THE BAREFOOT ECOLOGIST'S TOOLBOX

DR JEREMY PRINCE

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Contents

CHAPTER SIX

COLLECTING DATA FOR LBSPR ASSESSMENT

Introduction

The aim of this chapter is to describe in more technical detail the data requirements of LBSPR assessment, it has been written for the person designing and implementing the technical and quantitative aspects of the SPS approach.

There is some overlap with previous chapters which focused on how this material is communicated with community training workshops to initiate SPS projects and the underlying fisheries concepts. So the reader should already have an understanding of the underlying technical aspects of data collection and how to communicate them. In this chapter our focus turns to the practical side of collecting high quality data for LBSPR assessment.

Our discussion begins on a general level with aspects of the approach that apply more-or-less, regardless of species and fisheries; the over-arching principals and assumptions concerning how the data will be used and which provide the context for why and how we gather the data. In the following sections of this chapter, I dive into the practical detail of data-gathering protocols and data-sheets, that I have developed to use with finfish, crabs and spiny lobster. Anyone wanting to work with those groups of species should be able to download the available materials for immediate application to your own fishery. Hopefully, for those thinking about applying LBSPR assessment to other groups of species, these applied examples will assist by giving you materials to adapt. The blank page is always more difficult to work with, than a draft is to edit.

By focusing on these case studies, fish, crabs and lobster, I do not want to create the impression that LBSPR can, or should, only be used with these groups of species. It is just that these are the groups to which I have applied LBSPR so far. In the context of my work in tropical Indo-Pacific countries, these are the 3 groups of coastal fisheries I am most often consulted about. Over time, in partnership with others, I hope to apply it more broadly and expand this section.

If you go on from reading this to developing your own adaptation of SPS for other fisheries and are happy to share your work, please contact me and let me know. It would be great if this initiative could keep growing over time, with Barefoot

Ecologist's all over the world picking up and borrowing these tools, eventually returning them back to the toolbox with their own adaptation, embellishments and languages.

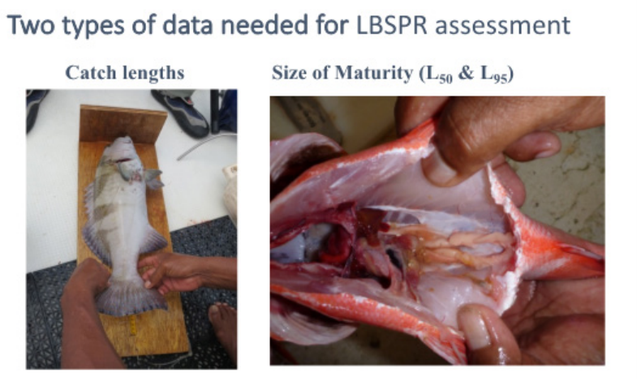


Figure 1. The two types of data that need to be collected to make an LBSPR assessment; the size composition of catches representative of the adult fish population (left) and size of maturity data (right).

The Data Required for LBSPR Assessments

Of the three types of data, or information, required to inform an LBSPR assessment:

1. Size composition of adult catch;
2. Size of maturity of the population being assessed;
3. The life history ratios (LHR) that define their family or genera;

it is the first and second forms of data (figure 1) that are the focus of this chapter. As they are the data that need to be correctly collected locally, to reliably assess your local stock and develop management recommendations. The third type of biological information in this list, the applicable life history ratios (LHR), is derived through synthesis of the international literature, which has been discussed briefly in the previous chapter and is discussed in more detail in the next chapter.

Good data on the size composition of catches (1) is the most critical information collected for LBSPR assessment, and should be the main focus of local SPS sampling programs. Some 5-10 times more length data, are required for high quality LBSPR assessments, than size of maturity data. For each species assessed by LBSPR assessment the aim (even if often impossible) should be to measure the length of > 1,000 fish, while reasonable size of maturity estimates (2) should be possible with samples of 150 – 200 fish.

The length composition of the catch needs sampling every time an assessment or re-assessment is made. The assumed M/K informs the LBSPR algorithms about the expected relative shape of that size composition data, but it is information about either asymptotic size (L_∞), or size of maturity (L_m) which informs the algorithms about the actual size of that shape. In the most data-poor form of LBSPR assessment focused on here, it is assumed that L_∞ cannot be estimated directly by field research, so that the size of maturity data and our assumption about L_m/L_∞ is used to inform our assessment about the real (absolute) size of our measured length composition data. In other words, a single estimate of L_m is required initially to establish or 'calibrate' our LBSPR assessment and unlike the length composition data it is not really necessary to continue collecting that aspect of the data. Once estimated L_m is expected to remain relatively stable over time, perhaps changing slowly over decades with changing water temperature and population density. Re-estimating size

of maturity every 10-15 years should be sufficient to track any of these long-term changes.

In the context of a longer-term program of regularly (every 1-3 years) monitoring size composition of the catch, my advice would be to simplify data collection once solid estimates of size of maturity have been developed and focus on collecting the catch size composition data.

Size Composition Data

The most important underlying assumption used by the standard form of LBSPR assessment, accessed through the barefootecologist.com.au website, is that the size composition of the sampled catch accurately represents the adult size composition of the sampled population. The simple logic being applied is that if larger size groups of fish are missing from the size composition, it is because fishing pressure has removed them.

Dome Shaped Selectivity

If the size composition of the catch is affected by dome shaped size selectivity, and mainly contains smaller individuals, the standard version of the LBSPR will under-estimate SPR and over-estimate F/M. In the context of artisanal fisheries the most common cause of dome-shaped selectivity is probably from fishing pressure being most intense on smaller size classes in shallower depths, and lighter on larger adults further off-shore at depth, rather than simply due to the fishing gear being used.

A new version of LBSPR has been created by Homik et al. (2020) with which dome-shaped selectivity can be specified if it has been defined through independent studies of size selectivity, and then taken into account by the LBSPR assessment. That version is, as yet, unavailable through our website. A limitation with the new version is that it requires the dome-shaped selectivity to be accurately specified something that has rarely been done for a data-poor fishery. Rather I find myself assessing the anecdotal accounts of fishers, the range of fishing gears they use, the depths they fish, and my general knowledge of the species' biology to qualitatively assess the degree to which dome-shaped selectivity is likely to be affecting an LBSPR assessment.

