THE BAREFOOT ECOLOGIST'S TOOLBOX

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CHAPTER NINE

REFORMING THE MANAGEMENT OF SMALL-SCALE FISHERIES WITH LBSPR ASSESSMENT.

Introduction

In this chapter we examine how LBSPR assessment within the SPS approach can be used to develop and implement simple but effective fisheries management.

Having initiated an SPS program, collected data and completed LBSPR assessments for a previously unmanaged, or under-managed fishery, the barefoot ecologist wanting to facilitate effective community-based management ends up facing the question, what is the best type of management? There are a lot of proven options for sustainably managing fisheries, and a lot of advocacy for a range of less proven remedies, but not all these prescriptions are equally feasible and effective in the context of data-poor fisheries. This chapter aims to make sense of the wide range of options confronting the uninitiated but aspiring fisheries manager.

In this context my aim is not to be comprehensive and discuss equally every possible form of fisheries management. Rather, it is to concisely provide advice relevant to the context of data-poor fisheries, about how and why simple management with proven effectiveness should be implemented. My aim is to simplify the process of implementing effective management and steer readers as directly as possible towards proven effective management for 'data-poor fisheries'.

Management Objectives

In generally fisheries management aims to address three broad concerns:

Recruitment Overfishing

The most basic issue for fisheries requiring management is that of biological sustainability and the preservation of biodiversity. The need to ensure fish are allowed to complete sufficient spawning potential (SPR) to ensure future generations (recruitment) are abundant enough to replace parental generations. Catching fish before they complete sufficient SPR to replace themselves, results in recruitment overfishing, which left uncorrected causes the long-term decline of stocks, and eventually population collapse and local extinction. Internationally the level of SPR recognized as likely to result in recruitment overfishing is SPR < 20%, which is referred to as the Point of Recruitment Impairment (PRI). The most basic aim of fisheries management is to prevent recruitment overfishing by maintaining stocks above PRI or SPR 20% which is often used as a lower bound, or limit for management, called a Limit Reference Point.

Growth Overfishing

Having ensured recruitment overfishing cannot occur, the next priority for management is ensuring that optimal amounts of fish can be caught to feed communities. This requires managing to allow fish to finish their rapid juvenile phase of growth so that they fulfil their full growth potential before being caught. The potential of a fish stock to provide food for communities is compromised by catching the fish before they finish growing to their 'optimum length', the length at which a cohort, or age class attains its maximum biomass, rather like picking fruit or vegetables before they fill out and ripen. Growth and recruitment overfishing commonly occur together, with growth overfishing leading into recruitment overfishing. Maintaining SPR >20% generally limits the extent of growth overfishing, but the Target Reference Point for management of 30 - 40% is used as a proxy for producing the Maximum Sustainable Yield (MSY), which by definition precludes any degree of growth overfishing. Maintaining SPR 30-40%, should not only prevent populations collapsing, but ensure stocks are maintained at the optimal level for the capacity of their habitat and food resources, referred to as the carrying capacity of their environment, and are caught at optimal sizes having completed their rapid phase of juvenile growth.

Economic Overfishing

A final aim of fisheries management is to prevent economic overfishing by ensuring fisheries are economically efficient. Without the management of fishing pressure, fisheries tend to develop more capacity to catch fish than is needed to take the maximum sustainable yield (MSY). This inevitably occurs in unmanaged fisheries because with no perception that in aggregate the fishery is already 'over-capacity' the individual fishers each aim to maximize their individual shares of the catch, resulting in a competitive 'race for the fish'. The fisheries equivalent of an arms race. Even if catches can be sustained, the eventual consequences of the race for fish are reduced catch rates and wasteful aggregate expenditure by fishers on fuel, equipment and time. The ultimate goal of management is to ensure that optimal sustainable catches with the highest value, are caught efficiently at high catch rates and minimal expenditure of time, fuel and gear. This level of optimal catch referred to as Maximum Economic Yield (MEY) will inevitably be less than MSY, but it will be caught more profitably with much lower levels of effort and cost, at higher catch rates, and the body size of fish will be larger. In terms of SPR the proxy for MEY is SPR 45-50% but this management objective cannot be achieved by managing the size and SPR of fish alone. To manage the economic efficiency of a fishery the intensity of fishing pressure must also be managed at a level that minimizes competition between the fishers so as to maintain optimal catch rates.

Different Ways of Managing Fisheries

The various management tools used to achieve these objectives can be placed into four broad categories. These categories are not mutually exclusive, in the world's best-managed fisheries they are often used in combination. Internationally, as well as within countries, these various approaches to management have evolved over time. As understanding of fisheries dynamics has grown managers have responded to newly perceived challenges, by layering successive types of management on to previously implemented strategies.

Size Selectivity

Across Europe and North America through the 19th Century, some but by no means all experts maintained, that the great fish stocks of the world were unlikely to ever be depleted by the fishing technology of the time. In fact, by the time that statement was first written down by Huxley in Great Britain, there had already been an enquiry in the US demonstrating that the Atlantic halibut fishery had been depleted by overfishing. Through the early 20th Century understanding of the potential for growth overfishing grew, being conceptualized and analyzed initially by Baranov and others, with the earliest form of fisheries modeling – Yield Per Recruit (YPR) modeling. This aimed to use rates of growth, natural and fishing mortality, to estimate the optimal size to catch fish in order to prevent growth overfishing and optimize the yield from each recruit. At that stage there was little understanding that adult fish could be depleted to such an extent that the supply of young fish would be threatened and a fundamental assumption of YPR modeling is that regardless of fishing pressure the level of recruitment will always remain constant. The term recruitment overfishing would not be coined until the late 1940s. Baranov and others used YPR modeling to show that the North Sea trawlers were racing each other to the fish by competitively using smaller and smaller mesh sizes to catch the fish before other fishers using larger mesh sizes. This was leading to the fish being caught before they fulfilled their growth potential, growth overfishing, causing overall catches to decline. Their solution was to regulate the minimum size of mesh used by the fishing fleet, allowing small fish to escape through the nets until they reached the optimal length (L_{opt}) for maximizing catches, when rapid juvenile growth ends and energy begins being diverted from growth into reproduction. With this understanding of growth overfishing the initial focus of fisheries management in many jurisdictions was to study age and growth of their most important species and conduct YPR assessments to determine optimum lengths for capture which were then implemented with Minimum Size Limits (MSLs) and regulation of the type of fishing gears that could be used.

