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Holistic Image-Based Risk Assessment informing Management of the Indonesian Deep Demersal Fisheries for Snappers and Groupers

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Abstract

Deep demersal fisheries for snappers and groupers in Indonesia yielded close to 119,000 Metric Tons over a range of 100 species of fish, landed by a fleet of more than 11,500 fishing boats, and representing a global end value of close to US$ 1.3 billion in 2020. Before the present study, information on these dispersed small- to medium-scale fisheries was scarce, while reliable species-specific data on catch and effort were non-existent. This data-deficiency made stock assessments impossible and harvest strategies could not be specified. A Crew-Operated Data Recording System (CODRS) was therefore developed to collect species- and length-composition data from catches across all segments of the fleet. A fleet inventory was done for the entire Indonesian archipelago, and CODRS contracts were allocated to 440 fishing boats. The CODRS approach involves fishers taking photographs of all fish in the catch, displayed on measuring boards, while a low-cost GPS tracking system provides data on fishing grounds, effort and fleet dynamics.

With a contribution of 81% to the catch of the Top 100 species in 2020, snappers (*Lutjanidae*) and groupers (*Epinephelidae*), were the dominant families in these fisheries. The Top 3 Fisheries Management Areas (FMAs) for snapper production in 2020 were WPP 712, WPP 718, and WPP 573, whereas the Top 3 FMAs for grouper production in 2020 were WPP 711, WPP 712, and WPP 571. As snappers and groupers clearly dominated the fisheries, we focused stock assessments on the Top 16 species from these 2 families, together representing 71% of the total catch. Length-based assessments were applied to evaluate status and trends in the stocks for the main two FMAs, in terms of 2020 production, for each of the 16 target species. With more than 3 million CODRS images available by 2020, life-history parameters could be updated for all these species, based on the maximum observed length in the catch.

As a starting point for the length-based approach, we estimated the maximum attainable length (Lmax) from the size of the largest specimen in the catch. We then estimated the asymptotic length (Linf), the mean size in the cohort when it stops growing, as 90% of Lmax (Nadon and Ault, 2016). Using additional life history invariants (Newman et al., 2016) we estimated size at maturity (Lmat) from Linf. For estimation of the optimum harvest size (Lopt), we used the invariable M/K (natural mortality rate over growth rate) in the Beverton (1992) estimator, Lopt = Linf * 3/(3+(M/K)). An estimate for K was obtained from species-specific literature and a length-dependent M was calculated using an empirical formula that relates M to length and growth characteristics (Gislason et al., 2010), with addition of a family-dependent multiplicative correction factor. We used Spawning Potential Ration (SPR), percentage immature fish in the catch, exploitation level, and relative amount of “mega-spawners” (Froese, 2004), as indicators for sustainability.

Length based stock assessments showed high risk of overfishing in the Indonesian deep demersal fisheries for snappers and groupers in 2020. No less than 116 out of 128 (>90%) of the most relevant combinations of species, FMA, and sustainability indicator led to conclusions of unsustainable levels of exploitation. Most of the major target species of snappers and groupers show a rapid decline in numbers above the size where the species becomes vulnerable to the fisheries, indicating high fishing mortality. Time series up to 2020 also showed a deteriorating trend in the stocks of most species, across all major FMAs. In total 53 of 76 time series (70%) for combinations of species, FMAs and sustainability indicators, showed a deteriorating situation in these important fisheries, with a very high level of risk apparent at the end of these time series in 2020. There are major differences between FMAs, but in general it is clear that an effective management strategy is urgently needed across the Indonesian archipelago, and that harvest strategies need to be implemented in each of the most important FMAs to prevent collapse of these valuable but vulnerable fisheries.

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1 Introduction

Indonesian deep demersal fisheries for snappers (*Lutjanidae*) and groupers (*Epinephelidae*) are highly productive and of great national as well as international importance in terms of total volume, economic output and food security (Blaber et al., 2005; Cawthorn and Mariani, 2017; Dimarchopoulou et al., 2021; Wibisono et al., 2022). Snapper production in Indonesia was estimated to have contributed some 119,000 Metric Tons (MT) or 45% of the average global supply of just over 264,000 MT annually in the period 2006 to 2013 (Cawthorn and Mariani, 2017). Therewith Indonesia was by far the single largest Lutjanid-producing country in the World during that time. In a separate study on supply lines and official statistics, total snapper landings in Indonesia were estimated to reach close to 117,000 MT in 2007 (Anggraeni, 2012). Groupers make up a smaller part of total landings in the deep demersal fisheries in Indonesia, but are also of considerable economic importance due to the high price per kg for these species (Khasanah et al., 2019). Additional species in these multi-species fisheries include trevallies (*Carangidae*), emperors (*Lethrinidae*), grunts (*Haemulidae*), croakers (*Sciaenidae*) as well as species from many other co-occurring families (Dimarchopoulou et al., 2021). Snappers and groupers however are the main target species in these fisheries, which operate mostly at depths ranging between 30 and 350 meters. To differentiate from shallow water and coral reef fisheries that target the same families (but a different though somewhat overlapping spectrum of species) we will refer here to the “deep demersal fisheries for snappers and groupers” and we will focus in our assessment of these fisheries on the major target families and species. Issues of species overlap with other fisheries in Indonesia will be briefly discussed in the final chapter of this paper.

Tropical small- to medium-scale fisheries are often characterized by high species diversity, the use of multiple gear types, and a fleet that is dispersed over vast and remote stretches of coastline. The Indonesian deep demersal fisheries for snappers and groupers are no exception to this, and consequently conventional catch- and effort-based assessment methods have suffered from problems with species and gear identification, limited access to landing sites, difficulties with defining units of effort, and lack of resources for implementation of monitoring programs. Accurate port sampling would require well trained enumerators to be present at the site and time of landing, which poses a logistical challenge even when vessels do land in ports. Fleets in tropical small-scale fisheries are landing their fish in a very dispersed manner, outside major ports, making enumeration almost impossible. For longer fishing trips, it is also difficult to determine actual fishing grounds at the time of landing, when there are no tracking systems on board of the vessels. Logbooks are difficult to enforce, and unsuitable for small to medium scale fisheries. In Indonesia, logbooks are often completed on shore, while observer programs can only effectively be implemented on much larger vessels. With similar issues apparent around the world, global trade statistics currently lack granularity to properly inform traceability and management of these high-value fisheries (Cawthorn and Mariani, 2017).

Conventional fishery-dependent data collection methods (port sampling, logbooks, and observers), combined with fishery independent research, have long been the standard approach to monitoring of fisheries catch and effort across the globe. Standard methods have been developed over decades, mostly in temperate climate fisheries, to inform fisheries managers of stock status and trends over time, and to enable governments to regulate fisheries inputs (effort) with the aim of optimizing and sustaining the output (catch). Management on the basis of trends in Catch per Unit of Effor (CpUE) still forms the basis for harvest strategies in many major fisheries, also in Indonesia. The value of these methods to inform management, however, can be limited depending on the characteristics of the fishery, issues with hyperstability (Erisman et al., 2011) and the quality of the data. This has been a concern also in relation to Indonesian deep demersal fisheries.

In Indonesia, the standard catch and effort monitoring system (Yamamoto,1980) has not been successful in capturing data with sufficient resolution for accurate stock assessment in small- to medium-scale multi-species fisheries (Dudley and Harris, 1987). In that respect, the system has also not improved much in recent decades and years (Cawthorn and Mariani, 2017). Before 2015, there were no accurate species-specific catch and effort data available on the Indonesian deep demersal fisheries and currently available information is not yet fully integrated into official systems. The deep demersal fishing fleet has not yet been officially inventoried as a distinct fishery. Fleet dynamics were poorly understood before this study, making accurate and detailed effort estimates impossible. These kind of data poor situations are common in tropical small-scale, multi-species and multi-gear fisheries, and appropriate monitoring methods are urgently needed here. To obtain a complete inventory of the fleet, we implemented a frame survey between 2015 and 2020, covering the entire Indonesian coastline and mapping out all segments of the deep demersal fisheries for snappers and groupers. To address catch and effort data deficiencies, and enable length-based stock assessments, we developed a Crew-Operated Data Recording System (CODRS) for onboard monitoring of species- and length-composition of catches.

In data-poor fisheries, length-based assessment methods are a viable way to determine fishery status and pre-set management benchmarks (Sparre and Venema, 1992; Froese and Binohlan, 2000; Froese, 2004; Prince et al., 2014; Hordyk et al., 2015; Ault et al., 2022), but only if accurate data on fish species and sizes in the catch are available (Cawthorn and Mariani, 2017), and when catches originate from fisheries with broad selection curves. We therefore developed the CODRS with the goal to involve fishers in efficiently collecting verifiably accurate and complete species- and length-composition data on catches across all segments of the deep demersal fishing fleet (Dimarchopoulou et al., 2021; Wibisono et al., 2022).

The CODRS approach is based on photographic records of the fish in the catch, resulting in verifiable data. This system combines simple hand-operated cameras with GPS trackers to simultaneously record catch, time, and location. Species identification and measurements of the fish are verifiable from the images with fish displayed on measuring boards, while weight converted catch length frequencies can be verified against transaction records of landings. Fisheries activity data from onboard trackers provide verifiable information on fishing grounds and fishing activity for each segment of the fleet. This approach allowed us to assess status and trends for a range of the most import snapper and grouper species in the deep demersal fisheries, and thus inform management from a multi species perspective. Comparable multi-species approaches to length-based assessments for snapper and grouper fisheries are already supporting management decision making elsewhere, as for example in the southern Florida USA multispecies coral reef fish fishery (Ault et al., 2022).

Accurate species identification remains a major issue in the Indonesian deep demersal fisheries, with locally used common names often representing species groups rather than just one species, while similar names are sometimes referring to different species groups in different regions. Several species or groups of species also have different names in different regions. Species information in official statistics lacks resolution and is often incorrect, while population dynamics of target species remains mostly unknown. The Indonesian fisheries statistical system does not use scientific names for the range of target species in the deep demersal fisheries. In addition, official catch data include species categories such as the "not elsewhere included (nei)" category, that clumps many different species into one group. This categorization does not allow for stock assessments or analyses of catches based on similar biological and ecological properties. All these challenges are further exacerbated by limited technical capacity among workers tasked with collecting, processing and analyzing data for management purposes.

Before 2015 snapper and grouper Fisheries Improvement Programs (FIPs) in Indonesia worked with inaccurate species lists while some scientific publications still misidentified even the most common snapper in the deep demersal fishery, *Lutjanus malabaricus*, as *Lutjanus sanguineus* (Genisa, 1999), a species that does not occur in Indonesian waters (Froese and Pauly, 2018). Until 2016, information on species composition in the deep demersal fisheries catch was low-resolution at best and more often inaccurate, but this situation has improved during the current study (Dimarchopoulou et al., 2021; Wibisono et al., 2022). For some species in the deep demersal fishery, taxonomy is still developing though. Only recently have researchers concluded that a major ruby snapper species caught in Indonesian and Australian waters is not *Etelis carbunculus*, as it was often referred to, but rather a new species now described as *Etelis boweni* (Andrews et al., 2021), which grows much larger than *E. carbunculus.* A thorough review of the complete species spectrum in the catch of the Indonesian deep demersal fisheries was carried out between 2016 and 2020, to develop a solid foundation for the current study. A deep demersal species identification guide (Mous et al., 2019) and training manual were developed for technical staff who contributed to data processing and analysis. The image-based nature of the CODRS approach has been essential in enabling accuracy and quality control in species identification for assessment purposes, using the most up to date scientific names for all target species in the catch.

Our length-based approach focuses on 4 important length-based life-history parameters: length at maturity (Lmat), optimum harvest length (Lopt), asymptotic length (Linf), and maximum length (Lmax). Lmax is the maximum length a species can attain in the local population as targeted by the fishery. Linf is the mean length of fish in the cohort at infinite age, and Lmat is the smallest length at which 50% of the fish in a cohort are sexually mature. Lopt is the length class with the highest biomass in an un-fished population (Beverton, 1992). Linf is a key parameter and starting point in length-based assessments. In many growth studies published in recent decades, Linf for numerous species has been estimated by using age-length data to fit the Von Bertalanffy growth equation. Many of these studies, however, may be biased due to very small sample sizes, samples from highly selective gear, or aging error. In heavily fished situations researchers seldom have access to the extremely rare surviving specimen at maximum length. Sample sizes available for study are often too small, besides lacking the larger fish, while they can also be biased due to gear selectivity, sourcing from a single element of the fleet, at a specific moment in time or from a specific location on the fishing grounds. Under-estimation of Linf can occur when large fish are missing from samples used in growth studies.

An alternative approach to estimating the length-based life-history parameters, applied in the present study, is to start with estimating Lmax as the largest specimen from a very large sample of fish and use it to calculate other life-history parameter values based on known life history invariants, or relationships between the life history parameters (Nadon and Ault, 2016; Newman et al., 2016; Cope & Punt, 2009). In the present study we report findings from our CODRS, which by 2020 had produced close to 4 million verifiable length observations for the most abundant species in CODRS samples, originating from all segments of the fisheries. For most species in the catch of the deep demersal fisheries, the CODRS resulted in images of specimen larger than previously recorded in Indonesia or even beyond. CODRS images showed that these large fish are not "freak occurrences" but rather regular parts of the complete size frequency distribution. The CODRS therewith allowed us to set reliable life-history parameters for all of the most important species in the fishery, based on verifiable estimations of Lmax.

Additional growth and mortality parameters are needed, besides the above-mentioned length-based parameters, to estimate a Spawning Potential Ratio (SPR) as a key indicator of stock status in length-based assessments. Total mortality (Z) can be estimated from catch size frequencies, natural mortality (M) by using the Gislason et al. (2010) empirical formula, in combination with species specific literature. Fishing mortality F will follow as the difference between Z and M. The growth parameter K (von Bertalanffy) can be estimated from the combined literature on specific species groups, and the SPR can be estimated as the current spawning stock biomass divided by the pristine spawning stock biomass, using life-history parameters M, F, K, and Linf. In length-based stock assessments for the Indonesian deep demersal fisheries, we used SPR as well as percentage immature fish in the catch, percentage under Lopt (exploitation level), and relative amount of "mega-spawners" (Froese, 2004) as indicators for status of the stocks. We compared this range of population metrics relative to currently used sustainability reference points for the 16 most important snapper and grouper species (by 2020 catch volume) in the Indonesian deep demersal fisheries. In our analysis we employed a precautionary approach to evaluate exploitation status in 2020 and we looked at trends in indicators using data collected during a study period from 2015 through 2020 to further specify where management action is most urgently needed.

2 Materials and Methods

2.1 Study Area and Frame Survey

Policy and management of Indonesia's fisheries resources is organized across 11 Fisheries Management Areas (FMA) or Wilayah Pengelolaan Perikanan (WPP). These FMAs include multiple water bodies, joining the Indian Ocean in the southwest and mingling with the Pacific Ocean in the northeast (Figure. 2.1). Habitats and fisheries characteristics differ considerably between FMAs, and some are more important in terms of production than others. The bathymetry of FMAs 573, 713, 714, 715, 716 and 717 is characterized by mostly narrow coastal shelves, seamounts, and deep trenches. The bathymetry of FMA 711, 712 and 718 is mostly comprised of shallow waters over continental shelves (30 to 100 m depth). FMAs 571 and 572 have a mix of shallower continental shelf habitat and deeper slopes and drop offs in the Indian Ocean and Malacca Strait, around Sumatra.