Although wide-spread in fisheries, and a very real issue to be considered carefully when applying LBSPR, in the context of fishing pressure being almost invariably high, dome-shaped selectivity may often be more of a potential, than actual problem. This is because for the right hand-side of a dome-shaped selectivity curve to impact the composition of a catch, the fish in that stock must grow big enough to be affected by the right-hand side of the dome and become invulnerable to fishing. In today's heavily fished stocks it is common for few, if any, fish to reach the size classes protected by dome-shaped selectivity. If you apply Homik et al.'s (2020) new version of LBSPR to those stocks you will reach the same answer as if you use the standard version. Which is exactly what Shepherd et al. (2020) observed with their assessment of Nile tilapia in Lago Bayano in Panama.

The Selectivity of Multiple-gear types

Another issue related to the size selectivity of catches that arises here, and which people often ask about, is what happens when the catch being measured is made with multiple types of fishing gear with a variety of size selectivities?

Ideally, the aggregated catch composition reflects the adult size composition of the stock, and the overall composition of the aggregated catches has a simple logistic size composition on its left hand-side and a simple unimodal (bell-like) shape. Then you can simply ignore the fact that multiple gear types have been used. It should all come out in the wash although the logistic size selectivity being estimated results from the multiple gears, or the gear that catches the smallest size classes. In this case the correct approach would be to estimate the overall size composition of all catches (and not just your samples) by weighting up your samples of each gear, in proportion to their contribution to the overall catch. In order that the component size samples from each gear type, contribute to your final sample, in the same proportion that they are actually being taken from the stock, rather than just depending on how big your samples were for each gear type. Of course, where all the catches from every gear are just lumped together and mixed up, before you get to do the sampling, your sampling should already reflect the contribution of each gear type. This is the simple situation.

Unfortunately, the situation is often not that simple. In many cases, if some of the gears being used effectively catch the juveniles and sub-adults, but not adults, while others catch the adults, you will find that the catch of juvenile and sub-adult size classes can dwarf the catch of adult size classes. In these cases, you will often observe two size modes, one on the left being juveniles and sub-adults, and one on the right being mainly adults.

Once you start using LBSPR you will quickly see that the model can only fit a simple single bell-shaped mode to the data, and applying it to bi-modal data, with both a mode of juveniles or sub-adults, and an adult mode, invariably produces a poor fit at best, and a completely crazy answer saying you have zero SPR at worst.

This is because the LBSPR algorithms cannot make sense of bi-modal size distributions due to an assumption used in most types of stock assessment, that the rate of natural mortality is constant across all size classes, being incorrect. In fact, rates of natural mortality normally decline as size increases, and are usually thought to only be relatively stable for the adult size and age classes. However, in stock assessment we are generally most interested in the adult size classes as they are the only ones that contribute to breeding biomass and SPR, so we use the assumption of constant mortality because it more or less works for the part of the stock we are most interested in. And besides, we rarely have any information about the number of juveniles and how quickly they die-off. In our models they basically turn up as young adults which we track with the assumption of constant natural mortality.

The implication for us here, and for the LBSPR algorithms, is that if you sample the size composition of fishing gears that are effective at catching juvenile size classes, you will almost inevitably record juveniles in greater proportions than the LBSPR algorithms can predict. That is because they are much more numerous than predicted by the assumption of life-long constant mortality. It is the assumption that is wrong, not your sampling.

The point to be made here, is that when confronted with multiple gear types and size compositions, rather than attempting to estimate some complicated aggregated catch composition, especially when that aggregate size composition is multi-modal. You will often get the best result by just focussing on the size composition from the gear type which most effectively catches the full range of adult size classes, and disregarding the gear types which catch the juvenile and sub-adult size classes, and have dome-shaped size selectivity. This is not just my recommendation it is also the finding from a comparative study made by ICES scientists working on fisheries for small-pelagics in the South Atlantic (Pons et al. 2020).

More will be said about this in chapter 8 about completing LBSPR assessments.

Sample Sizes n > 1000

Ideally, for high quality LBSPR assessment, samples sizes greater than 1000 individuals would always be available for analysis (Hordyk et al. 2015). This is because LBSPR assessments are strongly influenced by the size of the largest fish in a population, which are naturally very rare, and unlikely to be fully represented until samples size >1000 are obtained (Erzini 1990). Under-representation of the largest size classes with small samples sizes results in lower estimates, than actual, of spawning potential (SPR) and higher estimates of relative fishing mortality (F/M).

In the real world of data poor fisheries assessment sample sizes of more >1000 individuals are themselves often rare, and it is necessary to make the best use of whatever data you are blessed with. In my experience with Indo-Pacific reef fish sampled from hook and line, and spearfishing, sample sizes greater than 100 can be worth analysing. If the length frequency histogram coherently describes an adult mode an indicative assessment can be made of whether the stock is heavily, moderately or lightly fished.

If sample sizes can then be increased to more than 1000 individuals with the same input assumptions, the original SPR estimate may increase by 0–20% SPR, but almost invariably the originally preliminary estimate is indicative of the final estimate.

So don't be discouraged by low sample sizes, go ahead try them. Better to use the data you have, get the fishing community thinking and talking about those data, what they might be indicating, how things can be improved.

Protocols for Sub-Sampling Catch Size Composition

Often fish measurers will not have the time, capacity, or inclination to measure every fish landed, so some sort of sub-sampling will occur. Accurately sub-sampling animals from a pile of fish is not as easy as it at first seems. People are very prone to unconsciously selecting bigger individuals in preference to smaller ones. Even the highly trained observer will unconsciously tend to select bigger rather than smaller fish, leaving the smallest fish to be measured last.

Remember that with LBSPR assessment the hard assumption is that the sample of fish represents the adult size composition of the population. So it is critically important that the fish being sub-sampled and measured, represent the size composition of the overall catch from which they are sub-sampled. Of course, if all the fish in a pile are measured, unconsciously selecting the big fish first to measure will not matter, because all the fish will eventually get measured. If, however, an observer picks away at a large pile and stops measuring at whim, before every fish is measured, you can be certain that somehow the measurer will have subconciously selected more 'attractive' bigger fish and left unmeasured more 'less attractive' smaller fish. So that if sampling is stopped part way through a pile of fish, almost certainly the sample will be skewed towards the biggest fish and our LBSPR assessment will end up over-estimating the level of spawning potential in the population.

