1 INTRODUCTION

This "*Length-Based Assessment Guide for Target Species in Indonesian Deep Slope "Snapper" Fisheries*" was prepared for The Nature Conservancy's (TNC's) Indonesia Fisheries Conservation Program, in support of TNC's Deep Slope "Snapper" Fisheries Conservation Project. In the early stages of this program it was recognized that all stakeholders involved in these fisheries (including fishers, buyers, processors, traders, retailers, consumers, managers, NGO workers, government agencies, scientific and educational institutions, etc.) would benefit from the development of (1) a dedicated fish identification guide for the Indonesian deep slope fisheries, and (2) a guide that explains available tools for length-based assessment of the status and trends in these fisheries.

The TNC "*Top 100 Species Identification Guide for snappers, groupers and emperors in Indonesian deep slope fisheries*" (Mous et al., 2017) was produced after taxonomic analysis of catches of deep slope drop line and bottom long line fisheries in Central and Eastern Indonesia between 2014 and 2017. This species ID guide for the deep slope fisheries is now available through the following link:

CLICK: Link to on-line E-Book Species ID Guide

The species ID provides a first good inventory of target species in the deep slope fisheries in Indonesia, with clear images for each target species in the fisheries, together with correct scientific names and a range of common names used in the fisheries and in the trade. At the completion of this guide, it was also clear that additional imagery would be useful for correct identification on board, on landing sites and at monitoring stations. A separate "Illustration Guide" was prepared for this purpose, providing additional images "trawled" from the internet, selected for high quality and best possible presentation and colors of live or fresh animals.

CLICK: Link to on-line E-Book Species Illustration Guide

The current length-based assessment guide includes simple length-based tools for the assessment of the target fisheries, as well as values of life history parameters for the main target species. This guide needs to be used together with the above mentioned species identification guide, and is meant to:

1. Provide up-to-date science-based information on species and fisheries.
2. Support species specific length-based assessments of data poor deep slope fisheries.
3. Define length-based life history characteristics, to enable length-based assessments.
4. Provide values by species for length-based life history parameters including:
   - Maximum attainable total length (Lmax), based on records or estimates from images,
   - Asymptotic length (Linf), defined as the mean length in a cohort fish, at the time when all individuals in that cohort have stopped growing,
   - Length at which 50% of individuals are mature (Lmat) and contributing to reproduction,
   - Optimum length for harvesting (Lopt) of a species in terms of maximizing yield.
5. Provide simple tools for length-based assessments, using the above length-based life history parameters in combination with catch length frequencies by species.
6. Stimulate discussion on management options among stakeholders and support management decision making based on length-based assessments.
7. Be readily accessible and comprehensible for all stakeholders mentioned above.

2 ESTIMATING VALUES OF KEY LIFE HISTORY PARAMETERS

2.1 Life History Parameter Values and Invariables

With the exception of *E. coruscans*, some of which (but not all) have a greatly elongated upper lobe of the tail fin, all length-based information in this document relates to Total Length (**TL**) of the fish, as measured from the tip of the snout to the longest tip of the tail fin. For E. coruscans we have used the tip of the lower lobe of the tail fin to measure total length. For cross checking of values in the literature on Fork Length (**FL**), we have used literature information on **TL/FL** conversion factors by species.

Our length-based assessment approach is based on four life-history characteristics or parameters; **Lmax, Linf, Lopt, and Lmat** (explained below). Published values for these characteristics are available for some species but lacking for many. Values for specific species vary between publications and are often unreliable due to misidentifications and/or sampling bias issues (small samples which lack the larger specimen). We therefore used an estimation procedure based on life history invariable values, which only requires accurate knowledge on Lmax, the maximum attainable size of each species, in combination with family-specific relationships (life history invariable) between Lmax and each of the other parameters. Meta-analysis results from the literature are available to obtain values for life history invariables for various ranges of species. This approach is gaining increasing interest in the scientific community (e.g. Nadon and Ault, 2016) and provides the breakthrough allowing accurate length based assessments of data poor fisheries.

2.2 Maximum Total Length

Maximum attainable total length (Lmax, maximum size) by species was estimated from a range of information sources, including published values, estimated lengths from images of trophy fish, recorded lengths of trophy fish, anecdotal information and an ever increasing amount of actual data from our fisheries monitoring work. Published values of maximum size were treated carefully as there are many issues with species identification, while under-estimation of Lmax is common in many publications that look only at small samples from intensively fished stocks.

We kept in mind that for some species larger maximum sizes are attained at greater latitudes in cooler waters. When analyzing information from literature or images from the internet, we included only sizes of fish that were observed at latitudes within or close to the range covered by Indonesian fishing grounds. Maximum attainable total length in this document and in length based assessment reports on Indonesian deep slope fisheries refer to maximum attainable total lengths at latitudes overlapping with or close to those of Indonesian fishing grounds.

By early 2017 our Crew Operated Data Recording System (CODRS) had produced over a quarter million images of the top 100 most abundant species from deep slope fisheries catches. With this huge sample size we were able to determine the sizes of the very largest specimen caught of each species, and determine their ID from CODRS images. For several species we found fish that were larger than previously reported for our region. In some other cases we had to decide on values for Lmax which were below sizes previously reported, mainly when we could not obtain confirmation on correct species ID for values presented in literature or on line. For many species we were able to verify estimates based on reliable information from nearby Australian fishing grounds or we obtained CODRS images proving maximum sizes to be obtained above what was previously reported.