The size of fish in a catch is determined by the size at which fish first become vulnerable to being caught, which we refer to as the size selectivity of the fishing, as well as the fishing pressure being applied to a stock. The LBSPR assessment software estimates the size selectivity of samples assuming an S-shaped or logistic curve defined by the parameters SL_{50} and SL_{95} Which are the size classes in which 50% and 95% of fish, respectively, will be caught if they encounter the fishing gear. As discussed more fully in chapter 5, the size selectivity of catches is normally a result of an interaction between the fishing gear being used, as well as, where and when that gear was used.

In general, smaller sized hooks, mesh and escape gaps tend to catch smaller fish than large hooks and mesh sizes. In addition to the influence of the size of gear, many fish and invertebrates segregate by size and age, which also influences the size range that can be caught. All this means that where and when you use fishing gear, as well as the type of gear used, will influence whether catches are primarily comprised of smaller juveniles, larger adults, or a mix of both. Clearly a type of fishing gear that potentially catches small and large size classes will only catch smaller size classes if used in nursery areas.

In addition to the size selectivity of fishing, fishing pressure is a major determinant of the size composition of a catch. With heavy pressure fish are unlikely to survive long enough, to grow much bigger than the size they first become vulnerable to being caught, the size of selectivity. Whereas, if fishing pressure is light. they may not encounter any fishing gear until they are much bigger than the size of selectivity. So the size at which fish get caught can be managed indirectly through the level of fishing pressure being applied, or by regulating types of fishing gear that can be used, and where or when fishing occurs, or directly with size limits that regulate the size of fish that can be landed.

When the nations of the world first began to appreciate that the great fish stocks of the world were indeed being depleted and should be managed to prevent this happening, they had to begin developing their capacity to manage fisheries. Initially they had no capacity to directly control fishing pressure and catches, so they began with the simplest form of management available, by controlling the size selectivity of fishing. Through the 1950s and 1960s countries like Australia, New Zealand, South Africa, and in North America and Europe, began regulating minimum mesh sizes to enable small fish to pass uncaught, escape gaps dimension in traps and pots to allow small crabs and lobsters to escape, and establishing minimum legal sizes (MSLs) for all their most important species. History has proved, that as an initial first step towards improving fisheries management, managing size selectivity was pretty successful. Most of the jurisdictions that began simply in this way have gone on to develop what today is recognized as 'best practice' fisheries management.

Input Controls

However, size selectivity can only manage the issues of biological sustainability and growth overfishing, alone it cannot prevent economic overfishing. For that purpose more sophisticated approaches to fisheries management are required.

Through the middle of the 20th Century, as the technologies and materials developed originally to fight the two world wars, were turned loose on fish stocks, complete collapse of fisheries began to be observed more regularly. Fisheries scientists came to the realization that it was not only possible to growth overfish stocks and reduce yields, but also to 'recruitment overfish' and collapse them completely. Assessment scientists first developed surplus yield models, which assumed stocks to be an amorphous biomass without age structure, and correlated long term trends in catch and effort to estimate the fishing pressure which would result in the Maximum Sustainable Yields (MSY). At this stage assessment scientists and managers shifted their focus from just controlling size selectivity, to managing the fishing pressure, or fishing mortality (F) on stocks, by controlling the 'inputs' to fishing; the number of boats, pots and nets put in to the water to extract fish. Managers began implementing systems for registering boats and fishers, and for limiting their number, preventing new entrants from starting fishing, without having first paid an existing fisher to stop. And regulations for limiting the numbers of traps, hooks and nets being used, and the length of fishing seasons, all with the aim of limiting and managing fishing mortality.

The difficulty of doing this soon became apparent. Fishers, intent on maximizing individual shares of catches, respond inventively to new regulations, devising alternative ways to make fishing gear more effective, and spending longer at sea each season. The result is an arms race between managers, trying to limit fish pressure, and fishers, trying to catch as much as possible within the regulations. Inevitably the pressure on fish stocks ratchets upwards; a phenomenon now called 'effort creep'. Pretty soon managers find themselves not just regulating the number of boats and fishers, but also the length, horsepower and holding capacity of every boat, the number of traps and hooks, the number and lengths of nets, even the number of times traps, hooks and nets can be set in a season, and shortening fishing seasons.

Surplus yield modeling typically relies on catch rates, catch per unit effort (CPUE), to provide an index of stock abundance, but the process of effort creep typically results in each defined and regulated unit of fishing effort becoming gradually more effective at catching fish. This in turn degrades the relationship between CPUE and fish abundance and the quality of the assessments based upon them. Over time the limitations of surplus yield modeling became increasingly evident. The SPR concept was developed during the 1970s and 1980s to address this weakness as a way of using the age and / or size composition of a stock to provide an index of a stock's risk of recruitment overfishing.

Output Controls

To circumvent effort creep jurisdictions with well-developed capacities for fisheries governance began experimenting with directly controlling the catch that comes out of a fishery with 'output controls', aiming to manage catches to the level of a Total Allowable Catch (TAC) estimated by stock assessment.

The earliest attempts at TAC management, involved competitively fishing up to the level of the TAC, with government officials monitoring landings, in close to real time, and declaring the fishing season closed when the TAC had been achieved. Competitive TACs caused their own set of problems, TACs were regularly exceeded as fishers proved quicker at landing catches, than the officials were at monitoring them. Like a snowball rolling down a steep hill, over successive years fishers became quicker and quicker at landing catches, and fishing seasons became shorter and shorter. In Canada and USA the annual season of some fisheries declined to just a few of days in the case of the west coast halibut fishery, and less than 15 minutes in the case of the British Columbian herring roe fishery. This extreme shortening of seasons drove massive over-capitalization, with fishers buying and equipping powerful specialized vessels that were only used for a short period each year, even spare boats in case one broke down. And also the wastage of fish, as large amounts of catch were landed all at once, flooding processing capacity and markets.