To prevent bias creeping into sub-sampling it is important to teach your fish measurers a couple of rules about sub-sampling:

1. If the catch of a single species is to be sub-sampled then choose some container, say a basket or crate, and pour or drag big bunches of fish, into that container, or containers, of choice.

2. This will be the sub-sample to be measured and all the fish of the sampled species in that sub-sample must be measured. It could be that not every species in that sub-sample are measured. But having started measuring a species in that sub-sample, all the individuals of that species must be measured.

3. The person doing the sub-sample must remember not to fill up those containers by picking fish out of the main pile one by one, because if they do that, they will inevitably unconsciously select bigger fish, and the reason for sub-sampling will be defeated.

4. The sub-sample must be selected 'en-masse' by pouring, or shovelling, or dividing the original pile into parts, specifically to avoid fish by fish selection. Alternatively, where the catch is multi-species, as it will be in the coral reef fish context, another way to sub-sample a catch is just to measure all the individuals of a certain species, and so choose to measure some species and not the other species. If in your program you do want the species composition data that would have been collected by measuring every fish of every species in the catch, your observers could simply identify and count every fish in the catch, but only measure a few species in each catch.

Focused on collecting high quality size data, I tell fish measurers that, it is not necessary to measure every catch, or every fish of every type in a catch, but having chosen a catch and a species to sample, they must measure every fish of the chosen species from that catch.

Gender-Specific Growth

The algorithms used for LBSPR assessment assume that a population with a single growth curve underlies the size composition being assessed. In some species of fish, and commonly with crustaceans, the genders grow at different rates to different asymptotic sizes. In these cases, the shape of the gender combined size composition will be the result of two different growth curves which will violate the assumptions being used to analyze the data. Effectively you will be analyzing two different populations using the assumption that they are one which will degrade quality of your LBSPR assessments. With

these species you really should collect the size composition by gender, and conduct your LBSPR assessment by gender.

Fortunately, with crustaceans this is not too much of a challenge because they can usually be sexed using their external morphology, as discussed below. For fish, however, this can be a real problem, necessitating cutting them all open so their gonads can be inspected. This is over and beyond the much smaller sample needed to estimate L_m. And because fishers, market sellers and buyers commonly want their fish intact, the dissected fish will generally need to be purchased using limited research funds.

A work around for this problem is to assume greater variance around the asymptotic size when conducting the LBSPR assessment, but at this stage the web-based version of the LBSPR software does not facilitate this. For that you will need the down-loadable version of the algorithms in R-code.

Fortunately, in many fish the genders grow similarly, or begin growing as one gender before changing into the other (discussed below), for these species the genders can be aggregated for the purpose of collecting the size data. So, that not every individual measured for size need be examined for gender. In this case size of maturity data need only be collected for several hundred individuals, to enable a good initial estimate of size of maturity, while the size composition data collection will need to continue being collected for >1000 individuals.

Sequential Hermaphrodism

In the context of this discussion of how different growth curves and life cycles effect the application of LBSPR the question of sequential hermaphrodism arises. This is the phenomena by which some species begin life as one gender and at some stage transition into the other gender. Typically, in parrotfish and wrasse, the smaller females transition into larger males, but in barramundi the reverse occurs. Some studies of growth for these species estimate separate gender-based growth parameters, which basically describe two phases of a life-long gender combined growth curve, which can also be described by a Von Bertalanffy curve. So for the purpose of LBSPR the genders of these species can be considered as experiencing a single gender combined growth curve and gender combined size composition data can be used for LBSPR assessment.

Size of Maturity Data

Size of maturity is normally assumed to remain relatively constant over time, perhaps gradually changing (declining) with higher temperatures and high population densities.

Size of maturity (L_m) is used directly in the assessment of SPR, and also indirectly where there is no independent estimate of a population's asymptotic size (L_∞), to derive an estimate using the LHR (L_m/L_∞) typical of the species, genus and family.

Unlike the size composition data, in each location for each species it is really only necessary to estimate size of maturity the one time, initially to develop the LBSPR assessment. Where there is already a pre-existing local estimate of size of maturity it may not technically be necessary to collect size of maturity data. A lot simpler just to use the pre-existing local estimates. However, even without a scientific need, a strong argument can be made sociologically, for teaching community-based observers to collect size of maturity data in any case, as the skill informs and facilitates change, by enabling fishers to see for themselves whether the fish they catch are mainly juvenile or adult. Using locally collected data to estimate L_m will also increase the buy-in of community members seeing their own data being given meaning.

Although common practice in our field, I caution against simply adopting and applying pre-existing estimates of size of maturity from generic sources like Fishbase (Pauly & Binohlan 1996). The field of fisheries has tended to assume that species are uniform over wide ranges, and has been relatively unaware of how much species vary across their ranges, and especially between differing temperature regimes. Where the only available estimate of size of maturity is from a different latitude, or topography, which may indicate a different temperature regime, you should be very cautious about applying an estimate of L_m borrowed from somewhere else. In that situation, I might start off by using the previous estimate, just to begin my analytical

process, while I initiate data collection to develop my own new local estimate.

As already discussed above, the point to be noted here is that unlike the size composition data, the size of maturity data does not have to be collected each time an LBSPR assessment or reassessment is repeated. It is only really needed to initiate assessments in each location, and then to recalibrate assessments if there are grounds for believing population densities and / or temperature regimes have changed since the original estimates were made. In our context of global climate change good practice may well be to repeat the size of maturity estimate every 10-15 years.

Protocols for Sub-Sampling Size of Maturity Data

The data on fish maturity are used in a different way to the size data. The size data should exactly represent the proportion of each size class in the catch while the size of maturity data should profile how gonad condition changes across the maturing size classes. In the context of estimating L_m your sampling will be more efficient if the fish you sample are selected from the catch to give you an even spread of 10-20 fish in each 5-10cm size category across the size range that spans from 100% immature to 100% adult. This can often mean purposefully building up the number of the smallest and / or largest size classes by searching through catches mainly comprised of mid-sized individuals.

Remember though, if you are going to purposefully select certain size classes to estimate L_m you should keep these 'size-selected' samples distinct from the size composition samples you use for the LBSPR assessment.

As fewer size of maturity data, than size composition, are required for LBSPR assessment, and the size of maturity data need not be collected proportionately to the size composition of the catch. It is legitimate to collect this form of data opportunistically, which can sometimes allow creative ways to be found for collecting the data without buying fish.