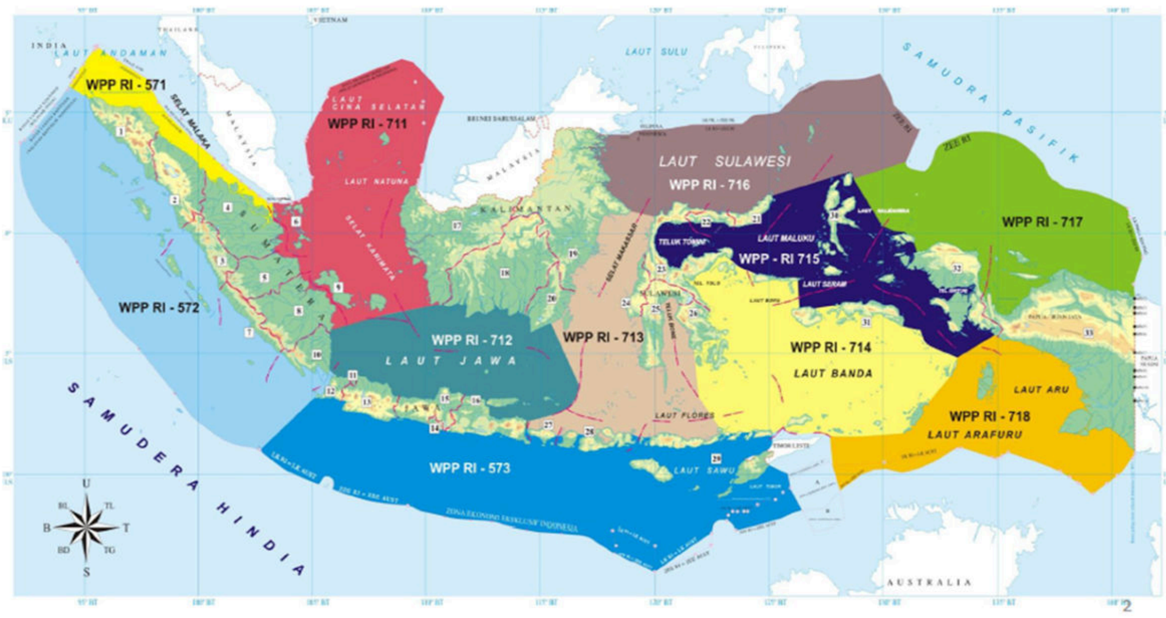


Figure 2.1: Fisheries Management Areas (*Wilayah Pengelolaan Perikanan* or WPP) in Indonesian marine waters.

To identify and describe the fleet involved in the deep demersal fisheries for snappers and groupers, we implemented a 5-year frame survey (2015-2020) covering the entire coastline of all Indonesian islands and all 11 FMAs. The frame survey was based on a combination of information from satellite image analysis and ground truthing visits to all locations where either satellite imagery or other forms of information indicated deep demersal fisheries for snappers and groupers. Data were collected at all locations with deep demersal fisheries activity, including information on boat size, gear type, port of registration, licensing for specific FMAs, captain contacts and other details, for all fishing boats in the relevant segments of the local fishing fleets. Following practices by fisheries managers in Indonesia we distinguished 4 boat size categories including “nano”’ ($<$5 GT), “small” (5-$<$ 10 GT), “medium” (10-30 GT), and “large” ($>$30 GT). We distinguished 4 major gear types used in these fisheries, including vertical drop lines, bottom set long lines, deep water gillnets and traps. We also distinguished between “dedicated” (full time) and “seasonal” operations, with the latter usually operating for only half of the year, sometimes in 2 periods of 3 months each.

2.2 Development of the Crew Operated Data Recording System

Between 2015 and 2021 we developed and implemented a Crew Operated Data Recording System (CODRS), starting in FMA 573, including the Timor and Savu Seas, as well as the Sumbawa, Lombok, Bali and Java southern coastlines, facing the Indian Ocean. By 2018 this CODRS program had expanded to all Indonesian fishing grounds including the Malacca Strait on the North East side of Sumatra (FMA 571), the Indian Ocean on the South West side of Sumatra (FMA 572), the Natuna Sea and the Karimata Strait (FMA 711), The Java Sea (FMA 712), the Makassar Strait (FMA 713), the Banda Sea (FMA 714), the Molucca and Seram Seas (FMA 715), the Sulu Sea (FMA 716), the Western Pacific Ocean (FMA 717), and the Arafura Sea (718).

The CODRS approach involves fishers taking photographs of all fish in the catch, displayed on measuring boards, while a low-cost GPS tracking system records the positions. We recruited captains for the CODRS program in all 11 FMAs, across the range of boat size and gear type categories (fleet segments). Field technicians facilitated allocation of CODRS contracts in all fleet segments present in each FMA, with at least one and where possible multiple repetitions within the same segment. As an incentive for collaboration, we provided captains with monthly compensation for data collection, scaled to their vessel size. In addition to monetary compensation, we also provided captains with a digital camera, fish measuring board, and a GPS tracking device (SPOT Trace). We then trained captains how to take photographs of their catch and ensured the GPS tracking device transmitted positions every hour. Technicians received the digital media with the pictures from the captains after each trip. We trained research technicians in fish identification using identification guides, frozen specimen, and photographs, so they could read the images and accurately input the data.

As the CODRS approach relies on fisher's collaboration and willingness to share information, this approach is comparable with a logbook system but enables verification of species and size data from any catch, by reviewing individual images that are linked to the other information in the database (date, time, location, vessel size, gear type, etc.). The system was implemented since 2015 and by 2020 produced data from close to 440 cooperating fishing boats, yielding images of close to 4 million individual fish. The monitoring program aimed to cover all fleet segments in all 11 FMA with about 40 CODRS vessels in each FMA in 2020 (noting that not all fleet segments are present in each FMA). Recruitment of captains from the overall fleet into the CODRS program was not exactly proportional to composition of the fleet in terms of vessel size, gear type and the FMA where the boat normally operates. Actual fleet composition by boat size and gear type, and activity in terms of numbers of active fishing days per year for each category, are therefore used when CODRS data are used for CpUE and catch calculations. Species composition in the catch is also not exactly the same as species composition in the CODRS samples. Catch characteristics in CODRS samples were therefore used together with fleet composition and activity information to obtain accurate catch information and species composition for each segment of the fleet, by FMA and for any specific year.

Data recording for a CODRS fishing trip begins when the boat leaves port with the GPS recording the vessel track while steaming out. After reaching the fishing ground, fishing starts, changing the track of recorded positions into a pattern that shows fishing instead of steaming. During the fishing activity, fish is collected on the deck or in chiller boxes on deck. The captain or crew then take pictures of all the fish before moving the fish from the deck or from the chiller to the hold, to be stored on ice or to be frozen. The process is slightly different on some of the “nano” boats (around 1 GT), where some crew take pictures upon landing instead of at sea. In these situations, the timestamps of the photographs are used to match images with fishing positions at those times. At the end of each fishing trip, which varies from a single day up two months in length, depending on vessel size, captains transfer the memory card with photographs of their catch to the technicians on shore. Technicians then identify the species of each fish on the images, and determine their total lengths (TL; cm). Based on the quality of the photographs, technicians also provide feedback to the fishers to improve data quality on subsequent trips. Sets of images from fishing trips with unacceptable low-quality photographs and/or only representing a small part of a multi-day fishing trip, were not included in the dataset.

After the first round of image processing by a field technician, more experienced senior technicians review the species identification and length measurement data for accuracy, before adding each data set to the database. A senior fisheries scientist further verifies any images of specimen exceeding the previous largest fish of that species in our database, before accepting it as a new estimate for Lmax. After a data set passes all reviews, and any necessary corrections have been made, the data are uploaded to a database (online). Vessel owners, captains, and researchers have access to the contents of the database, each with different viewing privileges. For instance, captains are not able to see the fishing grounds and corresponding catches of other captains, but researchers are able to see all. Fish traders can be given access to selected information on the fleet that they are buying from.

2.3 Catch per Unit of Effort, Total Catch and Value of the Trade

To determine the body weight (kg) of individual fish across their size range, as well as total weight of individual catches, allometric length-weight relationships were obtained from the literature to convert fish sizes taken from the CODRS images. When no values were found for a species, we used morphologically similar species to obtain the length-weight coefficients. Weight converted catch length frequencies of individual catches could therewith be verified against sales records of landings. These sales receipts were assumed to represent a fairly reliable estimate of the total weight of an individual catch (from a single trip, and including all species) that is independent from CODRS data. Species information on sales record is not reliable in these fisheries and was therefore not used for comparison with species information from CODRS data. Estimated total landing weights from CODRS data were always compared with receipts, before accepting any data set for specific purposes into the data base. When estimated weights from CODRS where above 90% of landed weights from receipts, they were considered complete and accepted for any use in length-based analysis and calculations of CpUE.

Converted weights from catch size frequencies, in combination with location and activity data from onboard trackers, were used to estimate Catch per Unit of Effort (CpUE) in KG per GT per Active Fishing Day, by fleet segment, by FMA and over time. CpUE is calculated on a day by day basis, in kg/GT/day, using only those days from the trip when images were actually collected. Medium size and larger vessels (10 GT and larger) do trips of at least a week up to over a month. There may be some days on which weather or other conditions are such that no images are collected, but sufficient days with images, within those trips usually remain for daily CpUE estimates and to supply samples for length-based analysis. For boats of 10 GT and above, incomplete data sets with 30% to 90% coverage were still used for CpUE analysis, using only those days on which images were collected. For boats below 10 GT (doing day trips or trips of just a few days) only complete data sets are used for CpUE calculations. All data sets on catches with less than 30% coverage were rejected. CpUE values for individual fishing days were accumulated per fleet segment (boat size and gear type) and used to calculate the average CpUE for that fleet segment every year, and for each FMA separately.

Effort in terms of "fishing vessel days" per year was calculated from the number of boats in each fleet segment multiplied with the average number of active fishing days per year, per fishing boat in that segment of the fleet. The average number of active fishing days per year, for each gear type and by boat size category, was derived from SPOT tracker data, looking at movement patterns and separating "steaming" from "fishing". Dedicated fishing boats on average were fishing actively between 200 and 250 days per year. Boats that operate seasonally in the deep demersal fisheries were flagged as such in the database and were estimated to be active for 50% of the time compared to dedicated boats. Total effort in a fleet segment was calculated from the total Gross Tonnage in the fleet segment and the average number of active fishing days per year for that segment.

Information on fleet activity, fleet size by gear type and boat size, and average size frequencies by species (per unit of effort) were used to estimate total catch by FMA. Average size frequency distributions by fleet segment and species for each FMA, in combination with the information on effort by fleet segment, were used to estimate catch length frequency distributions (LFD) from average CODRS LFD by fleet segment. Only annual sample sizes larger than 200 fish per species and 50 fish per fleet segment were used for further calculations. Numbers per size class for each species in the catch were multiplied with weights per size class, to calculate catches by fleet segment, species distribution in the total catch, as well as catch by species for each gear type separately. Catches for each fleet segment were added up to calculate total catch for each FMA and for Indonesia as a whole.

A global end value was estimated for the trade, based on catch volumes by species, percentages local retail and export and local as well as international retail prices. Processed products were converted to whole fish using yield information by species. Estimated percentages of catch volumes destined for local retail and for export are based on interviews with buyers, sellers and traders at various points in local and international supply lines. The major species of snappers and groupers from the Indonesian deep demersal fisheries are sold to buyers that supply local markets in Indonesia, as well as to international traders. Local retail price by species in Indonesia was determined by averaging consumer prices at various locations including Balikpapan, Jakarta, Bali, Kupang, Makassar, Semarang, and Manado. Prices were collected from supermarkets, from online marketplaces, from seafood shops (both physical and online), and from local markets that sell directly to end-customers. International retail values were collected from the major export destination countries. The retail values by species used in our assessment of the Global End Value are the averages of the consumer prices found in these countries.

2.4 Updating Life History Parameter and Invariant Values

As starting point for our length-based approach, we estimated the maximum attainable length (Lmax) for each species in the local population from the verifiable size of the largest recorded specimen in the catch. By late 2020, the CODRS program had produced close to 4 million verifiable length observations across a range of 100 species, originating from all segments of the fisheries. For most species in the catch of the deep demersal fisheries, CODRS images revealed specimen at least as large and often larger than ever recorded before in Indonesia or beyond. CODRS LFD also showed that these large fish form an integral part of the size frequency distribution of the population. Based on known relationships with Lmax, CODRS therewith enabled us to reliably estimate additional life-history parameters for the top 100 species in CODRS samples, with very large sample sizes for each individual species.

An essential life history parameter value needed in length-based assessment approaches is the asymptotic length (Linf). Linf is the mean size in the cohort when it stops growing, and therefore a size more common in the population than the maximum obtainable size. Under-estimation of Linf occurs frequently in the literature however, for species that are heavily fished, with limited size ranges present in the catch, and when only small sample sizes are available to researchers. Over- as well as under-estimation of Linf can occur due to misidentification of species as well as due to issues with samples and input data for estimation methods. In our study, CODRS images ensure verifiable species identification and the approach delivers very large sample sizes that included the largest fish in the local population.

Using verifiable estimates of Lmax from CODRS images, we could estimate Linf at 90% of the maximum attainable length in the local population (Linf = 0.9*Lmax), both for Lutjanidae as a family as well as over multiple families combined (Nadon and Ault, 2016). The size at maturity (Lmat) and the optimum fishing size (Lopt) were then estimated from Linf, using additional published life history invariants. Lmat for Lutjanidae was estimated with Lmat = 0.59*Linf (Newman et al., 2016) and for Epinephelidae with Lmat = 0.46*Linf (Newman et al., 2016). A general relationship of Log(Lmat) = -0.1189 + 0.9157 * Log(Lmax) as reported for ray-finned fishes from meta-analysis by Binohlan and Froese (2009) aligns very well with the above mentioned estimator for deep water snappers (Newman et al., 2016), but does not seem to work for early maturing females in sex changing groupers and may also not be ideal for some other tropical demersal species. For many important species, our estimates for Lmat could be verified with available literature on gonad maturation. We chose Lmat estimates as a point of comparison because biological studies on maturation have been shown to be more robust than studies on Linf (Brown Peterson et al., 2011). We excluded studies that published values for length at first maturity and we compared Lmat values from areas with similar latitudes as well as studies from other latitudes.