Individually Transferable Quotas (ITQ), also called catch shares, were developed to address the economic distortions caused by competitive TACs, by giving fishers and fishing companies defined entitlements to a specific weight or number of fish each season before they individually stopped fishing. These systems act something like a share market with companies and individuals trading and leasing entitlements to a share of the TAC which annually equated to a defined amount of fish, adjusting their own share of the TAC to suit their business strategy. With well-run ITQ systems fishers are motivated to optimize their own profitability, by minimizing costs and maximizing the value of their catch, rather than racing to fish. Because of their potential for effectively preventing economic overfishing, ITQs have come to be recommended by scientists, managers and NGOs working in jurisdictions with high functioning governance, as the ‘gold standard’ of fisheries management to be aspired to.

However, despite all their potential social benefits, output management systems are the most demanding, in terms of the resources needed for fisheries assessment, and governmental capacity for implementation and enforcement. Accurate regular stock assessments are required with dynamic age-based biomass models, so that Annual Catch Levels (ACLs) can be accurately estimated and recommended to the managers setting TACs. The age-based models require detailed biological studies of age, growth and size of maturity and extended continuous time series of trends in total catch and effort, and preferably, as well, data on the size and age composition of catches and fishery independent surveys of biomass trends. All of which requires a well-funded highly trained workforce of fisheries scientists and assessment modelers. High functioning governmental capacities are also needed to monitor the progressive catch of individuals and fisheries in real time, and in the case of ITQs to initially allocate shares of the TAC and then register changes to individual quota allocations as fishers trade and lease quota between themselves.

Marine Protected Areas

In recent decades marine protected areas (MPAs) have been widely advocated by some marine ecologists as the ideal management tool for small-scale and information poor fisheries (Clements et al. 2012; Lubchenco et al. 2003) and have gone on to become the most preferred form of management for study (McClanahan, 2011). It has been claimed that with 30-40% of fishing areas incorporated into MPAs other forms of management become unnecessary. The rise of the theory that MPAs by themselves can effectively manage fisheries was a consequence of the poor implementation of fisheries management in USA during the late 20th century, and the general decline of their fisheries during that period. This led to a few North American marine ecologists declaring orthodox fisheries management had failed, and proposing MPAs as their new alternative ‘silver bullet’.

The theoretical models used to build the profile of MPAs as a tool for fisheries management were themselves dangerously over simplistic. All exploited species were modelled as having relatively sedentary adults and highly dispersive larvae. So that in simulation their protected populations built up within MPAs, until larvae and adult started spilling-over onto the fishing grounds outside. The original MPA modeling did not consider species with other dispersal patterns, such as dispersive adults which return to place their young in specific restricted nursery areas (e.g many sharks and Pacific Salmon), or highly sedentary species with very limited adult and larval dispersal (e.g. abalone and coral reef fish). Moreover, the original MPA modeling, and almost all that has occurred since, took no account of the dispersal dynamics of the larvae from source populations. So that factors like the dilution of larvae with increasing distance from sources, and the need to maintain larval supplies back to the source populations exporting a high proportion of their own larvae, were not considered. Nor were the potentially complex homing behavior of larvae incorporated. The ridiculously over-simplified nature of MPA modelling is perhaps best exemplified by two recent high profile papers claiming the global benefits of MPAs (Cabral et al. 2020; Sala et al. 2021) which, amongst other things, purport to show how MPAs implemented in the Atlantic will result in spill-over benefiting Pacific fish stocks (Hilborn 2021; Ovando et al. 2021).

The result is that the effectiveness of MPAs for managing fisheries has been more theoretical, than observed in reality. While clearly capable of building fish biomass and sizes within MPAs (Lester et al., 2009) their effectiveness for sustaining fisheries outside remains entirely unsubstantiated (Clements et al., 2012; Hilborn, 2006; Kearney & Farebrother, 2014; Lester et al., 2009). The decline of the USA's major fisheries has largely been halted, and most are now rebuilding, but it was not the implementation of MPAs that achieved this, rather it was the proper implementation of output and input controls, and size selectivity, that was eventually compelled by the Magnuson-Stevenson Act of 1976. The many MPAs implemented in data-poor jurisdictions over the last few decades have also failed to live up to their promise of sustainably. In Fiji where they have been widely implemented, and community support was originally strong, the continuing decline of the surrounding fishing grounds has eroded support leading to declining compliance (Jupiter et al., 2017). A similar less well documented dynamic is occurring in many other countries as well, so that international donors are increasingly reviewing their historic investment in creating MPAs and changing their funding priorities. Consequently NGOs are down-scaling MPA focused interventions and without community support most MPAs end up being protected in name only. The places where this is not occurring, such as Palau and Raja Ampat, tourism industries developed to utilize the MPAs share the income from the MPAs with the communities making their continued support worthwhile. The sad reality remains, however, that rather than being a silver bullet for sustainable fisheries, the success of MPAs has depended on effective management outside the MPA.

The observable lack of effectiveness of MPAs for sustaining fisheries results from a combination of factors:

- Many species are much 'stickier' than originally expected by scientists. Larvae, juveniles and adults have all proved to be much more site attached than expected. Most larvae have more homing ability than originally assumed, and mainly return to settle within a few hundred meters of their parents. Juveniles and adults commonly also remain within the same location over their entire life cycle, perhaps just migrating periodically to nearby spawning aggregation sites. The result is that for many species spillover is nowhere near as great as the original theoretical MPA papers assumed and has been insufficient to sustain catches on the fishing grounds, much beyond the boarder of the MPA.

- On the other-hand, the adults of some species are highly migratory and travel long distances, so that only the largest MPAs provide much protection, and then provide only a brief respite from fishing pressure outside the MPA. So that ultimately the sustainability of these highly migratory species is still determined by the fishing pressure outside the MPA, rather than periodic protection within.

