady-state' or equilibrium. Similarly, predictions of stock status based on the equilibrium assumption are about the steady-state the stock will end up in if some combination of fishing pressure is applied constantly over several generations.

The equilibrium assumption is widely used in data-poor methodologies precisely because it provides a way of ignoring all the fluctuations that actually impact stocks, greatly simplifying the information required and the computations involved. This is also precisely the reason that the development of dynamic age-based assessment models that track variations in fishing pressure and recruitment, were hailed as a major advance in fisheries science during the 1980s. Undoubtedly dynamic age-based modelling is more realistic and sophisticated. That is not open for debate. The issue is whether or not you have all the information and data you need for that level of sophistication, or whether you need to face reality and fall back on the simplifying assumption of equilibrium, because that is all you have. This issue is rather like living in a jungle community without any proper roads and having to choose between driving a Porsche

or a Toyota land-cruiser. The Porsche might be more desirable but the land-cruiser will be a better fit for the purpose.

Our own sensitivity testing of the LBSPR methodology shows that the assumption of equilibrium does not need to be too strictly observed. Particularly in the context of tropical reef fish populations most of which are changing relatively slowly, over the time period of decades rather than years, the assumption is relatively safe to use, even if not strictly correct. In terms of the broader application of LBSPR there are some exceptions to be mindful of. For example, if you were applying it to a short-lived (2-4 years) stock experiencing big pulses of recruitment you should expect the LBPSR estimates to also 'pulse'. With SPR estimates rising and falling as each recruitment pulse enters and passes through the stock. In this case your best SPR estimate would be produced by averaging over several years, because the annual estimates will be cycling around the actual level. Another exception would be posed by the case of a long-lived population (30+ years) being fished down catastrophically over a short period of time (say 2-5 years). In that case LBSPR assessments conducted through the fish-down process, and for a generation time following, before the full effect of the fishing pressure had time to 'grow-through' the stock, would reflect the remnant adult stock, at its old equilibrium, rather than the new equilibrium the stock would be moving towards. Reflecting the state of the stock prior to the heavy fishing pressure the SPR estimates will remain too high, and F/M too low for at least one generation time of the fish.

While remaining mindful of these types of specific cases where the equilibrium assumption could be important, in most cases the barefoot ecologist applying LBSPR need not worry too much about the issue. Just getting a first indicative estimate of SPR and F/M will be useful in your situation, even if the precision is relatively low and the methodology far from being the Porsche of fisheries assessment.

Robin Hood Assessments

Remaining within the context of doing as much as possible in basic data-poor conditions, another useful aspect of the theory underpinning the LBSPR methodology, is that it provides a sound scientific basis for borrowing the biological information needed to assess unstudied stocks from better researched populations. Biological studies have been conducted on a relatively small proportion of fished stocks, perhaps <10% (Andrew et al 2007). So, fisheries scientists commonly find themselves assuming values for the LHP of data-poor assessments based on studies conducted on other populations, or correlations based on other attributes, developed through meta-analysis. This is called the 'Robin-Hood' approach to data-poor stock assessment; whereby information is borrowed from well-studied species in 'data-rich' fisheries and applied to the parameterization of data-poor stock assessments.

It was Holt (1958) who originally observed that the LHR (M/K and L_m/L_∞) are more informative for data-poor stock assessment, than the individual LHP, which he observed varied considerably within species. Holt argued this was so because the physiological constraints on species and taxa make the LHR less variable across species' ranges and taxonomic groupings. Prince et al. (2015) presented evidence to support Holt's claim, showing that the LHR characterize the life history strategies of species, genera and families. Implying that the LHR of well-studied species can be 'borrowed', to inform the assessment of taxonomically related unstudied species with similar life history strategies. The view was subsequently supported by Thorson et al. (2017) who conducted an analysis of the LHP data contained in FishBase and concluded that the LHR do indeed vary across taxa. Although because of the noisy data contained in FishBase they were unable to describe any underlying patterns in the inter-taxa variation of the LHR.

Thorson et al. (2017) concluded that a major shortcoming of their analysis, the most comprehensive to date, was their reliance on extracting data from FishBase without regard to the quality of LHP estimates.

Aiming to definitively settle this issue, we have now collected 1335 published studies and applied rigorous standardization and quality control procedures to develop a database of 1576 and 861 high quality estimates of M/K and L_m/L_∞, respectively. Two parallel analyses of our database were conducted independently of each other; a cross-validation study of the predictability of M/K by taxonomic category, and an evaluation of alternative models of the relationship between the LHRs using Akaike information criteria. We conclusively demonstrate that the LHRs vary significantly and predictably by taxa. Our results suggest that the LHRs of taxa can be related to nutritional richness or balance of the food-webs they typically exploit, referred to as their stoichiometric niche.

The results of our recent analyses provide a robust basis for assuming LHR values for previously unstudied populations, species, genera and even entire families. Previously unstudied species and genera can be assumed to share similar LHR to other species in the same family or genera. My experience suggests, that in most cases average LHR values estimated for an entire genus, or family, are more accurate than, and should be used in preference to, LHR values derived from studies of the stocks being assessed. This is because accurately estimating the LHP of a stock is far more complicated than most researchers realize and consequently many published LHP estimates turn out to be of very low quality.

To avoid the issue, I recommend that readers use the list of high quality, standardized LHR estimates for 69 teleost families that can be downloaded from the biospherics.com.au website (Slide 49).

Global Uptake

Thanks to its simplicity and cost-effectiveness the LBSPR methodology has gained widespread acceptance and is now being rapidly taken up and spread around the globe, becoming one of the most commonly used assessment methods for data-poor fisheries assessment (Canales et al. 2021). As of early 2021 the original three papers documenting the technique (Hordyk et al. 2015a, b, & Prince et al. 2015) had been cited in the international peer review literature more than 320 times in aggregate, and it has been applied to an eclectic mix of species in almost every part of the world (Table 1).

Table 1. Some of the published applications of LBSPR assessment methodology.

LOCATION	SPECIES	AUTHORS
Alantic Ocean NE	Atlantic bonito	Petukhova 2020
Amazon & Mekong rivers	various freshwater species	Shephard et al 2020
Atlantic ocean, Morroco	Atlantic bonito	Baibbat et al. 2019
Atlantic Ocean, southern	small tunas, mackerels & bonitos	Pons et al. 2019
Bay of Bengal	shad	Suresh et al. 2021
Belize	reef fish	Babcock et al. 2018
French Polynesia	bonefish	Filous et al. 2019
Guam, Western Pacific	coral reef fish	Nadon 2019
Gulf of Mexico	Atlantic sharpnose sharks	Bada-Sanchez et al. 2018
Indonesia	malabar snapper	Ernawati & Budiarti 2019
Indonesia	spiny lobsters	Ernawati et al 2019
Indonesia	skipjack tuna	Satria & Sadiyah 2017
Indonesia	long-barbel sheatsfish	Suman et al. 2020
Indonesia	blue swimmer crab Indonesia	Suman et al. 2020
Indonesia	2 x shrimp species	Tirtadanu & Chodrijah 2020
Indonesia	kawakawa tuna	Wujdi et al 2020
Ireland	sea trout	Shephard et al 2019
Kenya	tuna and tuna like species	Mueni et al 2019
Palau	coral Reef fish	Prince et al. 2015
southern Brazil	grouper	Rovani & Cardoso 2017
Sri Lanka & Indonesia	blue swimmer crab	Prince et al. 2020
SW Mediterranean	European hake	Martinez-Banos 2018
West Java, Indonesia	Nile Tilapia	Mulyadi et al 2019

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