For estimation of the optimum harvest size (Lopt), we use the invariant M/K (natural mortality rate over growth rate) in the Beverton (1992) estimator, Lopt = Linf * 3/(3+(M/K)). To obtain family-specific estimates for M/K, we searched literature for values of M, K, or M/K (some studies provided M/K as a ratio, without specifying the numerator and the denominator). We used publications with estimates for M and K values when those were based on ageing studies, or on meta-analyses of such studies (e.g. Aldonov and Druzhinin, 1979; Loubens, 1980; Matthews and Samuel, 1991; Honebrink, 2000; Newman, 2002; Newman and Dunk, 2003; Grandcourt et al., 2005; Grandcourt et al., 2006; Fry et al., 2006; Ebisawa & Ozawa, 2009; Mehanna et al, 2012; Newman et al., 2016). Most studies did not define the length range to which the estimate of M applied, and for application in our approach we assumed that published M values applied to adult fish, ie. with a length between Lmat and Linf, roughly around the estimate for Lopt (resulting in an estimate for M at Lopt). As an additional validation, we cross-checked whether our estimation of K for resulted in a reasonable estimate for the age-at-first maturity (e.g. around 4 years for snappers and groupers). We validated values for M/K against the accepted range as published for Type II Teleosts including tropical snappers (Prince et al., 2014) and against published values of M/K for specific tropical Indo Pacific species of snappers and groupers (Prince et al., 2019) that are important in the Indonesian deep demersal fisheries.

We compared resulting values for Lopt/Lmat with published values for this invariant for specific groups of species. For example, Cope and Punt (2009) estimated Lopt for various demersal fish species as **Lopt = 1.3 * Lmat**, based on the median values for this life history invariant (Lmat/Lopt = 0.77). This turns out to align well with Lopt in snappers, but we found somewhat different values for other families, and thus proceeded with using the Beverton (1992) estimator for snappers and groupers separately, using M/K values established as invariants within those families. We also cross-checked the results from the Beverton (1992) estimator for Lopt with published values of Lopt/Linf, and if a combination of M and K resulted in a value that appeared far outside the published range of Lopt/Linf (i.e., more than a 30% difference), we rejected that M/K value.

While we acknowledge a size dependency in M over the full size-range of any species (e.g. Gislason et al., 2010), we assumed a relatively constant M for the short and flattened part of the curve around Lopt, where we establish a constant M/K for the estimation of Lopt in each species. We also note that Lopt is not very sensitive to small variations in M (or in M/K), and we conclude that the effect of our assumptions on the eventual estimates of Lopt are negligible. As we will explain below, we will use a length-dependent value of M, based on Gislason et al. (2010) for calculation of Spawning Potential Ratio.

2.5 Estimating Mortality and Spawning Potential Ratio

As an indicator for Spawning Potential Ratio (SPR, Quinn and Deriso, 1999), we used the estimated spawning stock biomass as a fraction of the spawning stock biomass of that population if it would have been pristine (Meester et al 2001). We calculated SPR on a per-recruit basis from life-history parameters M, F, K, and Linf, and from gear selectivity parameters in the smaller part of the size spectrum caught by the fishery.

We estimated the instantaneous total mortality (Z) from the equilibrium Beverton-Holt estimator from length data using Ehrhardt and Ault (1992) bias-correction, implemented through the function bheq of the R Fishmethods package. For this estimation, we used the length range of the catch length-frequency distribution starting with the length 5% higher than the modal length and ending with the 99th percentile. We assumed that Z, and its constituents M and F, were constant over length range that we used to estimate Z. We calculated F (fishing mortality) as the difference between Z and M, assuming full selectivity for the size range starting at modal length and ending with the largest fish in the catch. We assumed an S-shaped (logistic) selectivity curve, with 99% selectivity achieved at modal length, and with the length at 50% selectivity halfway between the first percentile and modal length of the catch length-frequency distribution.

Gislason et al (2010) provides evidence that M increases with decreasing length, and fisheries scientists agree that the smaller size classes of each fish species experience higher mortality than larger fish due to higher predation risk. The method we used for calculating Z, however, assumes a Z that is constant, implicating a constant M, over the length range over which we estimated Z. To iron out this inconsistency, we applied the Gislason et al (2010) empirical relationship to the length classes (1 cm width) over which we estimated Z, we calculated the average M over these size classes, and we applied that average to the Z estimation range. Outside this range (i.e., at lengths below 1.05 times modal length and lengths above the 99th percentile), we assumed a varying M following Gislason's formula (reworked from its 2010 notation as a log-transformed model):

$$M = \frac{1.733 \cdot K.L_{\infty}^{1.44}}{L^{1.61}}$$

The empirical relationship of Gislason et al (2010) is based on 168 marine and brackish water fish species, with mean lengths mostly between 10 and 100 cm total length. The study by Gislason et al (2010) does not report a difference between demersal and pelagic fish species, and when we applied a model to the data, we did indeed find that "habitat" (pelagic or demersal) effect was very small (amounting to a multiplication faction of 0.98) and insignificant (P=0.85). Nevertheless, comparison with published values of natural mortality in the main families present in tropical deep water demersal fisheries in the Indo-Pacific (Newman et al., 2016) showed that the relationship by Gislason et al (2010) resulted in unrealistically high estimates of M for our target species.

Tropical deep-water snappers and groupers in the Indo-Pacific have low natural mortality rates, usually between 0.1 and 0.2 per year, and often below 0.15 per year (Newman, 2002; Newman and Dunk, 2003; Grandcourt et al., 2006; Newman et al., 2016). Therefore, we applied a family-dependent multiplicative correction factor (CF) to the Gislason et al (2010) relationship, as follows:

$$M = \frac{CF \cdot 1.733 \cdot K.L_{\infty}^{1.44}}{L^{1.61}}$$

For estimation of CF for snappers and groupers (Table 2.1), we assumed that the values for M we derived applied to the length at L-opt, where the dependency between length and mortality happens to be less strong. Next, we adjusted the intercept of the Gislason et al (2010) empirical relationship to fit the value of M we established for each family at Lopt. Finally, we applied the adjusted Gislason et (2010) empirical relationship to calculate the average M over the size range we used to calculate Z. We used that average M for this length range.

Table 2.1: Life-history parameter values and invariants, and a correction factor (CF), to adjust length-dependent M (Gislason et al 2010) to estimated M at Lopt for snappers and groupers caught in Indonesian deep demersal fisheries.

	Dispersion	Mortality		Growth	Life History Invariant Values			
	Linf/Lmax	M(Lopt)	CF	K	(M/K)opt	Lopt/Linf	Lmat/Lopt	Lmat/Linf
Snapper	0.90	0.18	0.67	0.23	0.79	0.79	0.75	0.59
Grouper	0.90	0.12	0.71	0.16	0.75	0.80	0.58	0.46

NB: Values of M(Lopt) and CF are valid for the main (medium sized to large) target species in the fisheries. These values will differ slightly from values predicted for other (e.g. smaller) species by the adjusted Gislason et al. (2010) formula. The discrepancy is small as M(Lopt) is not very sensitive to Linf and Lopt is not very sensitive to M or M/K. Resulting values for Lopt and SPR are not significantly affected. M/K values are within the range published for Type II Teleosts including tropical snappers (Prince et al., 2014) and aligned with published values for target species and families (Prince et al., 2019).

For length classes below and above the length range over which we established Z (i.e., lengths below modal length), we applied the adjusted Gislason et al (2010) empirical relationship. We found that the correction factors (CF) we applied kept our estimates for M still within the ballpark of the estimates provided by Gislason et al (2010). Gislason et al (2010) reports 95% confidence intervals for the factor 1.733 are 0.98 - 3.1 (see Gislason et al (2010), Table 1, Model 2), which amounts to a factor 0.56 downwards or upwards. Resulting estimates for M in our deep-water snappers and groupers are therefore within the 95% confidence limits presented by Gislason et al (2010).

We estimated M at Lopt for medium to large-sized species within families, as these are the main target species in the fisheries. This begs the question whether application of the adjusted Gislason et al (2010) formula will result in a value that is different from the M that we established for the family, which includes small as well as large species. We noted, however, that M at Lopt is not very sensitive to Linf, so for smaller species the M at Lopt differs only slightly from the value we estimated for the family. Furthermore, smaller species are not common among the main families in the catch. One exception is *Epinephelus areolatus*, a small-sized grouper species, which is very common in most WPPs. Finally, the insensitivity of L-opt in respect to M implies that the small variation in M within a family caused by the application of the modified Gislason et al (2010) formula does not invalidate our estimations of Lopt.

We applied a standard, age-based population dynamics model based on the parameters presented above to calculate the adult biomass starting from an arbitrary number of recruits. We then estimated Spawning Potential Ratio as the ratio between the modelled population biomass at estimated F and the modelled adult population biomass at F=0.

2.6 Length-Based Stock Assessments

Studies show that some stocks (depending on the species of fish) can maintain themselves if the spawning stock biomass per recruit can be kept at 20 to 35% (or more) of what it was in the unfished stock. Lower values of SPR may lead to severe stock declines (Wallace and Fletcher, 2001). Froese et al. (2016) considered a total population biomass B of half the pristine population biomass Bo to be the lower limit reference point for stock size, minimizing the impact of fishing. Using SPR and B/Bo estimates from our own data set, this Froese et al. (2016) lower limit reference point correlates with an SPR of about 40%, not far from but slightly more conservative than the Wallace and Fletcher (2001) reference point. We chose an SPR of 40% as our reference point for low risk and after similar comparisons we consider and SPR between 25% and 40% to represent a medium risk situation. We consider risks levels to be high at SPR values below 25%.

With 0% immature fish in the catch as an ideal target (Froese, 2004), a target of 10% or less is considered a reasonable indicator for sustainable harvesting (Fujita et al., 2012; Vasilakopoulos et al., 2011). Zhang et al. (2009) consider 20% immature fish in the catch as an indicator for a fishery at risk, in their approach to an ecosystem-based fisheries assessment. Results from meta-analysis over multiple fisheries showed stock status over a range of stocks to fall below precautionary limits at 30% or more immature fish in the catch (Vasilakopoulos et al., 2011). The fishery is considered at very great risk when more than 50% of the fish in the catch are immature and effort is high (Froese et al, 2016). We consider risk levels to be low at levels of 10% or less immatures in the catch, medium between 10% and 30% and to be high at levels above 30% immatures.

We also use the current exploitation level expressed as the percentage of fish in the catch below the optimum harvest size as an indicator for fisheries status. This is the reciprocal value of the percentage of large mature fish, above the optimum harvest size. We consider a proportion of 65% of the fish in the catch below the optimum harvest size as an indicator for growth overfishing. We also consider a majority in the catch around or above the optimum harvest size as an indicator for minimizing the impact of fishing (Froese et al., 2016). This indicator is achieved when less than 50% of the fish are below the optimum harvest size. We consider risk levels to be low at exploitation levels below 50%, medium between 50% and 65% and high at levels of 65% or more.

“Mega spawners” are fish larger than 1.1 times the optimum harvest size (Froese, 2004), and a proportion of 30% or more “mega spawners” in the total catch is considered to be a sign of a healthy population (when other fisheries do not catch much smaller fish), whereas lower proportions are increasingly leading to concerns, with proportions below 20% indicating a great risk to the fishery. The size structure in the total catch is assumed to represent the size structure in the population here, with a fishery characterized by a very broad selection range. Risk levels related to recruitment overfishing are thus considered to be low when 30% or more of the catch consists of “mega spawners”. Medium risk exists when “mega spawners” represent between 20% and 30% of the catch, and risks are high when the proportion of “mega spawners” drops below 20%.

Since the Indonesian deep demersal fisheries for snappers and groupers does not target any single species specifically, considering the entirety of the multiple exploited stocks comprising the fisheries complex, in a single framework, would best facilitate a holistic evaluation of the status and trends in the combined fisheries, and would provide the most solid basis for fisheries management decision making. Simultaneous length based evaluation for the 16 most important species of snappers and groupers, representing the main targets in the overall spectrum of exploited species in the deep demersal fisheries, is considered a powerful approach to such holistic evaluation (Ault et al., 2022). Given that managers struggle to predict or evaluate even one metric with certainty, we compared several key population metrics relative to currently used sustainability reference points, across the range of the main target species. To further zoom in on the most relevant fisheries in Indonesia, as a third dimension in our holistic approach, we evaluated the 16 target species with a range of length based sustainability indicators, within the 2 most important FMAs (in terms of catch volume) for each of the target species.

3 Results

3.1 Fishing Grounds and Fleet Composition by Boat Size and Gear Type

Fishing grounds exploited by the deep demersal fisheries for snappers and groupers in Indonesia stretch from North Sumatra in the West to Papua in the East (Figure 3.1), and are administratively divided into 11 FMAs. Frame surveys covered all coastlines in the country and thus identified all relevant segments in the fleet. Results were combined into a central database that includes information for each fishing vessel on boat size, gear type, port of registration, licenses for specific FMAs, main fishing grounds, captain contacts and other details. Origins of boats are not always near the location of their fishing grounds. Database queries produce reports on the fleet composition by FMA, based on the main FMA where vessels actually operated. This fleet information by fishing ground was then used in stock assessments by FMA. Information on the main fishing grounds for individual vessels is updated when vessels move to other fishing grounds. To improve the accuracy of effort calculations, we differentiated between dedicated and seasonally engaged fishing boats (Table 3.1), each characterized by a different average number of active fishing days per year.

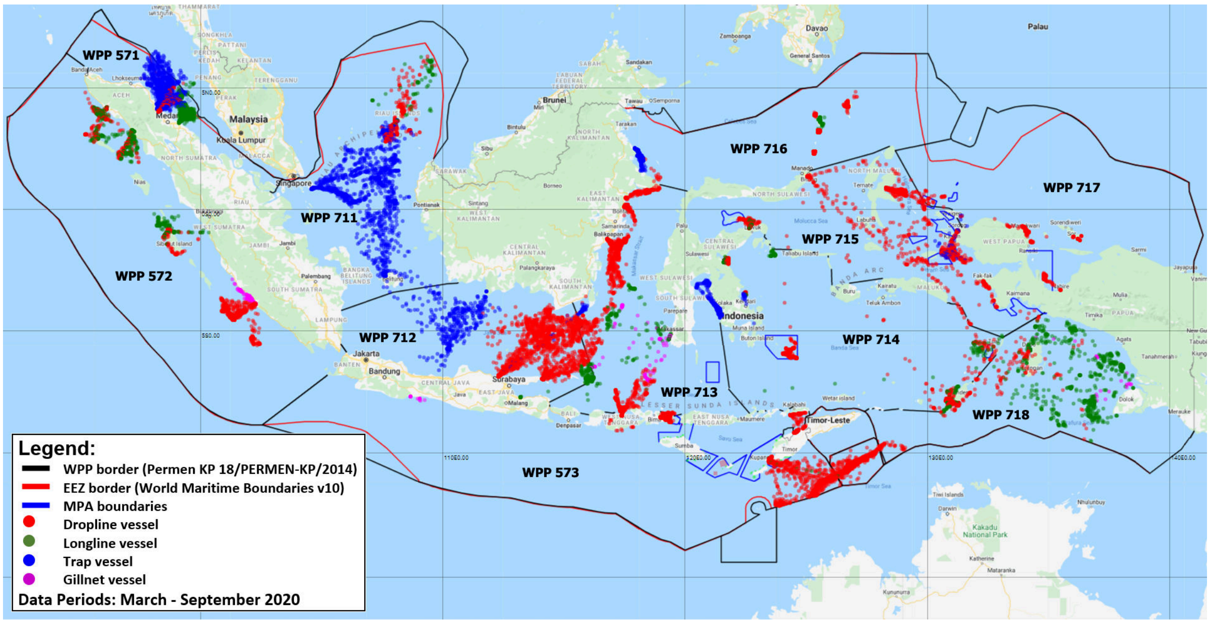


Figure 3.1: Map of 11 Fishery Management Areas (FMA) within Indonesian waters. Black lines denote FMA boundaries and coloured dots indicate vessel positions for various segments of the fleet.