Observers can just gather data on the fish being consumed in the village and send the other fish to market intact (after measuring their length). In Palau we made an arrangement with the staff member of a local fish shop who put the best and largest fish aside for the best customers buying fish for the restaurants, and who would request that the fish they bought be processed for them. So, at our request he collected size of maturity data on all the fish he processed for those customers and saved us the cost of buying those fish for gonad sampling. Also in Palau, for a donation to the cause of the women organizing a community fishing competition, they required all contestants to let us measure and sexually gauge each fish. In effect we got to briefly 'rent' each fish while we collected our data for ~10% of what the fish would have cost to buy.

At this point of the chapter, we end our generalized discussion about LBSPR data collection, and dive into talking practically and specifically about data collection protocols and data forms for finfish and crustaceans; blue swimmer crab and spiny lobster.

Finfish Sampling

I commonly incorporate the process of making fishing measuring boards into the SPS training workshops. This provides a chance for workshop participants to become hands-on and learn how simple it is to make and use a fish measuring board. The process of making their own measuring boards hopefully means they will be more invested in measuring fish, although sometimes the boards go onto be used in unexpected ways, in addition to measuring fish, such as removable additional boat seating in Fiji.

A list of the materials needed to equip a team with fish measuring boards is shown below. Using the materials and design below each board will cost about USD8-10 if old measuring tapes used from monitoring coral transects are used, or USD20-25 if you buy higher quality stainless steel rules. The sheets of ply bought from hardware shops come in a standard 2.4 m x 1.2 m, using the design below this allows for 9 measuring boards 300 mm x 900 mm and their 150 mm high head boards, to be cut. Even though it is more expensive I strongly recommend using marine ply 18 mm thick rather than the thinner, more readily available 12 mm. The 12mm is just a bit too thin for the head boards to be strongly attached. Once the headboard is broken off and there is nothing to slide the fish up against the sampling will become much less accurate. If marine grade ply wood is not available or not used due to cost you need to make sure plenty of varnish is used and allowed to dry properly or the boards will not last long.

Also included in the list of equipment needed are the stationary needed by the fish measurers including the pencils, clipboards with bulldog clips, and rubber bands to hold data sheets in place even in windy conditions. These I like to place into little satchels along with blank data sheets which are given to the observers.

MATERIALS

- 1 Board 2400 x 1200 x 18 mm thick plywood (marine grade if possible).
- Glue (for boards and tapes)
- Screws (to hold boards together)
- Medium & fine sandpaper
- Marine varnish
- Measuring tape (Cut up old 30m tape)
- Circular saw
- Screw driver
- 1/2" chisel or router
- Power drill and drills
- Clipboards with bulldog clips & rubber bands to hold down data sheets
- Pencils
- Data sheets & gonad categorization guides

Table 1. List of hardware materials need to make 9 fish measuring boards at ~$10USD per board.

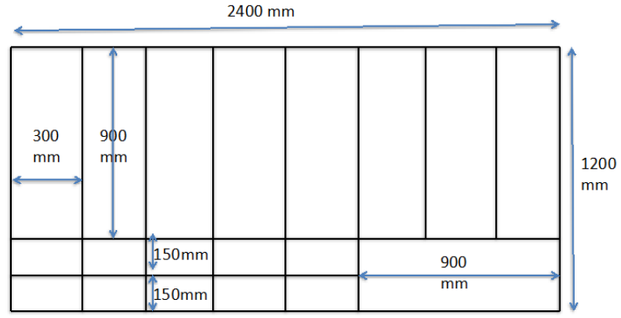


Figure 2. Measurements used with 2400 x 1200 mm board of marine ply to make 9 fish measuring boards.

In terms of the measuring tape on each board, the cheapest option is to look around for old wind-up vinyl tape measures, commonly used for coral surveying, to cut up. The first few meters of these wear out amongst the coral and then the whole tape gets junked into the corner of NGO offices waiting for some other purpose. In each meter of the tape the numbering of centimeters starts afresh, and as the wear is normally worst in the first part of the tape there is always plenty of good tape left that can be cannibalized for fish measuring. The off-cuts can be glued down onto the wood and then varnished over for protection against the elements making a cheap option for fish board measuring.

The problem with using these second-hand tapes is that normally they are marked off with 1 cm gradations. I find that armed with these the fish measurers will tend to round their measurements to the nearest 5cm, which for fish < ~75cm length will not be precise enough for good assessments. If your interest is primarily helping communities to inform themselves this may not be a problem, but if you aim to do some reasonable science and maybe write-up a reasonable analysis for species <

~75cm length you will need to get the measurement error down to 5-10 mm. This will mean finding measures that are graded in mm rather than cm, and asking your fish measurers to measure to the nearest 1mm. Then they will be more likely to round to the nearest 5mm mark. Some of the vinyl tape measures used in coral surveying might have this level of precision, but you should really consider going to a good hardware shop and paying an extra ~$USD10-15 per board to purchase stainless steel rules with the superior markings made to the mm. Incorporating these into the measuring boards will also make the boards much more long-lasting.

Measuring the length of fish

There are multiple scientific definitions for measuring fish e.g.:

- Fork length – measures from the tip of snout to the fork in the tail fin.
- Total Length – measures from the tip of the snout to the tip of the tail fin,
- Standard length – measures from the tip of the snout to the middle of the end of the tail fin,
- Peduncle length - measures from the tip of the snout to the tip of tail bone.

Each has its different uses. For example, peduncle length is commonly used for trawl caught fish, which tend to get their tails smashed up in the cod-end of the trawl net, while standard and total length are used for fish that don't have forks in their tail, and standard length gets used for fish which do not have clear forks but may have long trailing process of their tail fins. Our aim is to cut through complex scientific definitions to something we can simply teach our fish measurers, and to avoid burdening them with scientific terms. To this end we teach our fish measurers just to measure down the middle (centerline) of the fish (figure 3).

The simplest protocol to learn and teach is to:

1. Place the closed mouth of the fish against the headboard of the measuring board.
2. Use the tip of a knife to pinpoint the middle of the end tail against the measuring tape and then roll the fish away
3. Read the length from the tape to the nearest 1 mm.

This approach leaves it up to us (the technical advisers and analysts) to work out, from knowledge about the shape of the species being sampled, in scientific terms which type of measurement is made for each species. In species with a forked tail this will be fork length, while for species without forked tails this will be total or standard length. Which is really only of importance if we wish to compare our size compositions or estimates of L_m with other studies. With this approach it will generally be found that our measurement for a species will be the same as that used in published studies.