- Between these two extremes, some species are not strongly site attached to the MPA, nor highly mobile. Their populations can build up within MPAs and potentially produce significant amounts of spillover if the size of the MPA is correctly scaled to their mobility. If the MPAs are too small, there will not be sufficient protection to build-up a self-sustaining population and constant topping up from fished populations outside will be required. In this case if the fishing grounds are depleted, the population inside the MPA keeps providing spilling over but never gets topped back up, and slowly runs down, like a car battery disconnected from the alternator and no longer being recharged.

These real-world complications were not considered by the original MPA modelling. In order to be effective, the scale and location of MPAs needs to be very carefully matched to the dispersal patterns of the species being protected. Unfortunately, there are very few species for which our understanding of spatial dynamics is sufficient for the task. An undertaking which becomes even more complicated in a multi-species assemblage, like Indo-Pacific reef fish, which exhibit a wide range of dispersal patterns, across differing spatial scales, so that even with perfect knowledge and no political constraints, it would be impossible to implement an MPA that would work for a large proportion, let alone, all species.

The perceptive reader will have gathered from this discussion, that I am of the view that MPAs are not an effective means of managing productive fisheries, and that many of the claims to that effect have been wildly exaggerated. Let me hasten to add, however, that I do think they have a valuable place in the management of marine systems, and have witnessed them being used very effectively to achieve a range of objectives. In the broader context I believe they are an important part of a manager's toolbox. In Fiji they are effectively used as food banks. Sheltered fishing grounds close to communities, that would otherwise inevitably be overfished and depleted to low levels, get closed allowing stocks to accumulate. Then, when a periodic need arises, such as a big ceremony, or an extended period of bad weather prevents access to more distant fishing grounds, the communities declare a short opening and make fish available. Fishing grounds close to major population centers always become the focus of intense fishing pressure which is almost impossible to manage, so that almost inevitably they become depleted. Far better to have these grounds as permanent MPAs so that they become a valuable non-extractive resource for recreational divers and tourists, than as permanently depleted marine deserts. There is also great scientific value in having large MPAs in remote lightly fished areas, as reference areas in which relatively unfished ecosystems can be studied. In some fisheries, there are also species so vulnerable to depletion by incidental catching that their biodiversity value will only be preserved by complete protection with MPAs large enough to sustain remnant populations. So globally I see great value in MPAs, just not as a primary tool for sustaining productive fisheries.

Which Type of Management to Use?

Theoretically there are many ways to manage fish stocks to ensure biological sustainability and optimal yields, and no one 'silver bullet' for managing every fishery. Anyone that advocates that there is, should be regarded with deep suspicion. The reality is, however, that a country or fishing community's capacity to monitor and assess stocks, and to administer and enforce fisheries regulations, will significantly constrain what can feasibly be implemented. A society's capacity to manage can also be expected to change over time, as understanding, experience and organizational skills develop, and in response to new perceived challenges. Experience with managing fisheries simply, develops the capacity for more sophisticated forms of management. It is easily forgotten that the countries now recognized as having 'best practice' fisheries management developed their current capacities over 6-7 decades, and began simply managing size selectivity. Fisheries management is an evolutionary process, a journey to be embarked upon, rather than a structure to be constructed to a fixed design by an intended completion date.

The issue here then is; what is the best way to start managing your data-poor fishery?

How to Starting Managing?

Rationale for Size-Based Management

Controls on fishing effort and catches are widely used to manage fisheries. Directly controlling catches with ITQs, or catch shares, is widely advocated as 'best practice'. However, these input and output controls require the capacity to monitor and assess continuous time series of catch and effort data, to develop and maintain dynamic stock assessment models, and to control catch and fishing effort in something close to real time. Few of the developing nations I have had experience with currently have the capacity to accurately monitor trends in fishing effort and landings, let alone conduct regular fishery independent stock surveys. Even in the rich developed countries that are doing a relatively good job of monitoring, assessing and managing their major fisheries, few have the same capacity for all their small-scale and data-poor fisheries. Without the capacity to accurately monitor trends over long time periods dynamic assessment models cannot be developed to estimate sustainable levels of catch and effort, and there will be no capacity to directly manage catch and effort. Until those governmental capacities have been developed management with input and output controls is precluded. The recent popularity for managing fisheries with MPA's has been in part due to the apparent administrative simplicity of closing areas to fishing. The problem being, as discussed above, they are also an ineffective fisheries management tool, and there is no way of reliably predicting any benefit they might produce for a fishery.

In this context, for many small-scale and data-poor fisheries, managing size selectivity will be the only effective form of management that is immediately implementable to achieve planned levels of stock protection. The management benefits from changing size selectivity are well understood and predictable with simple analytical techniques, including the LBSPR methodology. Prince & Hordyk (2018) demonstrate that even when used alone, size selectivity management can stabilize and rebuild stocks, ensuring sustainable optimal yields, even when the fishing pressure is relatively unmanaged and heavy. In contrast to input and output management, which depend upon the capacity to measure and control catch and effort, size selectivity management removes the immediate imperative to develop those capacities. Consequently, starting with size selectivity management provides a simpler, easier starting point for a process of developing a country or communities, capacity for sustainable management.

It must be explicitly acknowledged that without some capacity to constrain fishing pressure the economic objectives of fisheries management cannot be achieved. This is because managing size selectivity alone cannot maintain high catch rates and keep fishing a productive, cost-effective activity. Unless the amount of fishing effort, or the amount of catch, can be controlled at moderate levels, catch rates will inevitably keep declining as fishers compete for the fish. This provides a powerful reason why communities and countries should aspire to move beyond just managing size selectivity to control fishing effort, but in the short-term for most data-poor and small-scale fisheries those economic objectives are less of a priority than stabilizing and rebuilding sustainable productivity which can be achieved by managing size selectivity. Size selectivity management provides a feasible starting point for management with the immediate objectives or stabilizing and restoring local stocks to achieve sustainable optimal yields, and to gain the time needed to pursue the longer-term aspiration of developing the capacity to also manage economic overfishing.