Fishing boat sizes ranged from “nano” sized canoes of less than 1 GT, up to the larger vessels measuring close to 100 GT. Following practices by fisheries managers in Indonesia we distinguish 4 boat size categories including “nano” (<5 GT), “small” (5-< 10 GT), “medium” (10-30 GT), and “large” (>30 GT). The most common gear types in the deep demersal fisheries for snappers and groupers in Indonesia are drop lines and bottom longlines, while a smaller number of boats use traps or gillnets - set either deep or vertical along outer reef walls. The deep demersal fishing fleet in Indonesia included just over 11,500 fishing boats in 2020, representing a total of close to 63,000 Hull Gross Tons (GT-hull) in vessel volume. With nano and small sized boats representing almost 90% of the fleet in terms of numbers of vessels, these are mostly small-scale fisheries, even though medium to large sized vessels made up for almost 60% of the total hull volume. Relatively large numbers of nano and small-sized boats were engaged in the drop line fisheries, while medium to large size boats were more dominant, especially in terms of total hull volume, in the fisheries with longlines, gillnets and traps. Overall, the fisheries are definitely "small scale", by global standards, with even the large vessels in the fleet measuring mostly under 100 GT hull volume.

Table 3.1: Total Number (N) and hull volume in Gross Tons (GT) of fishing boats, by gear type, in the deep demersal fishing fleet targeting snappers and groupers in Indonesia in 2020. With total catch by boat size for 2020.

Boat		Dropline		Longline		Gillnet		Trap		Total Fleet				Total Catch	
Size	Activity	N	GT	N	GT	N	GT	N	GT	N	%N	GT	%GT	MT	%
Nano	Dedicated	3610	4737	695	1048	4	4	227	722	4536	39	6510	10	24785	21
Nano	Seasonal	3085	5249	525	957	2	9	19	24	3631	31	6239	10	11386	10
Small	Dedicated	504	3412	118	799	6	48	653	4198	1281	11	8457	13	30276	26
Small	Seasonal	757	4672	30	222	7	45	0	0	794	7	4940	8	8865	7
Medium	Dedicated	267	4007	145	3003	39	946	324	5821	775	7	13776	22	18382	15
Medium	Seasonal	140	2408	80	1026	12	185	0	0	232	2	3619	6	2443	2
Large	Dedicated	5	195	189	11916	91	6961	1	31	286	2	19103	30	22511	19
Large	Seasonal	1	35	0	0	0	0	0	0	1	0	35	0	20	0
Total		8369	24715	1782	18970	161	8198	1224	10795	11536	100	62678	100	118670	100

Nano less than 5 GT. **Small** 5 - <10 GT. **Medium** 10 - 30 GT. **Large** >30 GT.

3.2 Total Catch by FMA, Target Species, and Type of Gear

The total volume of the Top 100 species in the catch in 2020 was close to 119,000 Metric Tons (MT) annually, and no less than 64% of this total catch was produced by vessels smaller than 10 GT (Table 3.1). The Top 25 species accounted for almost 100,000 MT or 84% of the total catch volume (Table 3.2) produced in 2020. These Top 25 species included 16 species of snappers (13) and groupers (3), the major target species in the deep demersal fisheries, as well as 3 trevallies and jacks, 3 emperors, 2 grunts and 1 croaker. The largest catches overall in 2020 (more than 10,000 MT per FMA) were produced in FMA 573, 711, 712, 715 and 718, with estimated volumes of 15,247 MT, 18,167 MT, 20,027 MT, 11,611 MT and 21,585 MT respectively for the combined Top 100 species in these FMAs. In the other FMAs catches ranged between 2,000 and 10,000 MT per year for the combined Top 100 species.

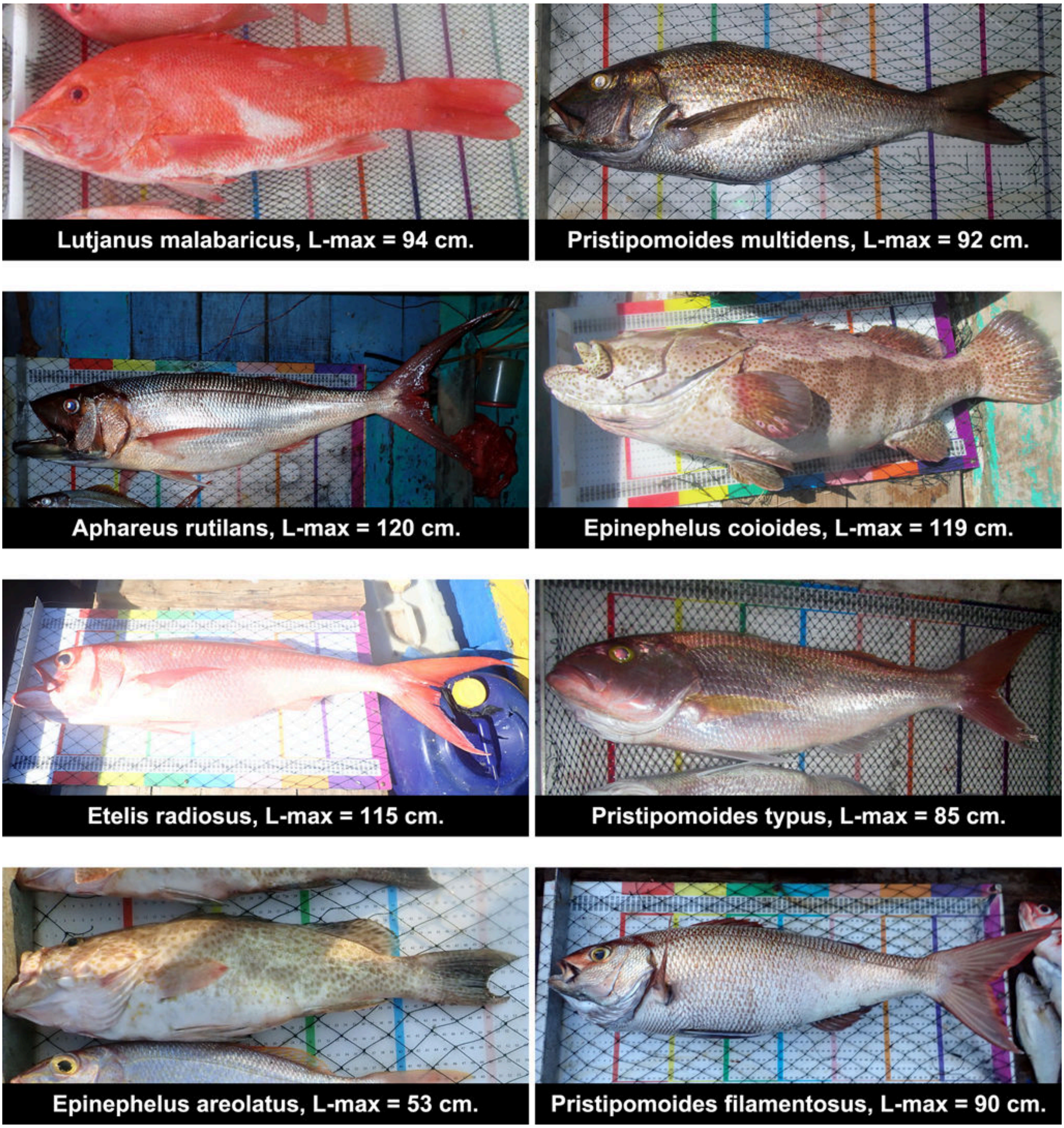
There are major differences between FMAs in terms of catch and species composition, but the most important species by volume overall was the Malabar Snapper (*Lutjanus malabaricus*), yielding an estimated 22,830 MT or 19% of the total catch in 2020. Three more snapper species of the genus *Lutjanus*, the Crimson Snapper (*Lutjanus erythropterus*) the Red Emperor (*Lutjanus sebae*), and the Golden Snapper (*Lutjanus johnii*) make the Top 25 with 2,160 MT of Crimson Snapper, 1,680 MT of Red Emperor and 1,423 MT of Golden Snapper in 2020. The above four species of Lutjanids, which are all red or reddish in color, and are therefore sometimes traded as "Red Snapper", together accounted for 28,093 MT or 24% of the total deep demersal catch (of Top 100 species) in 2020. The second most important species in terms of 2020 catch volume was the Goldband Snapper (*Pristipomoides multidens*), yielding 18,886 MT or 16% of the total catch. This species is commonly mixed in the trade with another Top 25 species, the Sharptooth Jobfish (*Pristipomoides typus*), which yielded 3,143 MT in 2020. Two more look-alike species, the Opakapaka (*Pristipomoides filamentosus*), and the Kale Kale (*Pristipomoides sieboldii*) are usually traded separately and were also in the Top 25 with around 2,600 MT each landed in 2020. These 4 closely resembling species of the genus *Pristipomoides*, all reddish in color including one with gold-colored bands, totaled 27,197 MT or 23%

of the deep demersal catch in 2020. A third important group of red colored snappers (*Lutjanidae*) includes the Rusty Jobfish (Aphareus rutilans), the Ruby Snapper (Etelis boweni), the Pale Snapper (Etelis radiosus) and the Flame Snapper (Etelis coruscans). Together these four large and red colored snappers accounted for 16,861 Metric Tons or 14% of the catch of Top 100 species in 2020. One more, poorly know species of deep-water snapper, the silver-brown Saddle Back Snapper (*Paracaesio kusakarii*), made the Top 25 with 1,320 MT in 2020.

Table 3.2: Total Catch by Fisheries Management Area (FMA) in Metric Tons, for the Top 25 species (by 2020 catch volume) in the deep water demersal fisheries targeting snappers and groupers in Indonesia. With Total Catch by FMA for combined Top 100 species.

Species / FMA	571	572	573	711	712	713	714	715	716	717	718	Total
Lutjanus malabaricus	26	47	1780	5089	7857	966	97	283	19	64	6602	22830
Pristipomoides multidens	204	339	4108	2297	4434	494	213	737	85	686	5289	18886
Aphareus rutilans	0	829	730	0	16	2091	403	3929	208	865	1	9073
Epinephelus coioides	1195	64	91	2154	1427	210	78	33	31	56	254	5593
Etelis radiosus	0	482	392	0	0	58	54	513	1188	1036	0	3724
Pristipomoides typus	4	347	1333	244	624	117	51	170	0	99	154	3143
Atrobucca brevis	0	0	0	0	0	0	0	0	0	0	2961	2961
Epinephelus areolatus	100	80	366	1098	799	231	30	34	4	86	83	2910
Pristipomoides filamentosus	0	993	610	0	21	57	84	627	158	30	22	2602
Pristipomoides sieboldii	0	1478	884	1	0	32	7	60	96	8	0	2566
Diagramma pictum	14	24	152	1707	322	226	25	29	12	1	1	2514
Etelis boweni	0	190	182	3	0	147	380	787	43	578	2	2312
Caranx sexfasciatus	55	195	176	45	116	924	72	349	153	143	38	2266
Plectropomus maculatus	0	11	0	1478	656	39	18	23	2	1	32	2261
Lutjanus erythropterus	0	29	219	143	1091	101	6	410	3	4	154	2160
Etelis coruscans	0	119	329	0	0	39	129	560	121	455	0	1752
Lutjanus sebae	0	4	219	509	243	134	19	11	0	6	535	1680
Lethrinus olivaceus	0	312	121	398	81	126	240	77	67	110	27	1560
Lutjanus johnii	34	86	10	846	288	18	3	10	17	0	112	1423
Diagramma labiosum	0	0	13	0	0	0	0	0	0	0	1348	1362
Paracaesio kusakarii	0	0	197	0	0	35	88	643	31	326	0	1320
Seriola rivoliana	0	56	522	3	12	81	46	167	35	298	9	1229
Caranx ignobilis	20	342	201	28	81	78	94	52	169	4	152	1221
Gymnocranius grandoculis	0	50	101	84	348	139	57	47	130	87	126	1168
Lethrinus laticaudis	0	0	0	0	0	0	0	22	0	0	1050	1072
Total Top 25 Species	1652	6079	12734	16125	18416	6344	2195	9572	2572	4944	18954	99588
Total Top 100 Species	2075	7777	15247	18167	20027	8759	3375	11611	3407	6640	21585	118670

Additional major target species in the Top 25 of deep demersal catches include 3 species of Groupers, the large growing Orange Spotted Grouper or Estuary Cod (*Epinephelus coioides*) the smaller Areolate Grouper or Square Tail Rock Cod (*E. areolatus*), and the medium sized Bar-Cheeked Coral Trout (*Plectropomus maculatus*), together contributing 10,764 MT to the catch in these fisheries. Three species of Emperors, the Long Nose Emperor (Lethrinus olivaceus), the Blue-lined Emperor (*Gymnocranius grandoculis*), and the Grass Emperor (*Lethrinus laticaudis*), jointly contributed 3,800 MT to the catch. The Grass Emperor (*Lethrinus laticaudis*) was mainly important locally in the Arafura Sea fisheries, where the Orange Croaker (*Attrobuca brevis*) and a second croaker, the Black Jewfish (*Protonibea diacanthus*) were also abundant in local catches. Orange croakers, targeted mainly for their swimming bladders, contributed almost 3,000 MT to the total catch. Jacks, Trevallies, and Grunts added close to 8,600 MT of mostly lower value species to the catch of Top 25 species in 2020. With a total of 84,235 MT in 2020, the Top 16 snappers and groupers (Figures 3.2 and 3.3) were by far the most important in the catch, contributing 85% to the combined volume of the Top 25 species and 71% to the overall total Top 100.



Lutjanus malabaricus, L-max = 94 cm.

Pristipomoides multidens, L-max = 92 cm.

Aphareus rutilans, L-max = 120 cm.

Epinephelus coioides, L-max = 119 cm.

Etelis radiosus, L-max = 115 cm.

Pristipomoides typus, L-max = 85 cm.

Epinephelus areolatus, L-max = 53 cm.

Pristipomoides filamentosus, L-max = 90 cm.

Figure 3.2: Top 8 out of Top 16 species of snappers and groupers caught in 2020, with maximum lengths recorded for each species, in the Indonesian deep demersal fisheries.

Pristipomoides sieboldii, L-max = 57 cm.

Etelis boweni, L-max = 118 cm.

Plectropomus maculatus, L-max = 84 cm.