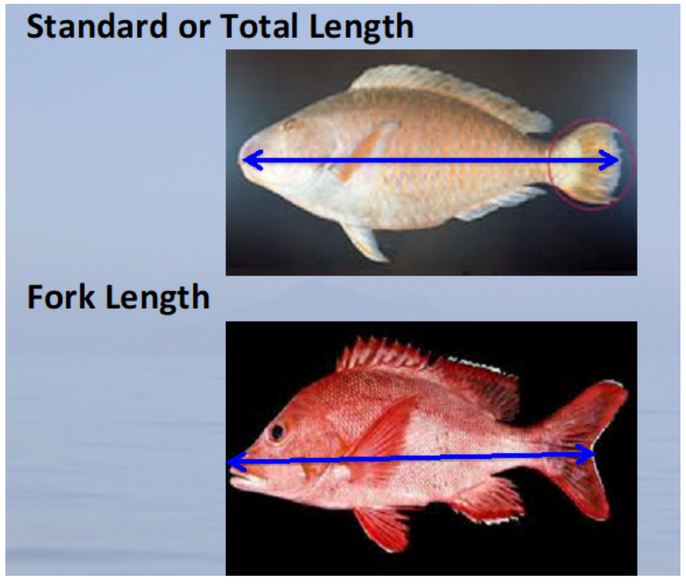


Figure 3. Illustration of the fish measurement used. The rule being simply to measure down the middle of the body, from the closed mouth snout to the middle of the end of the tail.

Gauging the maturity of fish

The appearance of fish gonads as they develop and cycle between breeding season is quite varied, in tropical reef fish especially. This can sometimes make the classification of sexual development and gender challenging, even for professionally trained fisheries biologists, let alone for the artisanal fishers we often collaborate with for our SPS approach. While this can

often make it difficult to be certain about individual gonads, and some species more challenging than others, our methodology does reliably define the bigger picture about the size range over which fish mature. The basic protocols described relatively briefly here, are described in more detail and with more pictures in a document entitled '3. Macroscopic categorization of fish gonads document' that can be downloaded from the 'Data Collection and Analytical Techniques' page of the 'biospherics.com.au' website.

This protocol aims to classify fish gonads simply by eye (macroscopically) as being male or female, and either immature, or adult, which by this definition includes maturing, resting and ripe stages.

The gonads of fish will always be found in pairs at the top of the gut cavity. Holding a dissected fish upside and peering into the gut cavity you will almost always find them lying along either side of the back bone. The primary distinguishing features are:

- In immature fish the gonads either cannot be found, or are only visible as thin twin transparent threads or straps of developing tissue. No three-dimensional structure or gender will be obvious.
- In adult fish the gonads will have a distinct, three-dimensional shape;
    - In females the ovaries tend to be bright yellow, orange or sometimes green and start off being sausage or tube-like before developing into sacks or bags in which the eggs will be either visible, or felt as small granules.
    - In males the testis tend to have a creamy color, developing first into a belt or strap like shape, before developing a triangular cross section, and a lobed liver-like shape.
- Fat around the intestine and / or gonad can appear like adult male testis in female and immature fish at times. But closer examination will reveal it has different 'greasy' feel and different colour to the testis, and it will be associated with the curls of the gut rather than lying in pairs next to the back-bone.

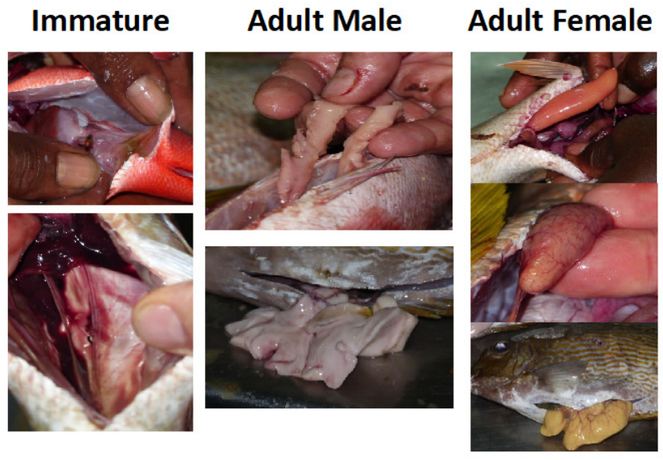


Figure 4. Illustration of the macroscopic classification of gender and maturity in fish

In some species mature gonads may regress between breeding seasons, generally during the period of warmest water temperatures, to such an extent that to the naked eye it looks as if the fish is immature. In our experience with tropical fish this is particularly so for the largest adult size classes, which can be very confusing. To help with my own confusion I apply a relatively arbitrary rule that: to be classed as adult the gonad should be longer than one third the length of the body cavity.

This is only partially true, the actual solution is not to get too bogged down with the accuracy of each observation, amongst the smallest and largest size classes you should expect to see confusing looking gonads, that only a microscope will help define. Rest assured though, that around L_m the gonads will be clearest, and the transition through 50% mature is almost always discernible in the aggregated data set. So just do your best and do not get too hung up on individual fish.

Alternative microscopic techniques are more accurate, especially when it comes down to the level of individual fish. However, our experience is that in aggregate this macroscopic approach produces much the same answer for much lower cost, and because it can be used simply in the field, is a far more useful technique. Not to mention the benefit of fishing communities being able to learn directly from their own experience. Although, there is no getting away from the fact that the gonads of some species can be very difficult to gauge macroscopically. Just do

your best and do not sweat on every observation.

Caps for Data & Datasheet

The Excel Workbook called '1. Excel template for fish data with analysis sheets' that can be downloaded from the 'Data Collection and Analytical Techniques' page of the 'biospherics.com.au' website, contains a template for a data sheet, which can be printed out and used, or modified as required. It also contains an entry form which with data can be developed into your own database.

The various columns are relatively self-explanatory so only a few notes are provided here.

Firstly, you should make sure you enter your data regularly while the data collection process is fresh in your memory, and each time, also do some of the basic analysis and summarizing of data that will be discussed in the next chapter. This is because, as hard as you try errors in data collection will occur, but they will only become evident through the process of entering and using your data. So best to be doing these things while the original data collection is fresh in your memory.