2.3 Asymptotic Length

Our next life history characteristic, the "**asymptotic length**" (**Linf**), is defined here as the mean length in a cohort of very old fish (a cohort of infinite age). As such it is by definition smaller than the maximum length obtained within the population of a specific species. This asymptotic length, or the mean length at infinite age, is one of the growth parameters in the well known Von Bertalanffy growth equation. Without further exploring that equation, it is important to remember that we define Linf here as the mean length in the oldest cohort in the population. This asymptotic length of each species is an important parameter in fisheries assessment methods and management decision support models.

We have extensively used literature information and sometimes found under-estimation of Linf for target species that are heavily fished, probably due to the limited size range in the catch. Under-estimation due to misidentification of species also occurs in the literature. Over-estimation was also found, possibly again due to misidentification or due to other issues with input data used to estimate Linf. As a general rule though, as confirmed from data in published meta-analysis, we found that Linf could very well be estimated as 90% of the maximum length, Lmax (e.g. Nadon and Ault, 2016).

A rule of thumb relationship "**Linf = 0.9 * Lmax**" can be explained by Lmax being the largest fish we observe, at about 1 standard deviation longer than Linf, in cohorts of fish with length frequencies that have a standard deviation of about 10% of the mean length. We could assume that in general we do not get to observe the very largest fish in the population, as that really is the needle in the oceanic hay stack, and, probably more importantly, hardly any fish in this day and age actually survives to reach its potential maximum size. This estimation method (Linf = 0.9 * Lmax) was applied by us in this guide, to ensure we have realistic parameter values for all species even in our data-poor environment.

2.4 Length at Maturation

The value of Linf (above) is important in the estimation of values of additional length-based life history characteristics for each target species, like the **length at maturation** (**Lmat**). Lmat is defined here as the smallest length class at which 50% of the individuals (in that length class) are mature. Size at maturity is a particularly important parameter used to assess and evaluate the impact of fishing mortality on the spawning stock and to determine levels of optimum fishery yield.

Information on length at maturation was collected from a wide variety of sources for the target species in this guide. General trends were found for various families including those containing the most important target species, starting with the Lutjanidae (snappers). An important characteristic of snapper reproductive biology is that they do not change sex during their life (whereas several other families of fish do, see below). Sexual dimorphism is rare in snappers, only reported for coloration in two species of the genus Pristipomoides from the Indo-Pacific.

An important meta-analysis of all available information on life history parameters for Lutjanidae was published by Martinez-Andrade in 2003. This researcher developed a data base with parameter values for a wide range of species and collected information on relationships between the various parameters to make estimates where values were missing. For example for the sub-family of Lutjaninae (snappers) a strong correlation between Lmat and Linf was found from the meta-analysis and Lmat was estimated for these species by Martinez-Andrade from Lmat = 0.52 * Linf.

Figure 1. Length at maturity vs. asymptotic length in species of the subfamily Lutjaninae.

Over the decade after Martinez-Andrade published the relationship between Lmat and Linf for a wide range of snappers, small and large, shallow and deep water species, a lot more work was done on species identification (clearing up some issues in the data used by Martinez-Andrade) and much more information has become available for deep water snappers. This enabled Newman and others (2016) to further refine the relationship for deep water snappers as **Lmat = 0.59*Linf**. As we are analyzing deep slope fisheries at depths below 50 meters in our program, we have adopted this life history invariable value and in this guide we use the general assumption that the **snappers targeted by our deep slope fisheries mature at about 59% of their asymptotic length**. This assumption was verified species by species, using a range of information sources, and was shown to hold for those species in our fisheries, for which reliable direct information on maturation was available.

Epinephelidae (groupers) in general mature initially as females and later in life change sex to males. This explains certain characteristics of grouper populations. Males tend to be larger on the average than females and there is usually an overall sex ratio in favor of females. There is some overlap in size distributions between males and females in most groupers, suggesting that sex change can occur over a size range rather than occurs at a very narrow size class. Size at sex change may be partly influenced by sex ratio in the population and sex change from female to male may occur at smaller sizes when larger males are rare or absent from the population.

After looking at information on maturation for a range of species of deep water groupers we concur with Newman and others (2016) that **"deep water" groupers mature as females at a size around 46% of Linf**. We define deep water groupers here as those species of Epinephelidae which commonly occur in deep slope fisheries catches, from waters deeper than 50 meters. We define Lmat in groupers as the female maturation size which is estimated from **Lmat = 0.46*Linf**. For most groupers sex change from female to male seems to start at around 1.33*Lmat (1.33 times size at female maturation), after the cohort has reached maximum biomass and therewith maximum fecundity. It makes evolutionary sense that sex change from female to male would not start earlier.

Many Lethrinids (emperors) can undergo sex change from female to male. But not all individuals seem to follow this pattern and both sexes are found over a range of sizes above the size of first maturity. Some species, like spangled emperor, sometimes change sex from female to male before they reach maturity (if they are going to change sex at all) and females and males can mature at around the same length. In general there is considerable overlap in size distributions between males and females in most emperor species, and for purposes of emperor fisheries management, it is more meaningful to define a length at maturity by species only, rather than separately for the sexes. **In general emperors seem to be maturing at about 50% of their asymptotic length**. We have used **Lmat = 0.5*Linf** on the basis of a review of a range of information sources and applied this for our estimates of size at maturity in emperors. In most if not all cases, this general assumption showed good overlap with published ranges for maturity in emperors.