I am suggesting planning a trajectory for developing management; with later stage developments arising from, and being contingent on, capacities developed in earlier stages. Although it was never planned from the outset, this type of successional development of management capacity occurred in many of the countries that today have the most advanced management and indeed has been followed by our field internationally. In the same way that environmental regeneration is often most effective when natural processes of succession are facilitated and supported. We should learn from the history of fisheries management, and plan to facilitate a 'natural successional process' for developing management in small-scale and data-poor fisheries, starting with size selectivity.

We also arrive at size-based management through our interest in social change and the simplicity of the messaging required. The simplicity of communicating the need for more larger fish reproducing for longer on fishing grounds, and the resonance of that concept, are key reasons for the successful uptake of SPS by communities. Our initial aim with the SPS process is to facilitate fishing communities recognizing their situation, and moving quickly beyond denial about the state of their stocks, into a shared understanding of the nature of the overfishing problem they confront and their need for change. To achieve that the SPS methodology initially focusses their attention on how the size of the fish they catch has changed, which is obvious to very member of a fishing community, whether they catch the fish, or buy them in the market. Having accepted their need for change we aim to initiate an iterative process through which they can discover the simplest most effective way for the community to manage by remaining focused on maintaining the size of the fish they catch. Our methodology empowers fishers, managers and local fisheries biologists to go on self-assessing the sustainability and effectiveness of management by the size of the fish they handle on a daily basis. From the standpoint of behavioral change, simply maintaining the focus on the size of fish throughout the SPS process and all the way through to size selectivity management, is a huge strength in enabling an ongoing process of changing social norms.

In a more technical sense, the choice of which type of management is trialed initially is not really so important, because tracking the size of fish in the catch can evaluate the effectiveness of any type of management, and something different can be tried if it is not. The really important thing is to facilitate beginning that trialing process, not the type of management a community wants to begin with. Never-the-less, there is a natural desire to assist fishing communities to move towards sustainably as efficiently, easily and quickly as possible. That pathway is challenging enough without rediscovering lessons learnt the hard way in other fisheries. Without being dogmatic on the topic, as outlined above, there is a wealth of science and experience to support the idea that size-based management is an optimal way to start small-scale fisheries on their road to sustainability. And, as will be discussed in more depth below, the results of the LBSPR assessments are particularly useful for informing size-based management.

Making Fishing Size Selective

THE PRINCIPAL OF SIZE-BASED MANAGEMENT

The principal of managing size selectivity is illustrated by figure 1. If the size selectivity of fishing is smaller than the size of maturity (figure 1 – left-hand panel) then fish can be caught before they breed, and if fishing pressure is heavy, the fish can all be caught before breeding or reaching the size at which they produce the optimal amount of food for fishers (L_{opt}). The smaller size selectivity is relative to size of maturity (L_m), the greater a stock's vulnerability to both growth and recruitment overfishing.

Increasing the size selectivity to being the same as the size of maturity (figure 1 - middle panel) confers some level of protection on a stock, by theoretically ensuring all fish get to breed, and by allowing all fish to be caught close to L_{opt} it is a formula for catching the Maximum Sustainable yield (MSY) from a stock. For many decades the aim of fisheries management was to obtain the MSY from stocks, and for this purpose the classic prescription for setting minimum size limits (MSL) was to set the minimum size limit at the the size of maturity (MSL = L_m). However, this prescription for size-based management was developed at a time when fishing techniques were less effective than today and most fish were expected to survive for several years after reaching the MSL and the concern of managers was to prevent too many fish going uncaught. Now powerful fishing gear and heavy fishing pressure are almost universal, and our concern is more about preserving sustainable levels of SPR and attaining optimal yields when most fish will be caught close to the MSL. In this setting MSL = L_m is likely to result in most fish being caught as they mature and few fish surviving long enough to complete their initial breeding season.

In today's world, if you want to be sure of protecting fish until after they have completed sustainable levels of SPR it is necessary to manage size selectivity to be bigger than the size of maturity (figure 1 – right-hand panel). It still remains true however, that if you make size selectivity too big relative to L_m many of the fish will end up dying of natural causes without being caught, which will result in smaller than optimal sustainable catch. There is, however, a goldilocks zone for setting size selectivity bigger than L_m which protects sufficient SPR for robust sustainability and produces an optimal 'Pretty Good Yield', only slightly less than MSY (Hilborn 2009). Prince & Hordyk (2018) demonstrate that this goldilocks zone is achieved by protecting fish until they achieve ~ 20% of their SPR and worked out a simple rule-of-thumb for estimating that size based on multiples of L_m which will be discussed in more detail below. If protected until they achieve at least SPR 20%, stocks will produce this minimally sustainable level of SPR and only slightly sub-optimal catches even under heavy fishing pressure, and more optimal higher levels of SPR (30-40%) and catch with moderate levels of fishing pressure.

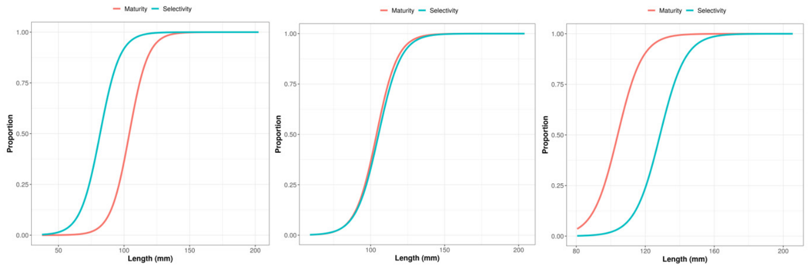

Figure 1. Managing size-selectivity. These panels depict on the vertical axes percent mature (red) and the proportion selected for catching (blue), by length class on the bottom axes. The left-hand panel illustrates fish being selected for catching before they reach maturity which makes them vulnerable to over-fishing. The middle panel illustrates fish being selected as they mature which provides some protection from overfishing if fishing pressure can be managed at low to moderate levels. The right-hand panel portrays fish being selected for catching 20% larger than the size of maturity, which as a rule-of-thumb conserves >20% SPR even with heavy fishing pressure, preventing recruitment collapse and maintaining optimum yields.