Lutjanus erythropterus, L-max = 70 cm.

Etelis coruscans, L-max = 120 cm.

Lutjanus sebae, L-max = 96 cm.

Lutjanus johnii, L-max = 90 cm.

Paracaesio kusakarii, L-max = 85 cm.

Figure 3.3: Bottom 8 out of Top 16 species of snappers and groupers caught in 2020, with maximum lengths recorded for each species, in the Indonesian deep demersal fisheries.

Table 3.3: Total catch volume in 2020 for the Top 100 species in the deep demersal fisheries targeting snappers and groupers in Indonesia, ranked by production for all 11 Fisheries Management Areas (FMA/WPP combined), and specified by major species category.

Rank	FMA	Catch Volume (MT) by Species Category							Total	
	WPP	Snappers	Groupers	Trevallies	Emperors	Grunts	Croakers	Others	MT	%
1	718	13175	892	958	1357	1682	3305	215	21585	18
2	712	15106	3366	400	587	322	35	210	20027	17
3	711	9897	5198	330	941	1707	0	93	18167	15
4	573	12289	865	1208	414	165	7	299	15247	13
5	715	9741	251	1107	270	30	1	212	11611	10
6	713	5506	776	1487	661	226	0	102	8759	7
7	572	5876	475	819	409	25	0	173	7777	7
8	717	4902	307	1037	283	1	0	108	6640	6
9	716	2389	92	409	296	13	0	208	3407	3
10	714	2176	306	346	416	26	0	106	3375	3
11	571	337	1469	81	22	131	0	36	2075	2
NA	Total	81395	13997	8183	5656	4327	3349	1762	118670	100
NA	%	69	12	7	5	4	3	1	100	NA

Table 3.4: Top 16 snapper and grouper species in the Indonesian deep demersal fisheries, ranked by catch volume in 2020, with production specified by gear type.

Rank	Species	Category	Dropline		Longline		Gillnet		Trap		Total		
			MT	%	MT	%	MT	%	MT	%	MT	%	Cumm%
1	Lutjanus malabaricus	Snapper	7171	6	5806	5	2691	2	7162	6	22830	19	19
2	Pristipomoides multidens	Snapper	8923	8	5208	4	3600	3	1155	1	18886	16	35
3	Aphareus rutilans	Snapper	7588	6	717	1	78	0	690	1	9073	8	43
4	Epinephelus coioides	Grouper	420	0	820	1	34	0	4320	4	5593	5	48
5	Etelis radiosus	Snapper	3426	3	194	0	22	0	82	0	3724	3	51
6	Pristipomoides typus	Snapper	2167	2	783	1	38	0	156	0	3143	3	53
7	Epinephelus areolatus	Grouper	1480	1	504	0	16	0	910	1	2910	2	56
8	Pristipomoides filamentosus	Snapper	2311	2	160	0	16	0	116	0	2602	2	58
9	Pristipomoides sieboldii	Snapper	2446	2	29	0	20	0	71	0	2566	2	60
10	Etelis boweni	Snapper	2082	2	106	0	14	0	109	0	2312	2	62
11	Plectropomus maculatus	Grouper	221	0	135	0	2	0	1903	2	2261	2	64
12	Lutjanus erythropterus	Snapper	1510	1	314	0	23	0	313	0	2160	2	66
13	Etelis coruscans	Snapper	1607	1	67	0	7	0	70	0	1752	1	67
14	Lutjanus sebae	Snapper	459	0	587	0	156	0	478	0	1680	1	69
15	Lutjanus johnii	Snapper	90	0	164	0	54	0	1116	1	1423	1	70
16	Paracaesio kusakarii	Snapper	1175	1	66	0	6	0	74	0	1320	1	71
NA	Total 16 Species		43075	36	15661	13	6776	6	18724	16	84235	71	71
NA	Total Top 100 Species		59275	50	26630	22	9669	8	23096	19	118670	100	100

With a total contribution of 81% to the catch volume of the Top 100 species in 2020, Snappers (*Lutjanidae*) and Groupers (*Epinephelidae*), are clearly the dominant species categories in these highly diverse fisheries (Table 3.3). The Snappers contributed by far the biggest volume with 69% of the total catch in 2020. Groupers were an economically important second group with 12% of the volume, and a relatively high market price compared to Trevallies, Emperors, Grunts and Croakers, which also contributed smaller amounts to the total catch. The Top 3 FMAs for Snapper production in 2020 were WPP 712, WPP 718, and WPP 573, whereas the Top 3 FMAs for Grouper production in 2020 were WPP 711, WPP 712, and WPP 571. This shows a concentration of Snapper production from the Java Sea to the East, whereas Grouper production is more concentrated from the Java Sea to the West. As Snappers and Groupers so clearly dominate these fisheries, we will focus stock assessments on the Top 16 species of Groupers and Snappers which together represent no less than 71% of the total catch across all gear types used in the fisheries (Table 3.4). Even just the Top 5 species of snappers and groupers already represent more than 50% of the total catch. Drop line and longline are the most productive gear types in the fisheries overall (Top 100 species), with 59,275 MT or 50% of the catch coming from drop line fisheries, and 26,630 MT or 22% coming from longlines. Traps and gillnets follow with contributions of 19% and 8% to the total catch respectively. Specific for the Top 16 species and snappers however, drop lines and traps are the most productive gear types, contributing 36% and 16% to the total catch respectively.

3.3 Species Groups, Commercial Products and Global End Value

The Red Snapper species *Lutjanus malabaricus*, *L. sebae*, *L. timorensis*, *L. erythropterus* and *L. lemniscatus* are often grouped in the trade under Malabar or Red Snapper, with *L. sebae* also going as Red Emperor and *L. erythropterus* as Crimson Snapper. These species are often traded as frozen skin-on fillets with the USA as one of the main destinations. *Pinjalo lewisi* is often mixed in as well with the above species, while *P. pinjalo* is more often sold locally. High quality fresh Red Snappers are also sold fresh to various Asian markets. Additional Lutjanus species like *Lutjanus bitaeniatus*, *L. argentimaculatus*, *L. bohar*, *L. johnii*, *L. ruselli*, *L. lemniscatus*, *L. rivulatus*, *Lipocheilus carnolabrum* and *Symphorus nematophorus* are also often grouped and traded as Red Snapper or *Lutjanus sp.*, at somewhat lower prices, and mainly sold as frozen skinless fillets to EU countries and Mauritius. *Lutjanus vitta* and *L. boutton* are sold mainly as “Surimi” or fish paste products, with export destinations Japan and other Asian countries. The Paracaesio species including *Paracaesio gonzalesi*, *Paracaesio xanthura*, *Paracaesio kusakarii* and *Paracaesio stonei* are mostly sold as frozen White Snapper skinless fillets.

The ruby colored and closely resembling species *Etelis boweni*, *E. radiosus* and *E. carbunculus*, are usually combined in a single group and traded as Ruby Sapper or Ehu. The valuable *E. coruscans* is sold separately as Flame snapper or Onaga. *Pristipomoides multidens* and *P. typus* are usually traded together as Gold Band Snapper but *P. multidens* is also sold separately in the Asian market. *P. filamentosus* is sold separately as Crimson Jobfish or Opakapaka, but also sometimes sold together with *P. typus* as Opakapaka. *P. sieboldii* (Kalekale), *P. argyrogrammicus*, and *P. flavipinnis* are mostly sold in the local market, with *P. sieboldii* also being exported in small quantities. *P. zonatus* is sold in the local market as “Kakap Bendera”, but also exported in small quantities to Hawaii as “Gindai”. *Aprion virescens* or “Uku” is a high quality species but not much is exported. *Aphareus rutilans* has a darker (browner) meat, and therefore its value is not that high.

Almost all grouper species from the deep demersal fisheries in Indonesia are destined for export to China and Taiwan as frozen whole fish, to Singapore, Hong Kong, other Asian & Middle Eastern countries as fresh whole fish and to the USA as frozen fillets. Red or golden or otherwise bright colored species are often the most valuable on the Asian markets and species like *Saloptia powelli*, *Cephalopholis miniata*, *Cephalopholis sexmaculata*, *Cephalopholis sonnerati*, *Cephalopholis igarashiensis*, *Epinephelus retouti*, *Epinephelus stictus*, *Plectropomus maculatus*, *Plectropomus leopardus*, and *Variola albimarginata* are sold mainly in fresh whole form in these countries. Other grouper species with brownish or dark skin color are mainly exported as frozen skinless fillets.

A global end value of close to US$ 1.3 billion was estimated for the trade in 100 target species in the Indonesian deep demersal fisheries for 2020, based on catch volumes by species, percentages local retail and export, and local as well as international retail (consumer) prices (Table 3.5). The combined catch of the Top 16 species of snappers and groupers made up a very significant percentage of the total value of the trade, with an estimated end value of well over US$ 1 billion for 2020. The relatively high value of the snappers and groupers in the trade, compared to other species, shows from the fact that 71% of the catch volume represents 84% of the end value of the trade. Interestingly, mark up between local retail value and international retail value can be quite different between the various species.

Table 3.5: Catch volumes, export percentages, retail prices and global end value of the trade in the Top 16 snappers and groupers from the Indonesian deep demersal fisheries, compared to end value of the total trade in all Top 100 species combined.

Species Name	Weight (1000kg)	Local %	Export %	Retail Local (US$/kg)	Retail Intl. (US$/kg)	End Value (1000US$)	Value %	Cumm. %
Lutjanus malabaricus	22830	30	70	7.43	18.77	350854	27.3	27.3
Pristipomoides multidens	18886	30	70	4.20	15.74	231885	18.0	45.3
Aphareus rutilans	9073	80	20	2.21	6.47	27782	2.2	47.5
Epinephelus coioides	5593	30	70	8.62	13.02	65437	5.1	52.6
Etelis radiosus	3724	50	50	3.32	23.13	49244	3.8	56.4
Pristipomoides typus	3143	30	70	2.24	11.77	28011	2.2	58.6
Epinephelus areolatus	2910	30	70	4.37	18.29	41078	3.2	61.8
Pristipomoides filamentosus	2602	50	50	2.47	29.49	41580	3.2	65.0
Pristipomoides sieboldii	2566	80	20	2.32	8.87	9314	0.7	65.8
Etelis boweni	2312	50	50	3.32	23.13	30570	2.4	68.1
Plectropomus maculatus	2261	30	70	6.47	38.93	66012	5.1	73.3
Lutjanus erythropterus	2160	30	70	5.78	20.19	34268	2.7	75.9
Etelis coruscans	1752	50	50	6.63	35.17	36609	2.8	78.8
Lutjanus sebae	1680	30	70	6.48	20.05	26841	2.1	80.9
Lutjanus johnii	1423	30	70	7.74	10.96	14226	1.1	82.0
Paracaesio kusakarii	1320	40	60	2.65	11.21	10279	0.8	82.8
Total 16 Species	84235					1063991		
Total Top 100 Species	118670					1285286		

3.4 Life History Parameter Values

The deep-slope demersal fisheries for snappers and groupers exploit more than 100 species of fish, but the Top 16 species of snappers and groupers together form the main target group, representing more than 70% of the total catch. This representative group was selected for a holistic length-based assessment of the fisheries, and samples ranging from 33,000 to 800,000 CODRS images of individual fish were obtained for each of the 16 target species. This resulted in a total of well over 3 million images for the main target group by late 2020 (Table 3.6), while an additional 2 million images were also collected for the other species in the Top 100. Species identification and measurement was highly accurate and precise based on the CODRS images with individual fish displayed on measuring boards. Life history parameter values could therewith be updated reliably, for the purpose of length-based assessments, based on the maximum observed length in the catch for each of the target species.

As the starting point for our length-based approach, we estimated the maximum attainable total length (Lmax) for each species as equal to the size of the largest recorded specimen in the local population (Nadon and Ault, 2016). The size of the largest specimen of each species recorded in the catch could be assumed to represent the largest size present in the population, as CODRS images included some of the largest specimen on record for most of the species in the target group (Table 3.6). For several species, CODRS images even proved values for maximum attainable lengths to be larger than previously reported. Photographs of specimen at Lmax form verifiable evidence of the lengths that these species can attain. By treating Lmax and Linf as biological parameters instead of curve fitting parameters we could estimate Linf directly from Lmax (Nadon and Ault, 2016). This method was supported by robust length-frequency distributions of each species, which demonstrated that specimen at Lmax were not anomalous fish in the populations of any of the target species. Estimates of Linf, based on recorded values of Lmax, were subsequently used to obtain estimates for Lmat and Lopt (Table 3.6), using known life history invariants from the literature. Weight at maturity is used by some traders as a limit in their purchasing strategy.

Table 3.6: Sample sizes (2016-2020) and life history parameter values for the 16 most important species of snappers and groupers, by 2020 catch volume, as included in the size-based assessment of the Indonesian deep demersal fisheries. Lengths in cm Total Length (TL) and weights in grams.

Rank	Species	Category	N	CummN	Lmax	Linf	Lopt	Lmat	Wmax	Wmat
1	Lutjanus malabaricus	Snapper	710729	710729	94	85	67	50	13202	1822
2	Pristipomoides multidens	Snapper	507285	1218014	92	83	66	49	8664	1356
3	Aphareus rutilans	Snapper	97808	1315822	120	108	85	64	13693	2129
4	Epinephelus coioides	Grouper	69801	1385623	119	107	86	49	26435	1713
5	Etelis radiosus	Snapper	38888	1424511	115	104	82	61	13967	2539
6	Pristipomoides typus	Snapper	238841	1663352	85	76	60	45	6047	946
7	Epinephelus areolatus	Grouper	321571	1984923	53	48	38	22	1931	132
8	Pristipomoides filamentosus	Snapper	109190	2094113	90	81	64	48	8078	1393
9	Pristipomoides sieboldii	Snapper	108896	2203009	57	51	40	30	2144	324
10	Etelis boweni	Snapper	55033	2258042	118	106	84	63	21722	3411
11	Plectropomus maculatus	Grouper	28431	2286473	84	76	61	35	9246	669
12	Lutjanus erythropterus	Snapper	157326	2443799	70	63	50	37	4817	773
13	Etelis coruscans	Snapper	43796	2487595	120	108	85	64	12049	2128
14	Lutjanus sebae	Snapper	75175	2562770	96	86	68	51	18291	2404
15	Lutjanus johnii	Snapper	28014	2590784	90	81	64	48	8486	1365
16	Paracaesio kusakarii	Snapper	42496	2633280	85	76	60	45	8220	1119

For some species and studies, the discrepancies in parameter values between our findings and previously reported values are large, whereas others were not. Lower values for both Lmax and Linf have been reported in various studies for a number of important species in the deep demersal fisheries, usually based on ageing and growth studies that (a) used much smaller samples than we had access to from the CODRS database, and (b) were lacking the largest fish from the population, therewith possibly underestimating Lmax and Linf, as we conclude from observed size frequencies in the catch. Analysis of previous research on the life-history parameters of the deep demersal species also requires careful consideration of potential mis-identifications, or even different definitions of similar parameters. For example, some studies reported Lmat as the length at first maturity, whereas other studies reported Lmat as the length at which 50% of the population is mature.