From sketchy available information we extrapolated that for most other species in our target list our best possible estimate for length at maturation would be around 50% of the asymptotic length, as found also for emperors. Starting from the meta-analysis of snappers by Martinez-Andrade (2003) right through a range of other information sources on length at maturation, a constant of about 50% of Linf was found to be our best estimator for length at maturation in most of our target species, except for the deep water snappers and groupers. This estimator is also confirmed by a relationship of Lmat = 0.461 * Lmax reported from another meta-analysis by Binohlan and Froese (2009). One exception to this general rule may exist for larger Carangids which are also found in the catches of the deep slope fisheries. Reliable and precise information however is scarce and we did not find enough detailed information to deviate from the general 50% rule for carangids either.

Figure 2. The biomass of a cohort of (imaginary) fish in an un-fished situation reaches its maximum at an age (and at the related size of the fish in the cohort) where growth of individuals has slowed down to the point that it does not make up anymore for biomass loss through natural mortality.

2.5 Optimum Harvest Size

The final length-based life history characteristic that we will be using in our length-based assessment method is the **length class with the highest biomass in an un-fished population (Lopt)**. It is at this length (and corresponding age) that the biomass expressed as the number of survivors (in an un-fished cohort) multiplied with their average weight reaches a maximum (Figure 1). A fishery will obtain the maximum possible yield if it catches fish mainly around this size. Thus, fisheries managers should strive to adjust the mean length (or median length) in their catch towards this value.

Reproductive output in terms of total number of eggs (fecundity) is also optimized at this length (Lopt), where the biomass of the un-fished cohort is maximized. So also from a perspective of maximizing recruitment to the fishery, managers would strive to focus their fishery on size classes around Lopt (well beyond Lmat). And for sex-changing groupers it is important that cohorts are not decimated before sufficient individuals have changed sex from female to male, a process which begins around the size of Lopt.

Lopt can be estimated from empirical relationships between Lopt and Lmat. Lopt for catching a range of demersal fish species could be estimated as 1.33 * the length where 50% of the fish are mature (**Lopt = 1.33 * Lmat**), based on the median values for this life history invariable (Lmat/Lopt = 0.75) over a range of demersal species (Cope and Punt, 2009). We have chosen to use this estimator of 1.33*Lmat for Lopt as the Cope and Punt (2009) study seemed to be one of the best researched situations in terms of estimating Lopt for a group of species with comparable biology and life history.

3 VERIFICATION OF LIFE HISTORY PARAMETER VALUES

Before applying the estimates for parameter values resulting from life history invariants in length based assessments of the fisheries, we verified those values first with available reliable values from comparable latitudes for the most important and most abundant species across the most important families in our fisheries. For the estimate of Lmax, the growing data set containing hundreds of thousands of CODRS images became an increasingly important tool for verification. For a number of species it was observed that sizes were obtained beyond what was previously reported at latitudes comparable to Indonesia and in these cases we could use our CODRS images directly to establish our estimates for Lmax. For a number of species we have also been able to fin reliable verification of Lmax in the Australian "North Coast Fish Identification Guide (Rome and Newman, 2010)" as well as various other reliable sources, include some that were used also by Martinez-Andrade (2003).

For an increasing number of species, CODRS images are showing sizes in the catch at least up to or around Linf, or about 10% below the estimated maximum attainable size. Linf is the mean size in the cohort when it stops growing and therefore a size more common in the population than the actual maximum obtainable size. We would expect, with very great sampling effort (a good part of the entire fisheries) to ultimately at least find specimen approach Linf, whereas specimen at Lmax are extremely rare of course, especially in hevily fished situations. This pattern is indeed being observed from CODRS data analysis for most if not all important species in our fisheries.

For a few species we have not (yet) observed specimen close to their estimated Linf but these are not very important species in the deep slope fisheries. For these species we are confident that they grow much larger than what we see in the deep slope catch but we do not have ready explanations on why very large fish are missing from the sample. For example for the cobia and the black jewfish this is the case and for these species additional checks will follow.

The most important and most abundant species in the deep slope drop- and long-line fisheries for snappers, groupers and emperors in Indonesia is the Goldband Snapper or Goldband Jobfish, *Pristipomoides multidens*. This species can reach an estimated maximum size of up to 100 cm (Total Length) in Indonesian waters and this is verified as the maximum size for the same species in neighboring Northern Australian waters by Rome and Newman (2010).

With our method of estimating the asymptotic size for our target species this means an estimated Linf of 90 cm for *Pristipomoides multidens* in Indonesia. This would be the mean size in the cohort if it was left to grow infinitely. With a very large sample size we would expect to ultimately find a specimen approaching Linf and indeed the largest specimen photographed in our CODRS program was 90 cm.

Using 0.59*Linf as the estimator for Lmat in deep water Lutjanidae (Newman et al, 2016), we could estimate the length at 50% maturity for *Pristipomoides multidens* to be reached at 53 cm total length. This converts to around 46 cm fork length for Lmat in this species and these values are not significantly different (almost the same, 55 cm TL and 47 cm FL) from what is reported for this species for Northern Australian waters. This is another very important verification of the approach.

There is less information available on the co-occurring and very similar Sharptooth

Jobfish, *Pristipomoides typus*, which is the second most important species in the fisheries. This species is very similar to the Goldband Snapper, often mixed in the trade, and there is no reason to assume different values for life history invariable values. Rome and Newman (2010) report a maximum size of 80 cm from Northern Australia, but slightly larger fish were encountered in our CODRS program. Therewith a highly reliable estimate of 85 cm for the maximum size followed for this species. Resulting values for Linf, Lopt and Lmat followed from the above explained approach.