Setting Minimum Size Limits

Where fishers can be highly selective with regard to the size of the fish they catch, as can divers picking up individual abalone, scallops or conch, or can release undersized fish alive and in good condition, as fishers can release lobsters from a trap, the simplest and most robust form of size-based management will be to implement a minimum size limit (MSL). When properly implemented and enforced, an MSL changes the typical S-shaped size selectivity curve depicted in figure 1 to a square shape, referred to as knife-edge selectivity, with fish smaller than the MSL being 100% released and those larger than the MSL being 100% retained. In this simplest of cases, in order to ensure stocks remain robust under heavy fishing pressure, an MSL should be set to the size at which the fish in a stock on average complete 20% SPR which Prince & Hordyk (2018) demonstrate, as a rule of thumb can be approximated as being 20% bigger than the size of maturity (MSL = 1.2 x L_m).

Of course, not everything can be caught precisely by size, like diver selected shell fish, or released unharmed, like lobsters from a trap. In many cases the process of catching fish causes great harm, such as catching fish with gill or trawl nets. In those cases, an MSL can be a blunt management tool, and is not recommended, and the fishing gear itself may need to be managed to adjust the size range being captured, as will be discussed below. Between these two extremes there are cases where some level of damage and mortality is inflicted by catching, but might be minimized with careful handling, or the catch of undersize might be minimized through modification of the fishing technique. In those cases, an MSL might still be usefully implemented, and its effectiveness enhanced with education and management of the fishing gear.

The Indo-Pacific reef fish assemblage is a case in point. Most, but not all, species are reasonably robust when line caught from <20m depth and with care can be measured and released if undersized with a high chance of survival, and motivated spearfishers operating in clear water, can learn to be size selective. Minimum size limits have been widely, and relatively successfully, applied to this, and the parallel assemblage of Caribbean reef fish, by USA and Australian jurisdictions. However, some level of undersized mortality is unavoidable, when small fish swallow hooks, get caught at depth, or are accidentally speared. Currently most artisanal fishers think releasing any little fish is a waste of good food and fish indiscriminately for all sizes of fish. The SPS process aims to directly address that heuristic way of thinking and develop an appreciation of the importance of conserving small fish. Fishers, however, will always struggle with the morality of discarding undersized fish that are clearly going to die, and those circumstances will present an ongoing compliance risk for any jurisdiction. The approach taken in most developed nation jurisdictions where fishing is for the purpose of commerce or recreation, rather than subsistence, is to police the MSL regulations rigorously and enforce the wastage of fish. In the hope that fishers will eventually find ways to avoid the wastage. To do otherwise, creates the moral hazard of implicitly encouraging fishers to kill undersize fish. In jurisdictions where fishing is for subsistence purposes and compliance monitoring is weaker, that policy may not be as practical. Especially when fishing communities are only just beginning to develop an ethos about size selective fishing. An alternative approach, at least for a transitional period, may be to regulate and strictly enforce the MSLs for the sale of fish in markets, but to tolerate the subsistence use of undersize fish. This will of course still create the moral hazard by allowing fishers to benefit from retaining undersized fish, but it will constrain the extent to which this occurs and prevent it from being monetized.

Multi-species Size Limits

Where a large number of species are caught together, many species-specific MSLs will result in a management system that is too complex to implement and enforce. For example, catches of Indo-Pacific reef fish are commonly comprised of 100+ species, and in the Solomon Islands may be comprised of 200+ species, making the notion of setting species-specific MSLs species completely impractical. In this context it becomes necessary to group species into a pragmatically few MSLs that protect all species from depletion and optimize the potential productivity of the species assemblage.

For this purpose, Adrian Hordyk (UBC) and I developed a multi-species yield-per-recruit model (MSYPR) that evaluates the trade-offs involved in different MSL groupings of a multi-species assemblage. For a range of alternative MSL groupings, the MSYPR estimates aggregate sustainable yield, as well as, the number of species left prone to eventual local extinction by high fishing pressure. The aim being to determine the least number of MSLs an assemblage can be grouped under to optimize potential yields and prevent species extinctions. To date we have used the MSYPR model with the Indo-Pacific reef fish assemblage being caught in Fiji, Palau and Solomon Islands (Prince et al, 2018, 2020). Our results make explicit the cost, in terms of lost biodiversity and food security, of not effectively managing these reef fish fisheries. Indicating that ~70% of the potential yield, and >50% of the species, could eventually be lost. On the positive side our results suggest that, local extinctions can be prevented and >90% of potential yields sustained under high fishing pressure, with a system of as few as 4 -6 multi-species MSLs.

At this stage the MSYPR model has not being made available through the biospherics.com.au. I do not have sufficient spare capacity to provide the documentation needed to provide user friendly support sufficient for the greater technical complexity of that analysis. Any readers particularly interested in the approach should read the papers cited above and then contact me directly to discuss how I might be able to facilitate accessing that analytical framework.

Why Slot Limits Seem Like a Good Idea just Not For Data-Poor Fisheries

Slot limits involve both minimum and maximum size limits and are commonly advocated as a way of protecting the largest individuals in a population, referred to as mega-spawners. Mega-spawners have been defined as being >10% larger than L_m and are regarded as being ‘disproportionately effective’ at reproduction (Froese 2004; Ahrens et al. 2019). Part of the disproportionate effectiveness of individual ‘mega-spawners’ is simply due to the fact that fecundity (the number of eggs produced) increases in proportion to body weight, itself a cubic function of adult body length (L^3). There is also however, some evidence that the greater experience, and better provisioning of eggs, by larger individuals enhances the survival of the eggs they produce as well.

The idea of slot limits is superficially attractive and seems to make a lot of sense, but it is more technically difficult to implement effectively than MSLs, and will only work where there is also the capacity to directly manage the intensity of fishing pressure (Ahrens et al. 2019). While the relationship between fish length and fecundity is well defined, the enhanced survival of eggs from larger bodied fish is not, because of this there is no quantitative basis for setting the maximum size of a slot limit. In addition, the protection provided by any slot length, will depend entirely upon fishing pressure. If fishing pressure is too great for the size of the slot, no individuals will survive long enough to grow into the protection of the upper size limit. And without survival through to the upper size limit the actual management effect becomes that of the lower size limit. Thus, in effect, a slot limit will act as an MSL if fishing pressure is not managed proportionately to the slot size. On the other hand, with very light fishing pressure and high survival through the slot, an upper limit could become too effective, and prevent a large proportion of the stock from being sustainably fished, causing a degree of ‘under-fishing’. As a consequence, setting slot limits and ensuring their effectiveness, will depend upon a jurisdiction's capacity to effectively quantify and manage fishing pressure. Capacities we have already concluded are not a normal characteristic of small-scale and data-poor fisheries.