We also found a disparity between available information in the literature and abundance of the species in the catch. Hardly any studies are available for example on *Pristipomoides typus*, the fifth most important snapper species in Indonesian deep demersal catches in 2020. This species is similar to, and often mixed by traders with, *Pristipomoides multidens*, which grows to a larger maximum size than *P. typus* and thus has other values for life history parameters as well. These two species may also experience different vulnerability to the gear, show different catch size frequency distributions and therefore need to be separately assessed. Also, for the second most important grouper species, *Epinephelus areolatus*, very few studies are available on life history parameters or other biological characteristics. These disparities highlight a data gap in the literature that would have hampered our ability to assess these important deep demersal fisheries without the new information obtained from the CODRS approach, in combination with the use of life history invariants for parameter value estimation.

3.5 Length-Based Stock Assessment for Snappers and Groupers

Length based stock assessments by FMA show dangerously low SPR values and thus high risk of overfishing in most FMAs and for most target species in the deep demersal fisheries in Indonesia (Table 3.7). For some species there are significant differences in SPR values between FMA, but in the main and secondary FMAs (FMA1 and FMA2) for each species, where the largest catches were produced for these species in 2020, the SPR is below our limit reference point of 25% for all the Top 16 species, except for one grouper (*Plectropomus maculatus*). Zooming in on those main and secondary FMAs in terms of 2020 catch volume for each of the 16 species separately, provides us with a representative sample of 32 cases (species * FMA) for a holistic assessment of the fisheries, across Indonesia. The catch volume for the Top 16 species of groupers and snappers across their main FMAs, in terms of 2020 production, already represents 26% of the total catch of the Top 100 species for all of Indonesia (Table 3.8). With another 18% from secondary FMAs for each species, the 32 cases used in our assessment together represent 45% or almost half of the catch in the Indonesian deep-water fisheries for snappers and groupers in 2020. FMAs 712 and 718 stand out as either main on secondary FMA for the 2 most important species of snappers (*L. malabaricus* and *P. multidens*), whereas FMAs 711 and 712 respectively were the main and secondary FMAs in 2020 for all 3 grouper species out of our Top 16 list.

Table 3.7: Spawning Potential Ratio (SPR) by FMA for the Top 16 species of snappers and groupers in the catch (by 2020 volume) in the Indonesian deep water demersal fisheries.

Rank	Species	Category	SPR by FMA										
			571	572	573	711	712	713	714	715	716	717	718
1	Lutjanus malabaricus	Snapper	6	0	6	3	5	11	13	3	0	NA	7
2	Pristipomoides multidens	Snapper	18	6	11	7	19	30	16	11	NA	8	11
3	Aphareus rutilans	Snapper	NA	7	26	NA	NA	10	8	4	7	8	NA
4	Epinephelus coioides	Grouper	5	5	NA	10	8	7	17	NA	2	NA	12
5	Etelis radiosus	Snapper	NA	2	8	NA	NA	11	3	8	18	5	NA
6	Pristipomoides typus	Snapper	41	7	9	4	11	11	8	11	NA	8	15
7	Epinephelus areolatus	Grouper	15	16	16	10	14	7	12	11	NA	6	16
8	Pristipomoides filamentosus	Snapper	NA	0	4	NA	NA	0	9	8	1	0	42
9	Pristipomoides sieboldii	Snapper	NA	14	17	NA	NA	8	22	8	3	NA	NA
10	Etelis boweni	Snapper	NA	4	7	NA	NA	14	7	5	NA	4	NA
11	Plectropomus maculatus	Grouper	NA	NA	NA	31	78	12	23	NA	18	NA	100
12	Lutjanus erythropterus	Snapper	NA	18	64	2	8	8	NA	23	6	NA	100
13	Etelis coruscans	Snapper	NA	3	2	NA	NA	1	7	3	4	4	NA
14	Lutjanus sebae	Snapper	NA	NA	5	0	1	2	NA	NA	NA	NA	4
15	Lutjanus johnii	Snapper	8	30	NA	12	4	40	NA	NA	1	NA	21
16	Paracaesio kusakarii	Snapper	NA	NA	39	NA	NA	17	7	7	0	1	NA

Traps were the most productive gear type for our 3 major grouper species in 2020, in all cases except for *E. areolatus* in FMA 712. Dropline was the most productive gear type in the snapper fisheries in most of the main and secondary FMAs. Longline dominated *L. malabaricus* and *L. sebae* catches in FMA 718, and *P. typus* catches in FMA 712. Trap catches dominated for *L. johnii* in FMA 711 and 712, and for *L. sebae* in FMA 711. Gillnet was only recorded as the main gear type in a single case, for *P. multidens* in FMA 718. The average recorded CpUE of *P. multidens* from a limited number of gillnet landings was indeed high in WPP 718 in 2020, but it is not clear if this was representative of performance in this segment of the fleet. This fleet of gillnet boats was substantial, but due to circumstances in the field only few were contracted in the CODRS program for 2020, resulting in a limited sample size of gillnet CpUE observations. Therefore, potential bias may have affected our estimate of the contribution of gillnets to the catch of *P. multidens* in WPP 718, and this may also have affected the estimate of total catch.

Table 3.8: Total catch volume in Metric Tons (MT) for Top 16 snapper and grouper species in the Indonesian deep demersal fisheries in 2020, for main and secondary FMA by species, with main gear types by FMA for each species, and percentage of total catch Top 100 species.

Species	Category	FMA1				FMA2				FMA1+2	
		WPP	Main Gear	MT	%	WPP	Main Gear	MT	%	MT	%
Lutjanus malabaricus	Snapper	712	Dropline	7857	7	718	Longline	6602	6	14459	12
Pristipomoides multidens	Snapper	718	Gillnet*	5289	4	712	Dropline	4434	4	9723	8
Aphareus rutilans	Snapper	715	Dropline	3929	3	713	Dropline	2091	2	6020	5
Epinephelus coioides	Grouper	711	Trap	2154	2	712	Trap	1427	1	3582	3
Etelis radiosus	Snapper	716	Dropline	1188	1	717	Dropline	1036	1	2224	2
Pristipomoides typus	Snapper	573	Dropline	1333	1	712	Longline	624	1	1958	2
Epinephelus areolatus	Grouper	711	Trap	1098	1	712	Dropline	799	1	1897	2
Pristipomoides filamentosus	Snapper	572	Dropline	993	1	715	Dropline	627	1	1619	1
Pristipomoides sieboldii	Snapper	572	Dropline	1478	1	573	Dropline	884	1	2362	2
Etelis boweni	Snapper	715	Dropline	787	1	717	Dropline	578	0	1365	1
Plectropomus maculatus	Grouper	711	Trap	1478	1	712	Trap	656	1	2134	2
Lutjanus erythropterus	Snapper	712	Dropline	1091	1	715	Dropline	410	0	1501	1
Etelis coruscans	Snapper	715	Dropline	560	0	717	Dropline	455	0	1014	1
Lutjanus sebae	Snapper	718	Longline	535	0	711	Trap	509	0	1044	1
Lutjanus johnii	Snapper	711	Trap	846	1	712	Trap	288	0	1133	1
Paracaesio kusakarii	Snapper	715	Dropline	643	1	717	Dropline	326	0	969	1
Total 16 Species				31257	26			21747	18	53004	45
Total Top 100 Species				48543	41			27331	23	72913	61

* Recorded average CpUE of *P. multidens* from a limited number of gillnet catch observations was high in WPP 718 in 2020, but it is unclear if this was representative of performance in the fleet segment that year. The fleet of gillnet boats was substantial, but due to field circumstances only few were contracted in the CODRS program here in 2020, resulting in a limited sample size of gillnet CpUE observations. Therefore potential bias may have affected our estimate of the relative contribution of gillnets to the catch of *P. multidens* in WPP 718.

The status of stocks of the Top 16 snappers and groupers in the Indonesian deep demersal fisheries was analyzed in the main and secondary FMA for each of these species, in a holistic assessment. Each of these 32 cases was assessed across four length-based indicators, providing a 3-dimensional view of the status of the fisheries, with 128 combinations of species, FMA, and indicator, and representing almost half of the total catch in 2020. In total 116 out of 128 combinations (>90%) showed a high risk of overfishing (Table 3.9), clearly indicating an overall unsustainable situation at present. As an individual indicator, the percentage of immature fish in the catch showed the lowest percentage of high-risk cases (species * FMA), with 22 out of 32 (close to 70%) at high risk. Only the two smallest species out of 16, the smallest grouper, *E. areolatus*, and the smallest snapper, *P. sieboldii*, showed a consistent low risk of overfishing from targeting of juveniles. The two other groupers showed medium risk in their main FMAs, and either medium or low risk in their secondary FMAs. Two important snappers, *L. malabaricus* and *L. erythropterus*, showed high risk from targeting juveniles in their main FMAs and medium risk for this indicator in their secondary FMAs. Only *P. maculatus* showed low to medium risk for SPR, while all other species showed high risk for overfishing in both FMAs under this indicator. The remaining two indicators, exploitation level and percentage mega spawners, showed high risk of overfishing for all 16 target species in both main and secondary FMAs.

Table 3.9: Risk levels in the Indonesian deep demersal fisheries for snappers and groupers in 2020 based on estimated SPR and other length-based indicators, for the Top 16 target species, in the main FMA (FMA1) and secondary FMA (FMA2) for each species, ranked by volume in the catch.

Species	Immatures		Exploitation		Mega Spawners		SPR	
	FMA1	FMA2	FMA1	FMA2	FMA1	FMA2	FMA1	FMA2
Lutjanus malabaricus	**high**	**medium**	**high**	**high**	**high**	**high**	**high**	**high**
Pristipomoides multidens	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Aphareus rutilans	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Epinephelus coioides	**medium**	**medium**	**high**	**high**	**high**	**high**	**high**	**high**
Etelis radiosus	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Pristipomoides typus	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Epinephelus areolatus	**low**	**low**	**high**	**high**	**high**	**high**	**high**	**high**
Pristipomoides filamentosus	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Pristipomoides sieboldii	**low**	**low**	**high**	**high**	**high**	**high**	**high**	**high**
Etelis boweni	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Plectropomus maculatus	**medium**	**low**	**high**	**high**	**high**	**high**	**medium**	**low**
Lutjanus erythropterus	**high**	**medium**	**high**	**high**	**high**	**high**	**high**	**high**
Etelis coruscans	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Lutjanus sebae	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Lutjanus johnii	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**
Paracaesio kusakarii	**high**	**high**	**high**	**high**	**high**	**high**	**high**	**high**

Looking at trends in the various indicators across all cases, the picture is a bit more mixed and perhaps a little more encouraging for a few species in some of the FMAs (Table 3.10). An overall pattern of deterioration is unfortunately evident though, for many species in most FMAs in Indonesia. For a total of 76 out of 128 combinations of species, FMA and indicator, we had time series available of at least 3 years to enable reviewing trends in the indicators, representing a total of 19 cases (species * FMA). In total 53 of the available 76 time series (70%) showed a deteriorating situation, with the remaining 30% including mostly improving and a few stable situations. For the most important red snapper species in the catch, *L. malabaricus*, the current situation is not only unsustainable, but the stocks are also in continuous decline, as observed across all indicators in both the main and secondary FMA based on 2020 production.

Across the board deterioration of the fisheries situation is also observed from all indicators for *P. typus*, another important snapper. For two other large and important snappers, *P. multidens* and *A. rutilans*, the situation seems to be mostly deteriorating in their primary FMAs, while it is improving in their secondary FMAs, according to most indicators. The situation is either deteriorating or trends are unknown for the two larger groupers, *E. coioides* and *P. maculatus*, as well as for a number of other large snappers, including *P. filamentosus*, *E. boweni*, *E. coruscans* and *P. kusakarii*. For the smallest grouper, *E. areolatus*, as well as for the smallest snapper, *P. sieboldii*, the situation seems to be approving according to multiple indicators in at least their secondary FMAs, for which time series are available. Trends seem to show either a stable or improving situation for the Red Emperor, *L. sebae*, but for this species we need to keep in mind that the stocks were in a very seriously depleted situation already in 2020. For two more large snapper species, *E. radiosus* and *L. johnii*, time series were not available to evaluate trends in indicators.

Table 3.10: Trends in relative abundance by size group and Spawning Potential Ratio (SPR) in the Indonesian deep demersal fisheries for snappers and groupers between 2015 and 2020, in the 2 main FMAs for each of the Top 16 species, ranked by volume in the catch.

Species	% Matures		% Large Matures		% Mega Spawners		SPR	
	FMA1	FMA2	FMA1	FMA2	FMA1	FMA2	FMA1	FMA2
L. malabaricus	**declining**	**declining**	**declining**	**declining**	**declining**	**declining**	**declining**	**declining**
P. multidens	**declining**	**declining**	**declining**	**improving**	**declining**	**improving**	**improving**	**improving**
A. rutilans	**declining**	**improving**	**declining**	**improving**	**declining**	**improving**	**declining**	**improving**
E. coioides	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**
E. radiosus	**unknown**	**unknown**	**unknown**	**unknown**	**unknown**	**unknown**	**unknown**	**unknown**
P. typus	**declining**	**declining**	**declining**	**declining**	**declining**	**declining**	**declining**	**declining**
E. areolatus	**unknown**	**declining**	**unknown**	**improving**	**unknown**	**improving**	**unknown**	**improving**
P. filamentosus	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**
P. sieboldii	**unknown**	**declining**	**unknown**	**improving**	**unknown**	**improving**	**unknown**	**improving**
E. boweni	**improving**	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**	**unknown**
P. maculatus	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**
L. erythropterus	**improving**	**declining**	**improving**	**declining**	**improving**	**declining**	**improving**	**declining**
E. coruscans	**declining**	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**	**unknown**
L. sebae	**improving**	**unknown**	**improving**	**unknown**	**stable**	**unknown**	**stable**	**unknown**
L. johnii	**unknown**	**unknown**	**unknown**	**unknown**	**unknown**	**unknown**	**unknown**	**unknown**
P. kusakarii	**declining**	**unknown**	**declining**	**unknown**	**declining**	**unknown**	**declining**	**unknown**

NB: Trends are "unknown" when there are no time series available of at least 3 years or more.

Even though status indicators show similar conclusions, and time trends are pointing in the same direction across FMAs, also within species, the differences between FMAs can be substantial, when catch size frequency distributions and trend graphs are studied in detail. These differences in the details can be quite important when management interventions are prioritized and when recovery trajectories are projected. A good example, for the need to examine details, is the most important species in the catch, *L. malabaricus*, which shows high risk of overfishing across almost all indicators, as well as consistent trends of deterioration, both in its primary FMA (WPP 712) and in its secondary FMA (WPP 718). There is no difference between these two FMAs when it comes to the major conclusions related to the status and trends in the stocks of *L. malabaricus*. Length frequency distributions of the catch, however, do show significant differences between the two FMAs (Figures 3.4 to 3.7).