To help with the process of data correction and verification assign a sample number (extreme left) to each record in the order you enter them into the database. Subsequent to entering your data you will end up doing various sorts which will change the order of the data in the database. If you assign a sample number to each row of data, a sort by sample number, will always arrange your data back into the order of the original data sheets. This will make it much easier to go back to your hard copy data and check it against the entered data. For the same reason it is also useful to record the name of the people who collected the data, then you will always be able to go back and ask them about any data that later is found to be confused.

In the context of collecting accurate data for coral reef-fish, and planning ways for being able to check back on confusing data records. I have also developed the practice of giving observers digital cameras and getting them to lay out fish and photograph them in the same order as they are measured. And of getting the person entering the data to use the 'Comments' column to enter the name of the image that corresponds to each line of data. This way fish IDs can be checked and other simple errors detected and corrected.

A way of minimizing errors in the size of maturity data is to be strict about the symbols used to denote gender and maturity. With immature fish (I) it may not be possible to know if they are male or female; so leave that column blank in the datasheet. It should, however, always be possible for Adult (A) fish to be categorized as male (M) or Female (F). For the purpose of maintaining data quality it is important to use 'A' to denote Adult fish and 'I' to indicate Immature fish. This is to maintain a clear distinction from 'M' for Male fish and 'F' for Female fish. If 'M' is used to indicate both Mature and Male fish there will inevitably end up being confusion at some stage, either in the data recorder, or for the person entering the data into the computer. A common error with these data, is that they get written into the wrong column of the data sheet. If the notation of A/I and M/F is always used this type of error will be easily resolved, but if M is used for both Male and Mature the error will be less resolvable.

Collect information about the date, time of day, fishing method and location of fishing, because when you start analyzing the data some of these factors could become important. For example, different locations may produce different sizes of fish because they are subject to different levels of fishing pressure. Some types of fishing may have 'dome-shaped' selectivity and only catch juveniles, meaning they should be excluded from your LBSPR assessment, although their information might be useful for your estimation of L_m. It may be that none of these factors end up being important for your analysis, but you will only know that once you have started analyzing your data, and you will not know one way or the other, if you do not collect that type of data in the first place.

Crustacean Sampling

The final sections of this chapter focus on collecting LBSPR data for crustaceans; crabs and spiny lobster.

The great thing about applying LBSPR to crustaceans, compared to fish, is that gender and sexual maturity can be gauged from external morphology, meaning no dissection is necessary. The data is easier and cheaper to gather because sampled catches can be sold intact in market places.

This is convenient, because with crustaceans the genders commonly attain very different sizes. For those unfamiliar with crustacean biology; females can only mate while they are most vulnerable with a soft new shell following a moult. Male crustaceans pick up the soft, newly moulted, and reproductively receptive females, and invert them for mating. They then commonly carry the female around, beneath them for some days, protecting them while their shells harden. For this to be possible males must be larger than the female they are slinging under their abdomen. To facilitate this pairing of un-equal sizes, male crustaceans commonly grow to larger sizes than females.

As discussed above, the implication of this gender difference for LBSPR assessment is that the assessments should be gender specific. Generally, I just assess the female part of the stock. The solution is to record the gender of every individual measured, and not just for the sub-sample used estimating size of maturity.

Because it is relatively easy to do, and cheap, the projects I have worked with applying LBSPR to crustaceans have just continued collecting the full suite of maturity stage, gender and length data, even after strong estimates of size of maturity have been developed.

Crab Sampling

MEASURING CRABS SIZES

The size of crabs is commonly measured across the width of their carapace.

Some studies record carapace length (from front to back) and there is no real reason it cannot be used. From my point of view the measurement of carapace length is less useful, because growth in length occurs over a smaller range than width, requiring more accurate measuring to achieve equivalent assessment precision. Besides which, I find myself more likely to be nipped while measuring the carapace length of live crabs. So I recommend focusing on carapace width.

Figure 5. A cost-effective measuring device for blue swimming crabs, the clear plastic rule with blue wooden 'end block' makes the measurement of carapace width more efficient and accurate.

Carapace width can be measured with a variety of instruments and many scientists default to using standard vernier calipers. In our context, vernier calipers are relatively expensive. They also require simultaneously aligning the two caliper tips, with the pointed tips either side of the carapace (while avoiding being nipped). A process that I find relatively slow and inaccurate. I recommend using the simple crab measuring device developed by Steve Creech of Pelagikos in Sri Lanka and pictured in figure 5. Steve manufactures the device by cutting the end of off a plastic rule, and attaching a block of wood to the zero mark as a stop to push one side of the crab's carapace against. The tool can then be placed across the crab's carapace, pulled up against one side of the carapace, and the width read off through the clear plastic of the rule.

Gauging the maturity of Crabs

In crabs the abdominal flap, that wraps around the center of the underside of the carapace, from back to front, changes shape with maturity, into distinctively gender specific adult

shapes (Ingles & Braum 1989; Van Engel 1958). Females carry their fertilized eggs (or berry) externally beneath their abdominal flap. Figure 6 illustrates the changes that occur in adult male and female blue swimming crabs (*Portunus spp*.) in which the abdominal flap goes from being almost an exactly triangular shape in juvenile males and females, through to being quite convex shaped on the sides in females, and concave shaped for the males. When teaching this material to prospective BSC measurers, trying to lodge these shapes and their meaning into memory, I point out that the adult female shape is breast like with a nipple on top, while the adult male is quite male-like. Of course, the adult female is even more obvious when 'in berry' and carrying the egg mass tucked underneath the abdominal flap.

The different groups of crabs develop differently and the change in shape of the abdominal flap is characteristic for each, but in general similar changes in shape occur for all (or at least most crab species). Get your eye in with your first crab species, and you will be able to pick it in every other species, anywhere in the world.

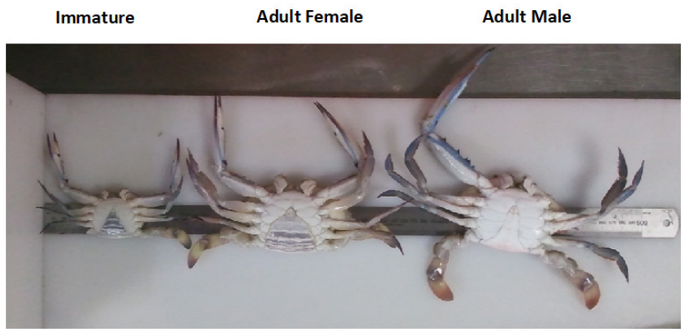


Figure 6. Illustration of the differently shaped abdominal flaps used to distinguish between juvenile, adult female and adult male blue swimming crabs.