In reality setting MSLs with the methodology described here will be a more practical and robust way of providing the desired protection of mega-spawners than implementing a slot limit. The SPR concept and the LBSPR algorithms incorporate the relationship between fecundity and weight, so that, using SPR as a reference point for management, provides a quantitative basis for accounting for that aspect of the ‘disproportionate effectiveness of mega-spawners’. Although the unquantified enhanced survival of eggs produced by larger individuals cannot yet be accounted for by any method. Our recommendation to set MSLs = 1.2 x L_m to preserve at least 20% SPR will conserve, at least, the smaller size classes of mega-spawners, and depending on fishing pressure, some larger mega-spawners as well. To the extent a fishery manager remains concerned about providing additional protection for mega-spawners, MSLs could be set to conserve a higher level of SPR, say 1.3 x L_m which should protect at least 30% SPR. In this way management can be planned to provide a quantifiable level of protection for a stock, rather than hoping for poorly defined benefits, which cannot be attained with any level of surety, and will be determined by unmanaged levels of fishing pressure.

Setting Mesh and Hook Sizes

Where relatively large amounts of undersized fish are unavoidably caught and killed or damaged, MSL’s are likely to be ineffective, and difficult to enforce because discarding perfectly edible dead fish goes deeply against the grain for most fishers. For example, nets, traps and hooks naturally catch a relatively wide range of sizes, and net caught fish cannot normally be released unharmed, while hook-caught fish hauled up from depth have their swim bladders inflate and die if returned to the water at the surface. While fishers for blue swimming crabs through South-east Asia are unlikely to sort nippy undersized crabs and release them in good condition, preferring to let them ‘quieten down’ in the bottom of the canoe before sorting them, and then are likely to take them home for the pot.

In some of these cases regulating the size of hooks, mesh in nets, or escape gaps (hatches or vents) in traps (e.g. Boutson et al. 2009) could increase size of selectivity sufficiently to conserve the recommended >20% SPR. Prince & Hordyk (2018) demonstrated that as rule of thumb this can be achieved by adjusting gear size until the size of 50% selectivity (SL_{50}) is 30% larger than L_m ($SL_{50} = L_m$ x 1.3).

The analytical tools provided by the LBSPR software can be used to work out the gear alterations needed to achieve this for your fishery. Simply collect catch length-frequency data with the different types of gear you are interested in trialling (i.e. a range of mesh, hook or escape gap sizes) and analyse the catch size composition data from each gear type with the LBSPR software to estimate the SL_{50} and SL_{95} of each. The gear configuration you want may not be in use in your fishery so this might mean purchasing, or constructing some experimental fishing gear to use. Once you have found, or made up the gear, just go out and start fishing until you have caught and measured the 200-500 fish, with each type of fishing gear, needed to make good estimates of size selectivity with the LBSPR software. Better still, set up a collaborative fishing project and involve some of the fishers you will want to be the early adopters of the new fishing gear, to fish with each of the different sized fishing gears and sample their catches. If none of the gear types produces a size composition with $SL_{50} = L_{50}$ x 1.3 simply make a plot of SL50 against the different sizes of gear, and by extrapolation you will be able to estimate the gear size needed.

Regulating How, When & Where

Some types of fishing are just inherently non-size-selective, or prone to killing small fish, and if the aim is to manage size selectivity may need to be prohibited or tightly restricted. The worst are the highly destructive fishing techniques of bombing and poisoning, besides destroying fish habitats, they are completely indiscriminate killing everything in range. Fortunately, they are now banned in most places, but they should be banned everywhere.

Other types of fishing gear, such as nets, can be more or less selective depending on when and where they are used. Through the Indo-Pacific beach seines and small mesh gillnets used in shallow coral, seagrass and mangrove nursery grounds are indiscriminate in the size and type of fish they catch, and fish are either dead or badly damaged by the time they are removed from the net. These sorts of practices need to be either banned, or restricted to a few locations to limit their impact on stocks. With regulations to establish the right minimum mesh sizes, agreed target species and allowable areas for setting, nets can be made sustainable. The huge variety of coral reef species, with diverse body sizes and shapes means that even if only one mesh size is allowed, gillnets used in coral reefs will always catch an indiscriminate array of juvenile and adult fish of many species. Similarly fishing in the nursery areas, shallow coral rubble shallows, seagrass beds, or mangroves, will inevitably kill a lot of juvenile fish. However, nets with the right mesh size, used to target schools of mullet along sandy beaches and channels, for example, can efficiently produce a sustainably species and size specific catch.

Continuing in the context of Indo-Pacific reef fish, night-time spearfishing almost invariably results in a catch of predominately juvenile fish and many jurisdictions have flirted with banning it. There is no innate reason that night-time spearfishing must be size indiscriminate. Spearfishing involves visually selecting individual fish to shoot and can be made highly selective if fishers want to be compliant with MSLs. Night-time fishers, however, normally operate in the coral shallows, which are nursery grounds, and in low light conditions tend to react quickly and shoot everything they see, but it would not be impossible for the divers to operate in deeper water, to slow down and only shoot fish above an MSL. Although, if the night-time spearfishers are resistant to change, it may be more expedient for fishing communities to just prohibit the activity. Or follow New Caledonia's example, and prohibit the sale of all speared fish, so that spearfishing in the night or day-time is allowed for subsistence, but not commercial purposes, which at least limits its overall impact.

While there is a clear role for the national government in establishing regulations regarding minimum size limits and legal types of fishing gear, the types of fine-scale spatial and temporal regulations that help make fishing more size selective need to be developed and implemented through local community management committees working closely with the detailed knowledge of the local fishers.