The median size in the catch (Lmed) of *L. malabaricus* in WPP 712 was 39cm TL in 2020, well below the size of maturity (50cm TL), while the median size in the catch of this species was 54cm TL in WPP 718, and thus just above the size of maturity in that FMA. There is a very large difference of 15 cm between median sizes in the catch in these two FMAs, while the percentage of immatures in the catch of *L. malabaricus* is also much higher in WPP 712 than in WPP 718. In fact, the percentage of immatures in WPP 718 only results in medium risk for that indicator, the only indicator which is not pointing at high risk in either of the two FMAs for this species. All this has obvious consequences for potential recovery trajectories. Numbers do drop rapidly above the median size in the catch of *L. malabaricus* in WPP 718, so there are clear signs of over-exploitation visible at the right side of the catch curve, but recovery time may be shorter there, compared to what can be expected in WPP 712, when fishing mortality could be reduced in both FMAs to allow more fish to grow a little larger.

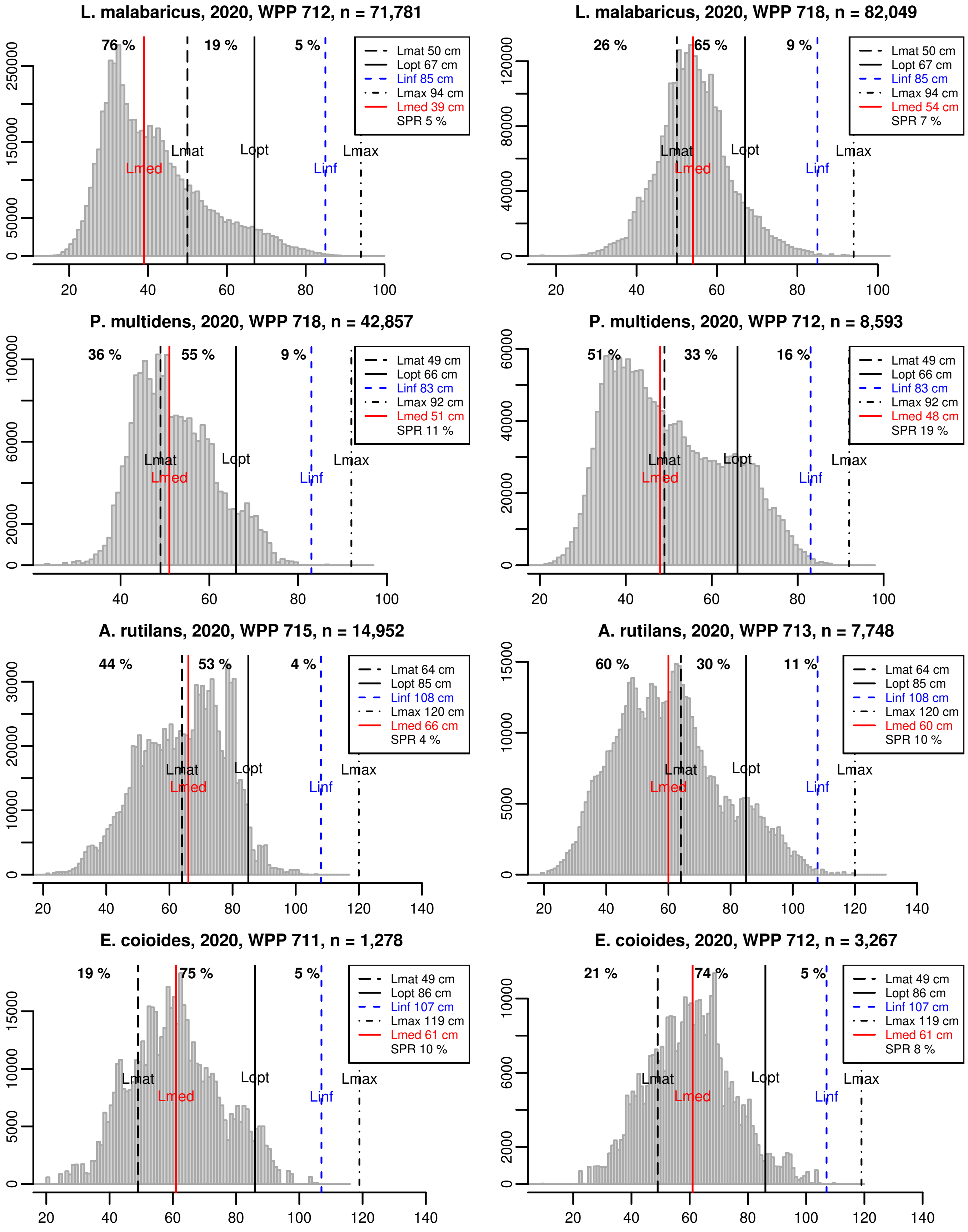


Figure 3.4: Reconstructed total catch size frequency distributions with median size in the catch (Lmed) for the Top 4 out of 16 species of snappers and groupers in the Indonesian deep demersal fisheries in their primary and secondary FMAs by 2020 production. With 2020 CODRS sample sizes (n) and percentages immatures (<Lmat), small matures (>=Lmat and <=Lopt) and large matures (>Lopt) indicated for each species in each FMA. Sizes in cm Total Length (TL).

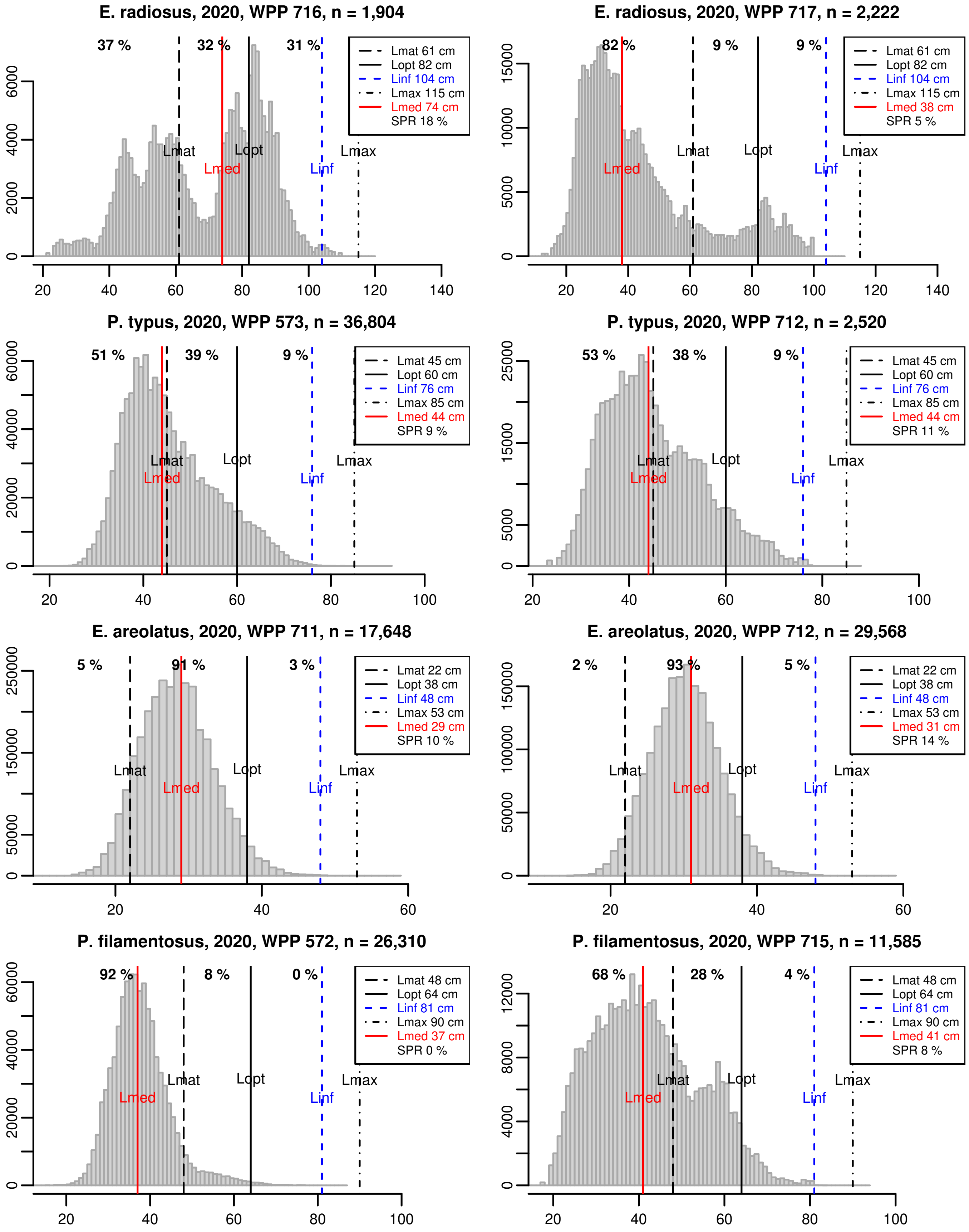


Figure 3.5: Reconstructed total catch size frequency distributions with median size in the catch (Lmed) for numbers 5 to 8 out of 16 species of snappers and groupers in the Indonesian deep demersal fisheries in their primary and secondary FMAs by 2020 production. With 2020 CODRS sample sizes (n) and percentages immatures (<Lmat), small matures (>=Lmat and <=Lopt) and large matures (>Lopt) indicated for each species in each FMA. Sizes in cm Total Length (TL).

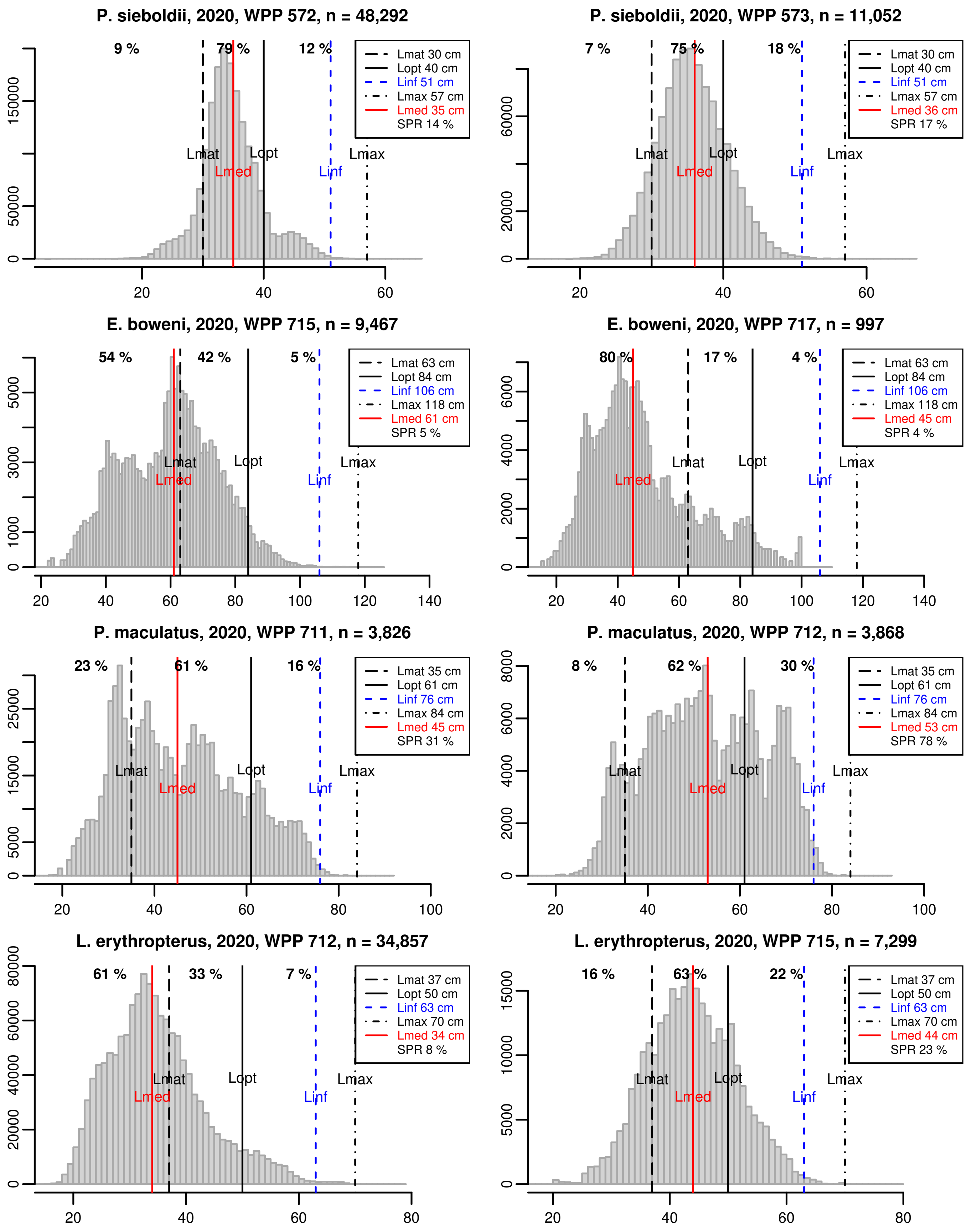


Figure 3.6: Reconstructed total catch size frequency distributions with median size in the catch (Lmed) for numbers 9 to 12 out of 16 species of snappers and groupers in the Indonesian deep demersal fisheries in their primary and secondary FMAs by 2020 production. With 2020 CODRS sample sizes (n) and percentages immatures (<Lmat), small matures (>=Lmat and <=Lopt) and large matures (>Lopt) indicated for each species in each FMA. Sizes in cm Total Length (TL).