Crab data protocol and sheet

The Excel Workbook called '4. Excel template for blue swimming crab data with analysis sheets' that can be downloaded from the 'Data Collection and Analytical Techniques' page of the 'biospherics.com.au' website, contains a template for a data sheet I developed for use with blue swimming crabs in Indonesia.

And the text below is based on the protocols I developed for that project.

The aim of this sampling protocol is to accurately represent the size composition of the catch by gender (i.e. the proportion of each size class and gender being caught) so:

a. sampling should occur at the landing or first receival site, before any sorting of the catch (by size) takes place, and

b. to prevent unconscious biasing of the samples by accidentally selecting the larger crabs, **All** the crabs in one of the 20kg crates or baskets used to accumulate the landed crabs before and after cooking should be measured.

To make sure optimal sample sizes are built up for each sampling site two 20kg crates of BSC should be measured every week.

The following information should be recorded:

1. The location of the sampling site
2. The date of sampling
3. The carapace width of every crab in mm or cm to the first decimal point.
4. The weight of every crab in grams to the first decimal point
5. The gender (male or female) of every crab
6. The breeding status of every crab should be classified (immature=1, Adult=2, berried female=3) as shown by Figure 6.

Table 3. Example of Spawning Potential Ratio (SPR) assessment data sheet for BSC showing essential elements.

Location	Date	Crab #	Carapace Width (mm)	Weight (g)	Gender (M/F)	Immature/adult/berried
		1				
		2				
		3				
		4				
		5				

It will be noted above that this protocol includes the measurement of individual weights for the BSC. This is not strictly necessary for the LBSPR analysis itself, however, my Indonesian partners use the weight data to cleverly verify the quality of the size data being gathered by observers. For this purpose they have a well-documented relationship between the carapace

width and total weight with known variance. They compare the length-weight data being collected by each observer with the known relationship and variance, where differences are detected the noisy data can be rejected, and problems with the observer addressed.

Spiny Lobster Sampling

This final section describes data collection protocols developed for assessing spiny lobster stocks in Fiji and Sri Lanka. The powerpoint presentation called '7. Lobster data collection protocols' which can be downloaded from the 'Data Collection and Analytical Techniques' page of the 'biospherics.com.au' website, provides an alternative and additional illustration of the material covered in this section and the reader may wish to work through it as they read this section.

Measuring Spiny Lobsters

The size of lobsters is normally measured by the carapace length; between the two horns at the front of the carapace down to the back edge of the carapace (figure 7). The narrowness and rounded shape of the gap between the two frontal horns means that this can only really be done with some degree of accuracy and efficiency with a pair of vernier callipers, which adds a degree of expense and technical difficulty to the sampling. The callipers can be the cheaper plastic versions, or the more expensive stainless steel ones with digital readout which are more expensive but simpler to read.

Figure 7. Measuring the length of a spiny lobster from between the horns at the front of the carapace to the back.

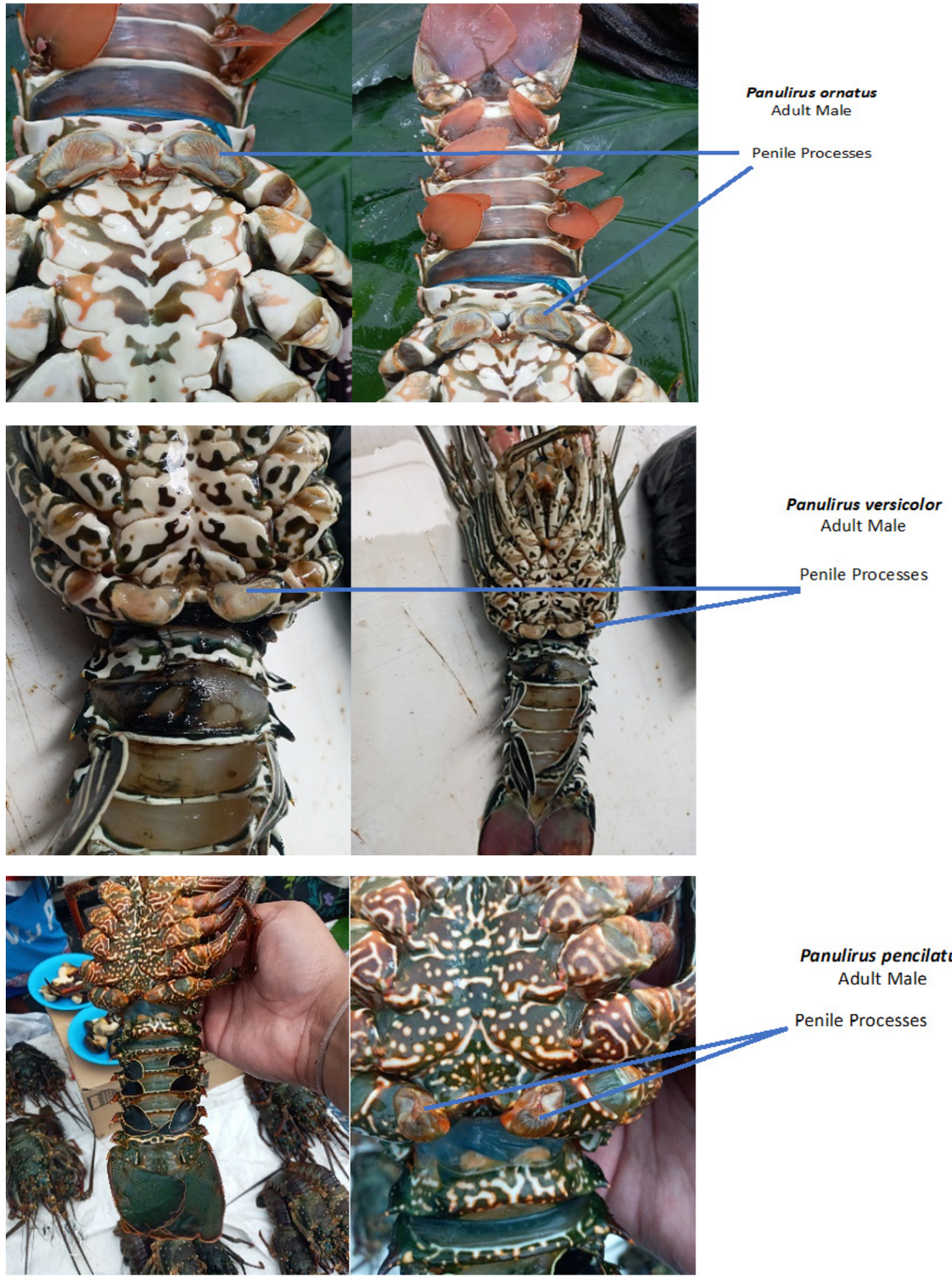
Gauging Gender and Maturity for Lobsters.