The third most abundant species in the combined catches from drop- and long-line fisheries in Indonesia is the Rosy Jobfish or "Opakapaka", *Pristipomoides filamentosus*. Reported to grow up to 80 cm in Northern Australia, but specimen encountered up to 86 cm total length in Indonesia, leading to an estimated maximum total length in our waters of about 90 cm. This then leads to an estimate for Linf of 81 cm and Lmat of 48 cm total length which is well within the range of values reported in the literature for this species from comparable latitudes (reviewed a.o. also by Martinez Andrade in 2003 and by Newman et al. in 2016).

Another important species of Pristipomoides in the deep drop-line and bottom long-line snapper fisheries is the Lavender Jobfish or Lavender Snapper or "Kalekale", *Pristipomoides sieboldii*. This species is ranked number 8 on the list of most abundant species in our target fisheries. The Lavender Jobfish grows to a maximum total length of 60 cm in Indonesian waters which is the same as reported for North Australian waters (Rome and Newman, 2010). The largest specimen recorded in our CODRS program was 55 cm in total length, at the time of writing of this report, which is just over the estimated asymptotic length of 54 cm for this species, fully in line with what we would expect to find from a very large sample size (about 10,000 specimen at this time). *Pristipomoides sieboldii* was reported to mature (50%) at 29 cm Fork Length, (Demartini and Lau, 1999), equivalent to about 33 cm Total Length. This aligns perfectly again with the estimate of 32 cm Total Length following the application of the life history invariant approach.

There are four more species of Pristipomoides in the Top 100 species distribution covering the deep slope catches by drop-line and long-line vessels in Indonesia. These species are *Pristipomoides flavipinnis*, *P. argyrogrammicus*, *P. zonatus*, and *P. auricilla*. These species are not abundant or important in the catch and they are not as well studied as the more abundant species mentioned above. But still we could confidently estimate their life history parameters based on what we know about the maximum attainable size and the good fit of the model for all the other species above.

The Areolate Grouper or Squaretail Rockcod, *Epinephelus areolatus*, is the most important species of grouper (Epinephelidae) in the deep slope fisheries in Indonesia. And it is also the fourth most abundant species in these fisheries overall. Also for the groupers we found that the parameter values estimated with the life history invariant approach are aligned very well with reliable values for important and well researched species. *Epinephelus areolatus* is widely reported to grow to a maximum size of 50 cm and this value is also verified by our CODRS observations which show the largest fish in the catch to measure 49 cm at the time of writing of this report. With above explained approach of estimating Linf and Lmat this results in an estimated length at 50% female maturity for this species of 21 cm total length which also fully aligns with available literature values.

For some species of groupers the estimated maximum attainable size as reported in various literature sources does not seem to be supported by any verifiable data, such as for example for *Epinephelus morrhua*, the 2nd most important grouper in the deep slope fisheries in Indonesia and number 20 in the Top 100 of all species. Excessively large values appear in the literature for this species, possibly due to misidentifications. We found an estimate of 75 cm to be closest to what we could verify, and this number was confirmed in a review published by SPC in 1997 (Shakeel and Hudha, 1997).

The fifth most abundant species in the deep slope drop-line and bottom long-line fisheries is the Rusty Jobfish or "Lehi", *Aphareus rutilans*, a large deep water snapper which grows to about 125 cm Total Length in Indonesian waters, based on available evidence that was verifiable from images. Martinez-Andrade (2003) reported a maximum attainable size of 126 cm Total Length as the mean value from a number of studies, which is well aligned with our estimate for Indonesia. Larger maximum sizes (up to 150 cm) have been reported elsewhere, but such sizes could not be verified for our general latitude. The asymptotic length for this species as estimated from 0.9*Lmax is 113 cm for Indonesian waters, which is a size that could be verified from the largest specimen recorded from the CODRS program which measured 112 cm Total Length. Our estimate for length at 50% maturity in this species is 66 cm and this again aligns completely with the 66 cm as reported by Martinez-Andrade (2003).

The deep water snappers of the genus Etelis are very important species in our target fisheries, especially in catches from the deepest part of the depth range that is exploited by bottom long-line and drop line fishers in Eastern Indonesia. The Ruby Snapper or "Ehu", *Etelis carbunculus*, was recently discovered to be a separate small species that until a few years ago was mixed with a very similar but much larger species, the Giant Ruby Snapper, *Etelis sp.*, which is yet to be scientifically named although it has been exploited throughout the Pacific for many years.

The "true" *Etelis carbunculus* grows to a maximum size of about 60 cm and its asymptotic length is about 54 cm. The largest specimen encountered in our CODRS program to date was 55 cm which aligns again very well with estimates for Linf and Lmax. Estimated total length at 50% maturity is 32 cm using the life history invariable approach. Literature data from Hawaii indicate a size at 50% maturity of 28 cm Fork Length (Demartini and Lau, 1999) for this species, which equals about 31 cm Total Length and therefore aligns again perfectly. Newman et al. refer to a number of other studies showing a size at maturity of 30 cm Fork Length for this species from various locations, also right close to our result from the life history invariant approach.

Whereas the Ruby Snapper, *Etelis carbunculus*, actually turned out to be a fairly uncommon species in Indonesian deep slope catches, the Giant Ruby Snapper, Etelis sp., although yet to be named scientifically, is the 7th most abundant species in the catch. And due to its size, it is more important yet in total weight. Due to the recent developments in the taxonomy in these two species of Etelis, there are no direct literature references life history parameter values to compare with for Etelis sp., but we can look at values previously reported for Etelis carbunculus which clearly do not belong to that species if they are outside the maximum size it can reach.