Change Management

CREATING SHORT TERM WINS

According to Kotter's theory of change management, the initial steps trialing change should be bite-sized and achievable. The aim being to produce quick small positive experiences of change, so as to build trust between partners, and confidence in taking further steps towards change. Starting the process with small introductory steps enables communities to confront their fear of change, and experience that it is not so difficult or too painful. The introduction of an MSL for just one or two species in a multi-species assemblage is ideal for this purpose, because it can create a very quick positive example of what can be achieved with management.

The stocks we work with are almost inevitably fished down close to L_m because fishing pressure is almost universally high, and once fished down below L_m (i.e. SPR <10%) stocks tend to decline quickly and disappear from catches and our samples. So almost inevitably the stocks we encounter have about 20% SPR, and most fish are being caught close to L_m. The LHR of each species determines that around L_m the fastest proportional gain in weight occurs as each cohort approaches its peak biomass (see chapter 5). This biological hardwiring means that around L_m a surprising number of species are doubling in weight each year. So that delaying their age of captured by 6-12 months by introducing an MSL set at L_m x 1.2, can be relied on to almost double the weight of the catch within 12-24 months. Immediately, upon implementing a new MSL to a previously unmanaged species, there will of course be a sharp 6 – 12 month reduction in catches, while the fish just below the new MSL grow up to that size. But within 12 -24 months of that initial sacrifice, catches will rapidly and permanently improve as pre-existing fish grow through the new MSL and enter the fishery at close to double the weight they were previously being caught at. And because SPR will have been rebuilt to >20% SPR by the new MSL, recruitment rates are likely to start increasing, so that over a period of some years (5-20) catches can be expected to continue improving, although more slowly than the initial jump up in catches.

This all sounds too good to be real, and the first time I witnessed it I was taken completely by surprise, so powerful and rapid was the effect I observed. I have since witnessed the effect of correcting growth and recruitment overfishing many times, and I have come to expect and rely on it, and the positive impact it has on the fishing communities who experience it. The initial trial of one or two MSLs can be relied upon to give communities a very immediate and powerful initial experience of management, both the magnitude of the relatively small short-term sacrifice required, but also the larger longer term gains that result. Another reason for size selectivity management being a natural and powerful starting point for trialing fisheries management with any fishing community.

ADAPTIVE MANAGEMENT: LEARNING BY DOING

In the sections above I repeatedly recommend that fishing communities wanting to reform fisheries management start their process by managing size selectivity. I have described how estimates of L_m can be used to estimate MSLs or sizes for mesh, hooks and escape gaps to conserve at least 20% SPR and prevent recruitment declines and achieve optimal yields. I have also discussed how currently size-indiscriminate ways of fishing might be regulated to make them more size selective. Communities and organizations may also be interested in implementing other forms of management that I have not discussed, but have support amongst community members, such as closed areas and seasons. Fisheries that are relatively indiscriminate for size will be forced to confront the complexity of trying to control either fishing pressure or catch levels directly. In all these cases there will come a point when communities will ask themselves; is what we are doing working? Do we need to do more, or something different?

Re-assessment at 3 - 5 year intervals with LBSPR will enable progress to be monitored, enabling the effectiveness of any type of management to be evaluated, allowing fishing communities to learn from their experiences and adapt their strategies to make them more effective. Clearly if SPR starts trending towards, or remains around, internationally accepted sustainability targets (SPR = 30-40%) it means whatever the community is doing, is working. Conversely SPR declining, and remaining, below 20% signifies their current strategy is failing and needs changing. No matter what management strategy a community initiated their reform process with, the LBSPR technique can be used in this way to guide their subsequent steps. Re-assessment at more frequent intervals is not really necessary as size composition of populations change quite slowly, normally over a similar time period as it takes for a juvenile to mature and pass through the fishery. This is not to advice against annual assessment with LBSPR. If you have the resources and infrastructure required, go ahead, but bear in mind that for most fisheries the inter-annual variation you see, will be just variation around some much more slowly moving average trend in SPR.

Rather than considering the periodicity of sampling, I imagine that at this point most readers will actually be wondering whether they are ever likely to have the resources available to re-assess their community's fishery. In this case the principals of LBSPR assessment can be taught more qualitatively to community members, enabling them to re-assess their stocks and management more intuitively. For this purpose communities should be encourage to think about the size composition of the catch in relation to the size recommended as ideal for an MSL = L_m x 1.2, even if an MSL is not being implemented. In Fiji we came to refer to this size for each species as being 'Set Size' because Fijians use the word 'Set' in the same way many nationalities use 'OK'. For convenience I adopt this nomenclature here, so that Set Size = L_m x 1.2.

Whether or not an MSL has been implemented, this Set Size can be used by communities as a benchmark for simply assessing their stocks and determining whether things are improving, or not:

- Ideally, 80 - 100 % of the catch will reach Set Size or greater. If so, the stock will have >30% SPR, and at this level will produce optimal sustainable catches. To be sustainable a stock should have at least 50% of the fish getting to the Set Size or bigger.
- If <50% of the catch is reaching Set Size, the stock will have <20% SPR and recruitment to the stock is likely to be declining, so that the size of the population will be declining year after year. Management needs to be improved.
- If <10% of a catch is reaching the Set Size the stock is likely to have <10% SPR and be at risk of recruitment collapse, too few fish will be getting big enough to breed and restock the reef. A complete fishing ban might be required.

With these basic reference points for catch size composition, communities can simply and qualitatively compare their own catches to their targets, and monitor progress in relation to them. If the size of fish in the catch is getting smaller relative to their Set Size, they need to make management more effective e.g. larger mesh and hook sizes, shorter fishing season, less fishing permits, low daily trip limits. Alternatively, when the size of the fish in their catches become larger than the target, management measures can be relaxed.

With these simple techniques, adaptive science-based community fisheries management becomes possible and can be used to motivate endogenous long-term processes of change. And we are seeing our partnering communities intuitively adopt these methodologies and concepts using them to evaluate their own stocks, and inform dialogues within their communities about trialling new forms of management.

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