Although the changes in spiny lobsters are quite different to those in crabs, gender and stage of maturation can still be gauged from external morphology. A paper by George (2005) describes this with pictures for the various species of spiny lobster, and the material I present is based largely on that paper, augmented by pictures taken in Fiji by Max Tukana (USP).

Male vs Female Differences

Adult male spiny lobsters develop 'penile processes' that they use to stick tar-like spermatophores (sperm container) to the underside of the thoracic carapace of female lobsters. The penile processes (figure 8) are developed, as males mature, on either side of the middle, of the back edge of the under-side, of the thoracic carapace (i.e. the 'head-shell' of the lobster). Although their exact appearance varies between species, in general they appear in sub-adults as a small pair of rounded warty lumps, that grow in size and develop a little curvature as maturity is attained, and in some species, a few bristles as well. Penile processes develop in males relatively slowly, over quite a size range, beginning before maturity is attained. To perfect their use for any species in a location you will need to get your eye in by inspecting a wide size range of lobsters, ranging from immature to fully mature, so as to get a good idea of what the fully adult version looks like. Table 1 in George (2005) gives some description of the variation between the spiny lobster species. The bottom line for males is that distinguishing adults from maturing sub-adult, is more difficult than for females, so it will probably be better to concentrate your LBSPR analysis on female lobsters, and just use the presence or absence of spermatophores to distinguish between the genders.

Figure 8. Illustrations of fully developed penile processes in Fijian, Panulirus ornatus (top), Panulirus versicolor (center), Panulirus pencillatus (bottom).



Identifying Adult Females

The easiest identifier of adulthood is when they carry the eggs, or berry under their tail (figure 9; middle panels), but of course this is only seen while the female is brooding her egg mass. Adult female lobsters may also be identified for a time after mating, by the remnants of the spermatophore, or 'tarspot', that for some weeks, or even months, after mating can be seen on their underside at the back of the carapace, either intact or in outline (figure 9; first & third panels). Tarspots eventually wash or wear away, but for a time before the fertilized eggs are extruded, reliably indicate a female is mature and has been mated.

The most accurate and permanent sign of adulthood in females is the development of small softer clear 'de-calcified windows' on the underside of the thoracic carapace, around where the tarspot is deposited (figure 9; panels 1-3). These specially thinned windows enable the sperm of the male to migrate from the tarspot through the shell of the newly moulted female before she re-hardens. The appearance, number and exact location of these windows varies between species, but in each species they can be recognized as patches of slightly darker, more translucent shell, near the base of the thoracic carapace. You can learn more about the variation between species from Table 1 in George (2005) and figure 9.

In lobsters the females carry their eggs attached to specialised setose (hair) covered pleopods (fins) which run either side beneath the tail, inside the larger outer swimmarets (fins) that are observed in both males and females. These egg carrying pleopods are a reliable marker for the gender of lobster and they do change appearance somewhat through the breeding cycle, but they are not used reliably as a marker of maturity.

Figure 8. Illustrations of indicators of female maturity in Fijian, Panulirus ornatus (top), Panulirus versicolor (upper center), and Panulirus pencillatus adult (lower center) in comparison to juvenile morphology (bottom).

Learn by Doing

To some extent, because of the variation in species, you will need to put all this together for yourself by developing your own eye for how your lobsters change with size and season. I suggest you just start inspecting and photographing a whole range of lobsters until you have a good idea about how the various lobster bits look and how they change. After you have worked it out for yourself you can start teaching it to the team of observers you work with.

Spiny Lobster data protocol and sheet

The Excel Workbook called '6. Excel template for lobster data with analysis sheets' that can be downloaded from the 'Data Collection and Analytical Techniques' page of the 'biospherics.com.au' website, contains a template for a data sheet I developed for use with the Fijian lobster fishery which is also illustrated by table 4.

The meta-data for each collection of data are entered into the header of the data-sheet;

1. Date and
2. location of sampling,
3. identity of the observers.

The core data are entered in columns B & C; species name

and carapace length to the nearest mm.

With this data sheet each of the gender x maturation stage are numbered 1-7:

1. Immature
2. Immature Male
3. Adult Male
4. Immature Female
5. Adult Female – Softened windows
6. Adult female – Tar spots
7. Adult female – Carrying eggs

And each combination is entered into its own column from D to J. Note that adult females can be recorded as displaying more than one indicator of its maturity. Using this numbering system these data could really all be entered into a single column, but my Fijian colleagues prefer this arrangement, with a degree of planned redundancy. The Fijian observers tell me that that the care required to place the correct number in the correct column, reduces the mistakes they would make if they were simply to tick one of the columns, or enter number codes into a single column. This arrangement makes a little bit of extra work when it comes to collating the data for analysis, but not a significant amount more.

As with the fish and crab data the sequential record number in the first column (A) is inserted as the data are entered to ensure the data can always be restored to the order in which it was collected and written down on the original data sheets. As discussed above this helps with later error checking, and cleaning up of the data-base; when you start wanting to checking strange data entries against what was written onto the original data sheets.

Date:		12/9/20							
Location:		Suva							
Measurer:		Max and Kali							
No.	**Species**	**Carapace length (mm)**	**Immature (1)**	**Immature Male (2)**	**Adult Male (3)**	**Immature Female (4)**	**Adult Female soft windows (5)**	**Adult Female Tar Spot (6)**	**Adult Female eggs (7)**
1	*Panulirus ornatus*	148			3				
2	*Panulirus versicolor*	99							7
3	*Panulirus versicolor*	113			3				
4	*Panulirus pencilatus*	113			3				
5	*Panulirus ornatus*	145					5		
6	*Panulirus versicolor*	93			3				
7	*Panulirus versicolor*	95							

Table 4. Example of a datasheet my Fijian colleagues are using to collect data for spiny lobsters where several species are commonly landed.

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