The Giant Ruby Snapper, *Etelis sp.*, can reach a maximum Total Length of up to 130 cm, as was also reported for neighboring North Australian waters, where it was previously also misidentified as Etelis carbunculus (Rome and Newman, 2010). The estimated asymptotic length for this species is 117 cm, which could be verified from the largest specimen recorded from our CODRS program, measuring 120 cm. Application of the life history invariant approach resulted in an estimate of 69 cm for the Total Length at 50% maturity for this species. Polovina and Shomura (1990) reported 61 cm Fork Length as the size at maturity for Etelis carbunculus which we now know must also have been Etelis sp. This 61 cm Fork Length converts to 67 cm Total Length and therefore aligns very closely again with the estimate we obtained from the life history invariant approach.

The other 2 Etelis species in the Indonesian deep slope fisheries are the Flame Snapper or "Onaga", *Etelis coruscans*, and the Pale Snapper, *Etelis radiosus*. The Flame Snapper, *Etelis coruscans* is an important and well known target species, ranked number 11 in order of abundance in the catch. The Pale Snapper, *Etelis radiosus*, is less abundant and was only more recently described. Little research has been done on *Etelis radiosus*, which is ranked number 19 in the Top 100 for our fisheries and which has previously been mixed with other Etelis species both in the trade and in fisheries research. Fortunately we can confidently apply life history invariant approach to estimate parameter values from its maximum size of 105 cm, quite a bit larger than what was previously reported for this species but verified by CODRS images of specimen reaching up to 103 cm in the Indonesian deep slope catches.

Because of great variance in relative length of the long "Flame" upper lobe of the tail fin in *Etelis coruscans*, we decided to measure total length up to the tip of the lower lobe, which has a much more stable relative length. This may cause some discrepancy with values for total length reported elsewhere in the literature, although Fork Length is more often used and we can still convert that for reliable comparisons. The maximum size attained in Indonesia for *Etelis coruscans* is about 130 cm measured to the tip of the lower love of the tail. This leads to an estimated 117 cm asymptotic length which could be verified with CODRS data showing specimen up to 120 cm in the catch. The estimated length at 50% maturity for this species is 69 cm Total Length from the life history invariant approach. This estimate falls well within a range of values reported in the literature for this species (Everson et al., 1989; Martinez-Andrade, 2003, Newman et al., 2016).

A number of important Lutjanus species have been traded as a general group combined under "Red Snappers" since many years. This includes includes *Lutjanus malabaricus*, number 9 in the Top 100 of our fisheries and *L. erythropteris*, *L. timorensis*, and *L. sebae*, which take positions, 12, 13 and 18 respectively. Several other species of Lutjanus are included in the Top 100, including one more at position number 15, *Lutjanus vitta*, which is not red in color and which is (perhaps therefore) less preferred in the trade. Less abundant Lutjanus species which are often mixed into "Red Snapper" products, especially into filleted products, include *L. argentimalus* (28), *L. bohar* (31), *L. gibbus* (33), *L. bitaeniatus* (57), *L. lemniscatus* (61), and *L. russelli* (71).

We have focused on the most important species to verify our life history parameter value estimates. As reported also for North Australian and some other tropical waters, *Lutjanus malabaricus* can reach a maximum total length of 100 cm (e.g. Rome and Newman, 2010). Our estimate of asymptotic length of 90 cm was confirmed by CODRS images of specimen in the catch up to 90 cm total length. A fairly wide range of values is reported in the literature on length at 50% maturity. Our estimate of 53 cm fits well within the reported range and is very close to estimates reported from Vanuatu as well as from Northern Australia and the Arafura Sea (Martinez-Andrade, 2003).

The Crimson Snapper, *Lutjanus erythropterus*, is next in line for the Lutjanus species, at number 12 in the Top 100 most abundant species in catches by our fisheries. This red snapper can reach a maximum total length of 70 cm in Indonesian waters, although smaller maximum sizes are reported from Australia. Our CODRS data confirm *Lutjanus erythropterus* in the catch of up to 69 cm. The estimated asymptotic length is 63 cm and size at 50% maturity for this snapper is 37 cm. This estimate for size at maturity is in line with Lmat sizes reported from the Great Barrier Reef in Australia (Martinez-Andrade, 2003).

The highly priced *Lutjanus erythropterus* is often mixed in the "red snapper" trade with the poorly known and only recently (1987) described but highly abundant Slender Pinjalo (or "Red Pinjalo"), *Pinjalo lewisi*, which is number 10 in our Top 100, an amazingly high ranking for a species that was described only 30 years ago. Additional mixing takes place with the larger and better known Pinjalo Snapper, *Pinjalo pinjalo*, which is however much less abundant in catches by our target fisheries. *Pinjalo lewisi* grows to a maximum length of 55 cm in Indonesian waters, slightly larger than commonly reported in the literature. This can be verified from CODRS images showing specimen up to 52 cm in total length. Little is known about this abundant snapper species, but size at maturity is commonly assumed to follow the same trend as observed for other species of Lutjanidae.

Other important "red snappers" include the Timor Snapper, *Lutjanus timorensis*, which is number 13 in the Top 100 list, and the Red Emperor, *Lutjanus sebae*, which is ranked number 18. Both these species are commonly mixed with other red snappers in the trade but could in fact be separated quite easily based on visible external differences. The Timor Snapper and Red Emperor grow to maximum total lengths of 60 cm and 100 cm respectively. These maximum sizes are verified for Northern Australian waters (Rome and Newman, 2010) as well as from other studies. Estimated asymptotic lengths of 54 cm and 90 cm respectively for Lutjanus timorensis and Lutjanus sebae are also well within the range of available literature values (e.g. Martinez-Andrade, 2003) and further verification was obtained through CODRS data and images showing specimen in the catch for these 2 species up to 60 cm and 96 cm respectively. Literature values for length at 50% maturity for *Lutjanus sebae* mostly range between 48 cm and 55 cm total length for our latitudes (e.g. Martinez-Andrade, 2003), placing our estimate of 53 cm for this species well within this range. Information on size at maturity for *Lutjanus timorensis* is scarce, but limited information shows mature individuals of both sexes to be common at sizes above 28 cm Fork Length which aligns very well with our estimate of 32 cm Total Length for Lmat in this species.

Apart from the high priced "red snappers" in the Top 20 most abundant list, there are a number of poorly known snapper species that are underappreciated in the trade, possibly due to their dull colors, although eating quality is very good for these fish. These very common but not well known species include the Brownstripe Snapper, *Lutjanus vitta*, at number 15, the highly abundant Saddle Back Snapper, *Paracaesio kusakarii*, at number 6 and its closely related cousin, the very similar looking Cocoa Snapper, only recently (1983) described as *Paracaesio stonei*, at number 17. The maximum attainable lengths in Indonesian waters for these 3 species are 45 cm, 85 cm and 70 cm respectively. Somewhat larger than commonly reported in the literature (although *P. kusakarii* and *P. Stonei* have been mixed up in some reports) but clearly verified from CODRS data and images showing specimen in the catch up to 42 cm, 80 cm and 67 cm respectively for these 3 snappers. Our data provide strong support for estimates of asymptotic lengths of 41 cm, 77 cm and 63 cm respectively for these 3 poorly known but important species. Our estimate of

Lmat for the Brownstripe Snapper (24) is the same as what was reported from Malaysia while similar sizes (23 cm) were reported from the Philippines and Northern Australia (Martinez-Andrade, 2003). Very little is known about maturation in the Paracaesio species, but FishBase quotes a report on Lmat for *P. stonei* at 40 cm, which is just above our estimate of 37 cm for this species and jujst below our estimate of 45 cm for *P. kusakarii*. It is unclear however if mixing of these two very similar species may have occurred.

The most abundant species of emperors in our target fisheries are high quality fish which are however not very well known as specific species in the trade and usually are classified generally as "emperor" or sometimes even as "white snapper". The Blue-Lined Emperor, *Gymnocranius grandoculis*, is the most abundant and important emperor at number 14 on the list, while the Mozambique Large-Eye Bream, *Wattsia mossambica* is placed number 16. The maximum attainable sizes for these two emperors are 80 cm and 60 cm total length respectively. These maximum sizes are confirmed also for North Australian waters (Rome and Newman, 2010), with the note that Wattsia mossambica is assumed to grow up to just 55 cm there while our CODRS data show that somewhat larger sizes are attained in Indonesia. CODRS data include specimen in the catch of *Gymnocranius grandoculis* and *Wattsia mossambica* of up to 74 cm and 59 cm respectively, strongly supporting our estimates of 72 cm and 54 cm for Linf for these 2 species respectively.

The above described species cover the Top 20 most abundant species in the catch of our fisheries and some more. These species also cover close to 90% of the catch and therewith we have been able to verify the validity of the life history invariant approach for the major part of the catch. This was possible through cross-checks with reliable literature and though validation of Lmax and Linf estimates directly from our own CODRS images. These CODRS images have shown maximum sizes reached by target species sometimes to be in excess of what has previously been reported.

4 A SIMPLE LENGTH-BASED ASSESSMENT TOOL

4.1 Differentiating between Catch Categories

As the basis for a simple length-based assessment tool for the data poor deep slope fisheries, we can now obtain values for all key length-based life history characteristics for all species in our target list. And by overlaying these values over accumulated catch length frequencies, we can "split" the catch of each species in major "catch categories", for example including:

1. % in the catch < Lmat,
2. % in the catch >= Lmat but < Lopt, and
3. % in the catch >= Lopt.

These "catch categories" are (1) the percentage of fish in the catch (in terms of numbers) that never reached maturity, (2) the percentage that reached maturity but never reached the optimum harvest size, and (3) the percentage of fish in the catch that has reached the optimal harvest size and lived to grow beyond that.

Looking at these percentages for an accumulated catch length frequency (over a year) will give us an indication of the current impact of the fishery by species. If mostly immature fish are included in the catch, for example, there is reason for concern and a closer look. Following the same percentages over time (from year to year) also enables us to look for signs of improvement (for example increasing percentage in category 2, while the percentage in category 1 decreases) or note signs of deterioration (increasing percentages in category 1 for example).

4.2 Plotting Results from Length-Based Assessments

Using key length-based life history characteristics for our target species, we are now able to apply a simple tool for the analysis of length frequency distributions in the landed catches, therewith stimulating a focused discussion among stakeholders on the impact and status of the fisheries. We can start with visualizing the accumulated catch (for example over 1 year) in terms of the lengths of the fish in relation to the values of the key life history characteristics. The position and shape of the length frequency distribution relative to the positions of these values gives us a first tool to start our length-based assessment. As a next step, we can plot the percentages from multiple years in each of the "catch categories" in a line graph to see how the situation develops over time.

Figures 2 and 3 are examples of such plots with length frequency distributions of landings of *Lutjanus fantasticus*, an imaginary species of snapper. Figure 2 shows a plot for a situation where a large percentage of the fish in the catch is still immature and was removed by the fishery before being able to spawn or reach their full growth potential. Figure 3 shows a situation where relatively more fish in the catch are already mature, have therefore spawned before being caught and are closer to the optimum length for harvesting that species. Figures 4 and 5 are examples of plots with percentages of the catch categories over multiple years. Figure 4 shows a situation where initially mostly juvenile snappers were caught, while in later years the catch shifts to more adult and larger animals. Figure 5 shows a situation where initially mostly large fish were caught but eventually only juveniles remain.

Figure 3. Catch length frequency distribution of Lutjanus fantasticus for an example situation where a large percentage of the fish in the catch is still immature and was removed by the fishery before being able to spawn or reach the full growth potential. This is an example of a situation with overfishing including the targeting of juveniles.

Figure 4. Catch length frequency distribution of *Lutjanus fantasticus* for an example situation where a large percentage of the fish in the catch is mature and was removed by the fishery after being able to spawn and approaching the full growth potential. This is an example of a more sustainable situation with the fisheries are mainly targeting adults.

Figure 5. Shift in catch categories of *Lutjanus fantasticus* for an example situation where initially a large percentage of the fish in the catch is immature and was removed by the fishery before being able to spawn or reach the full growth potential. Over the years however, the situation improves with larger mature animals becoming more dominant in the catch.

Figure 6. Shift in catch categories of *Lutjanus fantasticus* for an example situation where initially a large percentage of the fish in the catch is mature and has approached their full growth potential. Over the years however, the situation deteriorates with smaller immature animals becoming more and more dominant in the catch. This development would be a clear reason for concern.

5 EVALUATING RESULTS FROM LENGTH-BASED ASSESSMENTS

When looking at results from length-based assessments, we do need to be careful with conclusions, and consider the ecology and dynamics in all of the fisheries targeting the species under assessment, in all of the habitats utilized by all of the life stages of these species. Snappers for example, like most of our other target species, have pelagic eggs and larvae. The larval pelagic stage lasts for 4 to 6 weeks, when larvae are between 1 and 2 cm long. Eggs and larvae can be displaced over great distances, and pre-settlers actively swim in specific directions, and towards specific habitats, during this time. At the end of their pelagic migration, juvenile snappers settle on nursery grounds.

After settlement, juveniles of many species of snappers remain on nursery grounds for a period of several years, and then move to other areas joining sub-adults at specific habitats until they reach maturity, and eventually the adult population, usually at the deepest range of their distribution, on the slopes of the continental shelf.

It is important to realize that these fish can and will be targeted by various fisheries during all these phases of their life, with different gear types, in all the habitats that they occupy. In Indonesia that even includes the small pelagic pre-settlers, which are often found in catches by small meshed lift net boats using light attraction to catch (very) small pelagic fish. It should be clear that even if one fishery is shown to harvest mainly large adult fish of a specific species, this does not necessarily mean that the species as a whole is being fished sustainably across its entire range of life stages and habitats.

Relative abundance of specific size classes in one fishery may not change in the case of another fishery decimating juveniles, and in such case only a decline in the total numbers in the catch, or rather in the catch per unit of effort, will show that there is a problem somewhere. It is therefore recommended to keep track of catch per unit of effort by species (for target fleets and species) as an independent second source of information to back up conclusions from length-based assessments.

6 MANAGEMENT CONSIDERATIONS

Adult stages of many target species in deep slope fisheries remain at well defined locations, at the edge of the continental shelf. These adult populations do not migrate to spawn or for other reasons. Deep water snappers and other deep water predators form feeding aggregations at edges of drop offs and canyons, seamounts and other highly predictable locations. This makes them extremely vulnerable to fishing, much more so than species which are spread out over the flat surface of the continental shelf. Overfishing can happen very quickly at those locations, much faster than the time it takes to collect and analyze data, formulate conclusions and management advice, and ultimately take management action. The locations where adult fish aggregate need to be managed very carefully. Access to these areas needs to be restricted to prevent overfishing. Some of these locations could effectively be set aside as “No Take” areas to protect spawning biomass.

For fisheries managers and other stakeholders it is also important to realize that due to the spatial segregation between size groups in the populations, the fisheries can be size selective to some extent. Fishermen can take conscious decisions to target sub adults and juveniles and will do so normally when densities of larger mature animals on deep water fishing grounds have declined. As such, a policy among fish traders to buy and trade (or not to buy and trade) certain size classes (for example sizes below size at maturity) can directly influence the sustainability of the fisheries when the buying behavior affects the behavior of fishers.

Stakeholders and managers should all prevent the targeting, selling, buying and trading of immature fish. Putting a premium on “plate size fish” for species which are not yet mature at such size, can be highly destructive to the stock as fishers are incentivized that way to target undersized fish. Incentives for fishers need to be geared towards catching mostly mature specimen of all target species. Fishers can decide to move on to a different location or different fishing depth when they find that they are fishing an aggregation of juvenile fish. They will do so only though if this makes immediate economic sense to them or if regulations on minimum sizes are in place and being enforced.

The choice of hook size also plays an important role in the selectivity of the fisheries, especially in combination with the choice of fishing location and target species. Small hooks with smaller baits, fished with thinner lines, in general catch smaller fish than large hooks with big baits fished with heavier lines. Fishing for deep water snapper in new locations often starts with large hooks and at fairly great depths. The main target species are the large deepwater snappers and within those species the larger specimen were targeted first. As adult populations at the deepest fishing grounds declined though, fishers explored different habitats, usually at somewhat shallower locations, with smaller hooks and smaller baits. This resulted in smaller specimen of the original target species to become more dominant in the catch. At the same time “new” species (new to the fisheries) of smaller maximum size, living in shallower waters were entering the catch. This situation become worse when traders started to pay premium price for under-sized âĂIJplate sizedâĂİ snappers, as mentioned above.

Selectivity is influenced by a combination of hook size and fishing location (depth and habitat) but the species range is so great in the Indonesian deep slope fisheries, that management by species is impossible. Length-based assessments need to be carried out over the range of target species to find out what the patterns look like and management options need to be selected that take into account this multi species character of the fisheries. Management solutions are not straight forward and the multi-species fisheries, operating from scattered locations with a great number of medium scale units, means that a precautionary approach necessitates wide-ranging management actions.

7 REFERENCES

To develop the guidelines and findings in this document, we used a wide variety of sources: scientific articles from peer-reviewed journals (especially meta-analysis, but also species specific), project reports, presentations and other "grey literature", technical reports from various institutions, websites of research and other institutions and fishing companies, and even blogs and comments posted by recreational and other fishers. Sources sometimes contradicted each other, and we found this was often caused by mistakes in species identification or by different interpretation of technical terms or by analyses that were based on incomplete or otherwise inadequate data sets.

Carefully documenting all these inconsistencies, and providing a complete list of all references would have slowed the process down considerably, and it would have made this document unwieldy and inaccessible to all but very determined readers. Hence, we decided to present our findings and guidelines without a meticulous review of corroborating or contradicting sources, and in the list of references below we only present a small subset of the sources we used. Whereas we feel that the guidelines and findings we present here will enable sound fishery management, we encourage readers to triangulate our guidelines with those from other sources. We also encourage users to use our guidelines and findings mainly as a starting point for discussions on fisheries impact and status, to be refined whenever additional information becomes available or is deemed necessary.

7.1 Selected Sources Referenced in The Text

- Binohlan, C. and R. Froese. 2009. Empirical equations for estimating maximum length from length at first maturity. Journal of Applied Ichthyology, 25(5): 611-613.
- Cope, J.M., and A.E. Punt. 2009. Length-based reference points for data-limited situations: applications and restrictions. Mar. Coast. Fish. Dyn. Mgmt. Ecosys. Sci. 1:169-186.
- Everson, A.R., Williams, H.A., and B.M Ito, 1989. Maturation and Reproduction in Two Hawaiian Eteline Snappers, Uku, Aprion virescens, and Onaga, Etelis coruscans. Fish. Bull., 87: 877–888.
- Martinez-Andrade F., 2003. A comparison of life histories and ecological aspects among snappers (Pisces: lutjanidae). Dissertation http://etd.lsu.edu/docs/available/etd-1113103-230518/unrestricted/Martinez-Andrade_dis.pdf
- Mous, P.J., Pet, J.S., Pramana, R. and E. Wibisono, 2017. 100 Species identification guide for deepwater hook-and-line fisheries targeting snappers and groupers in Indonesia. The Nature Conservancy Indonesia Fisheries Conservation Program, Denpasar, Bali, Indonesia.
- Nadon, M.O. and J.S. Ault, 2016. A stepwise stochastic simulation approach to estimate life history parameters for data-poor fisheries. Can. J. Fish. Aquat. Sci. 73: 1âĂŞ11.
- Newman, S.J., Williams, A.J., Wakefield, C.B., Nicol, S.J., Taylor, B.M. and J.M. O'Malley, 2016. Review of the life history characteristics, ecology and fisheries for deep-water tropical demersal fish in the Indo-Pacific region. Reviews in Fish Biology and Fisheries 26(3): 537-562.
- Rome, B.M. and S.J. Newman, 2010. North Coast Fish Identification Guide. Fisheries Occasional Publication No. 80. Department of Fisheries, Perth, Western Australia.
- Shakeel, H. and A. Hudha, 1997. Exploitation of reef resources, grouper and other

food fishes in the Maldives. SPC Live Reef Fish Information Bulletin #2, May 1997.

8 Catch length frequencies and life history parameter values

The Top 100 most abundant species in the catch over the above mentioned period cover more than 99% of the total catch and include the following families:

A. Lutjanidae (Snappers, species ID numbers 1-35),

B. Epinephelidae (Groupers, Cods and Coral Trout, species ID numbers 36-62),

C. Lethrinidae (Emperors, species ID numbers 63-72),

D. Carangidae (Jacks and Trevallies, species ID numbers 73-84),

E. Emmelichthyidae (Rubyfish, species ID number 85),

F. Sparidae (Sea Breams, species ID numbers 86-87),

G. Glaucosomatidae (Pearl Perch, species ID number 88),

H. Haemulidae (Sweetlips, species ID numbers 89-90),

I. Priacanthidae (Bullseye, species ID number 91),

J. Sphyraenidae (Barracudas, species ID numbers 92-94),

K. Nemipteridae (Monocle Bream, species ID number 95),

L. Holocentridae (Soldierfish, species ID number 96),

M. Rachycentridae (Cobia, species ID number 97),

N. Serranidae (Sea Perch, species ID number 98),

O. Sciaenidae (Black Jewfish, species ID number 99), and

P. Malacanthidae (Tilefish, species ID number 100).

Accumulated catch length frequencies with estimated values of key life history parameters by species are presented on the following pages, together with CODRS images of the largest specimen encountered to date for each of those species. The presented catch length frequencies cover the total sample sizes by species, collected in our overall area of interest (WPP 712+713+715+716+718) over a period from late 2014 until early 2017. The CODRS images are those of the largest specimen by species encountered and photographed during that same period of time. It is possible that larger specimen will be encountered anytime after early 2017 and if any specimen exceeds the current value of Lmax then all life history parameters for that species will be revised accordingly. This document will also be updated each time when parameter values need to be revised.