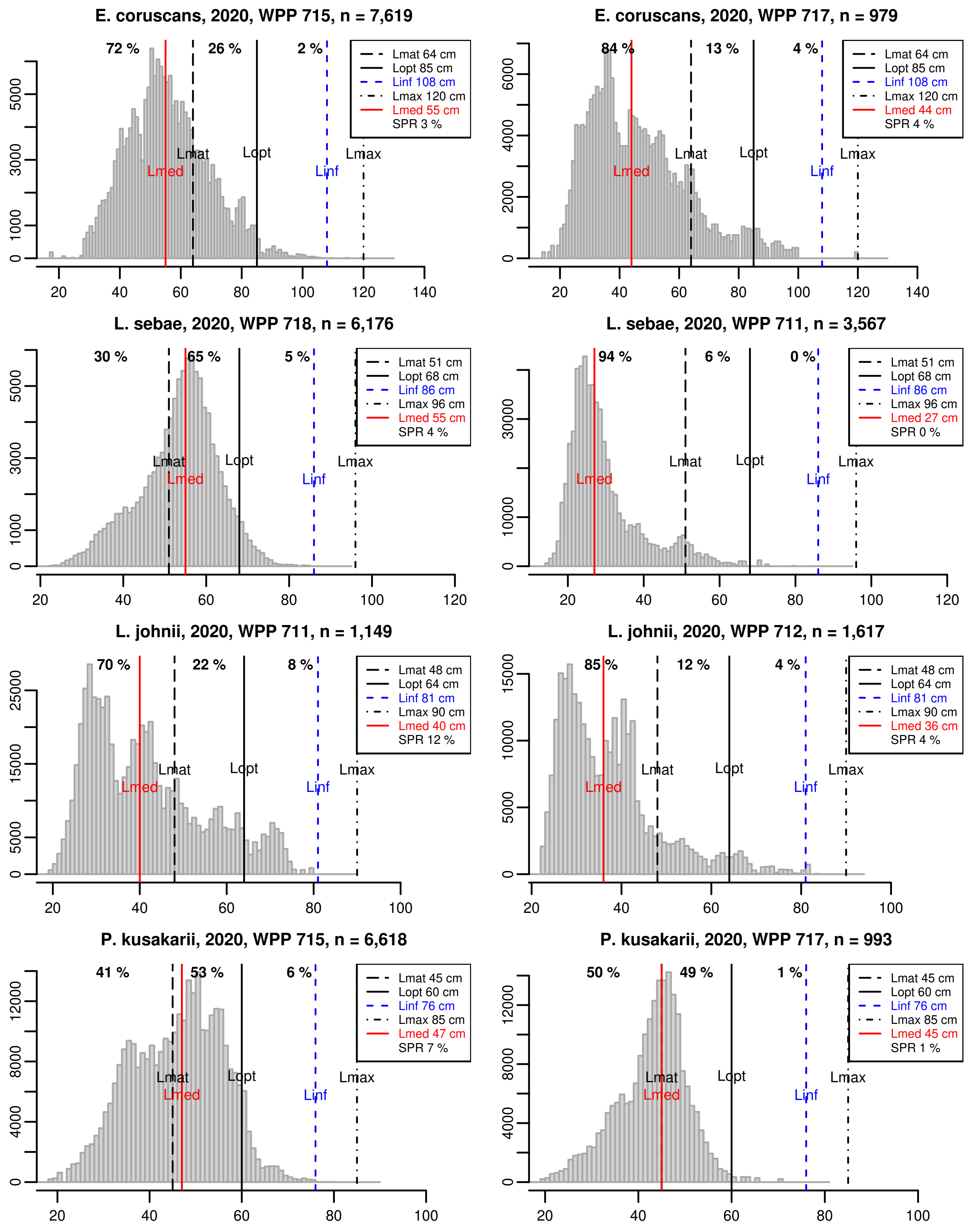


Figure 3.7: Reconstructed total catch size frequency distributions with median size in the catch (Lmed) for numbers 13 to 16 out of 16 species of snappers and groupers in the Indonesian deep demersal fisheries in their primary and secondary FMAs by 2020 production. With 2020 CODRS sample sizes (n) and percentages immatures (<Lmat), small matures (>=Lmat and <=Lopt) and large matures (>Lopt) indicated for each species in each FMA. Sizes in cm Total Length (TL).

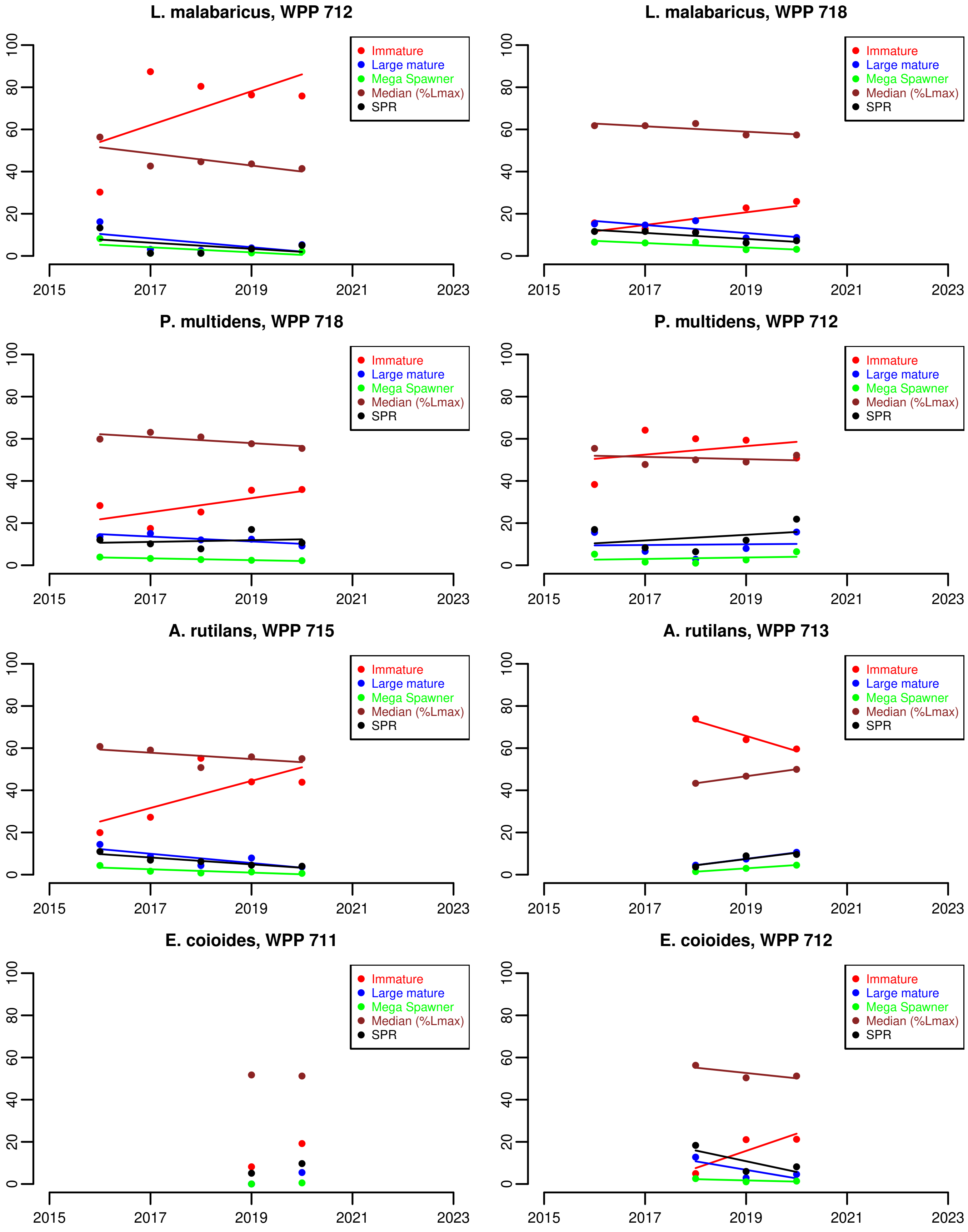


Figure 3.8: Time trends in length based indicators for the Top 4 out of 16 species of snappers and groupers in the Indonesian deep demersal fisheries in their primary and secondary FMAs by 2020 production. With percentages immatures, large matures and mega spawners, median size in the catch as percentage of maximum size, and SPR plotted from 2015 through 2020, for as far as data were available. Trends indicated by linear regressions when data series were available for at least 3 years.

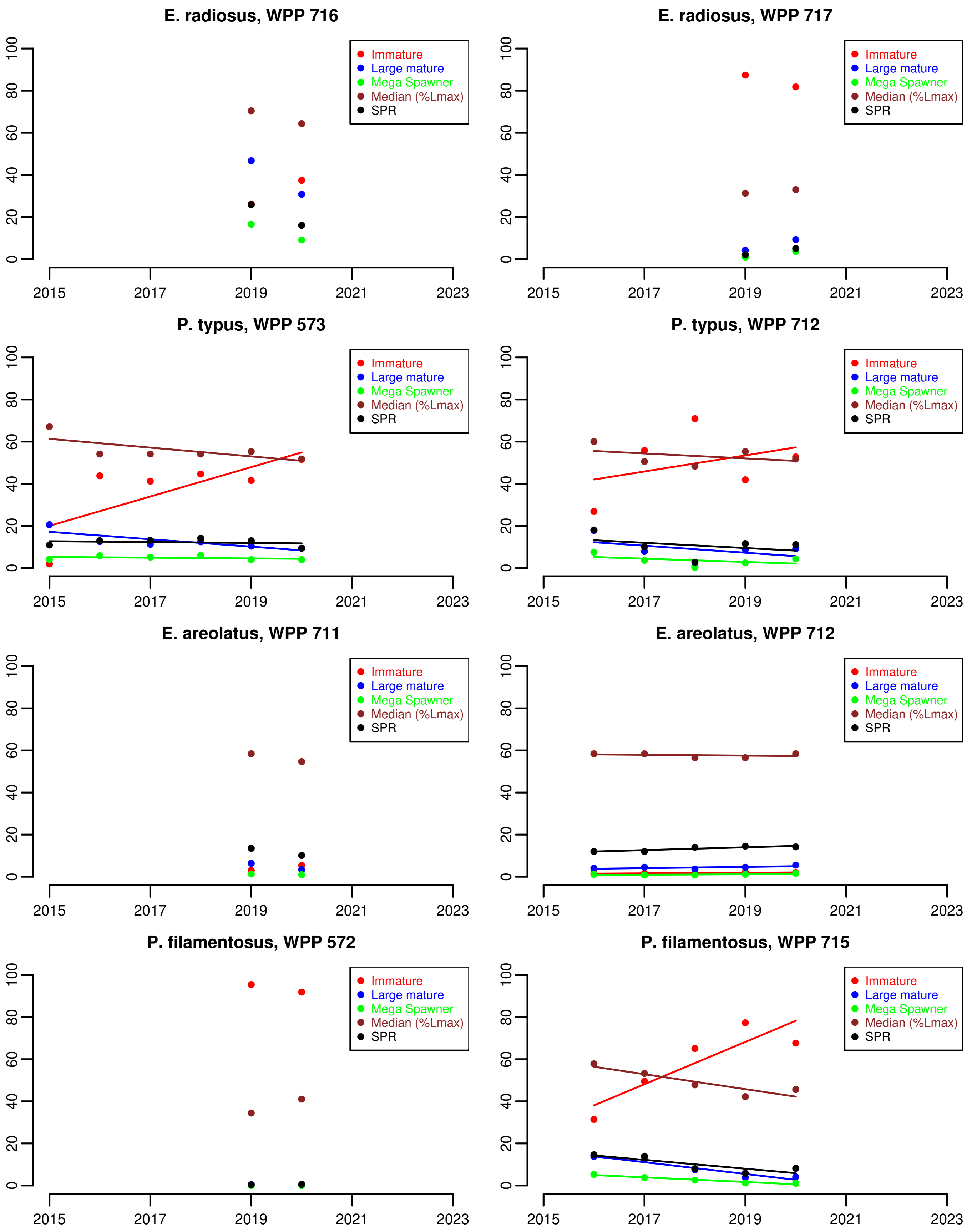


Figure 3.9: Time trends in length based indicators for the numbers 5 to 8 out of 16 species of snappers and groupers in the Indonesian deep demersal fisheries in their primary and secondary FMAs by 2020 production. With percentages immatures, large matures and mega spawners, median size in the catch as percentage of maximum size, and SPR plotted from 2015 through 2020, for as far as data were available. Trends indicated by linear regressions when data series were available for at least 3 years.

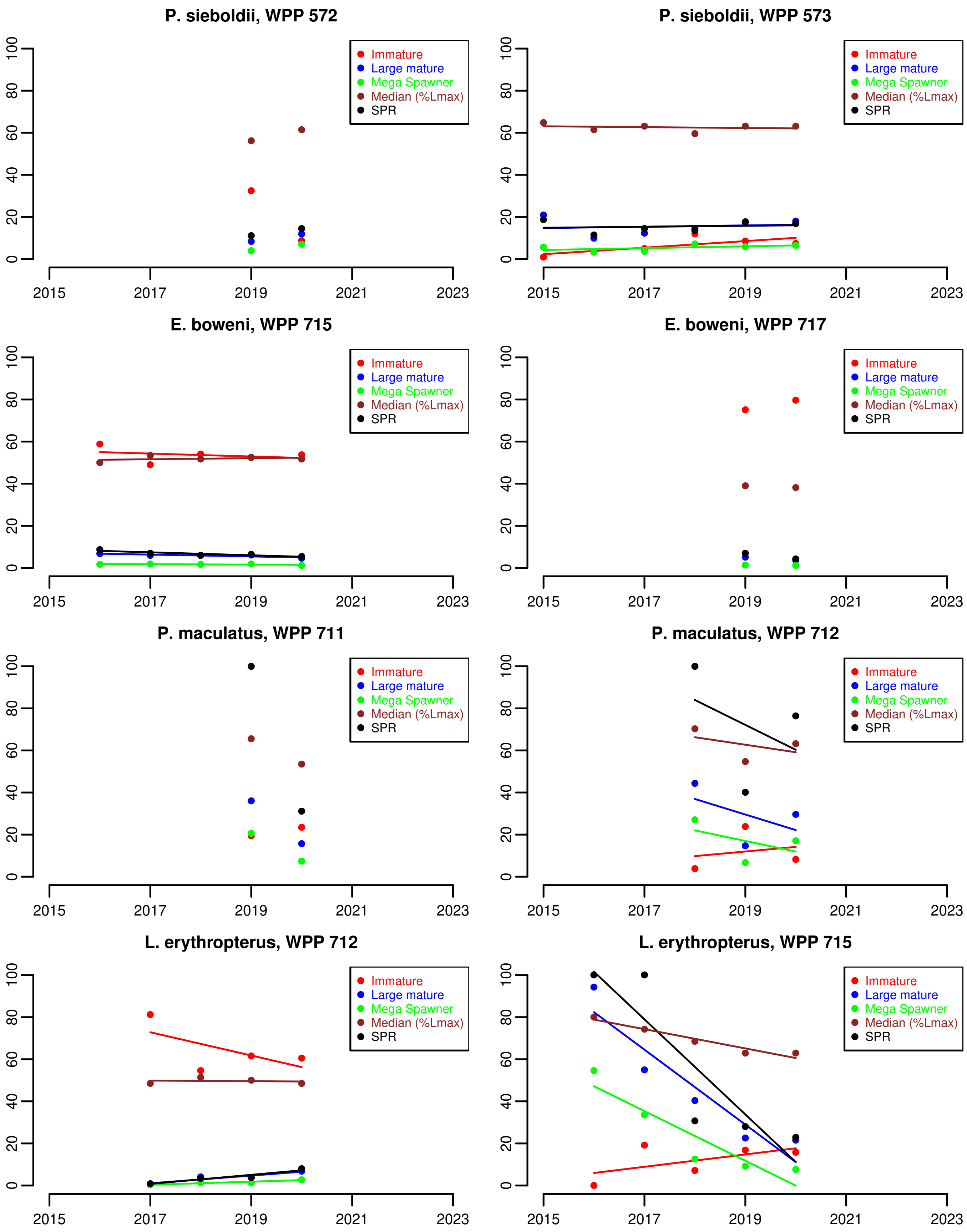


Figure 3.10: Time trends in length based indicators for the numbers 9 to 12 out of 16 species of snappers and groupers in the Indonesian deep demersal fisheries in their primary and secondary FMAs by 2020 production. With percentages immatures, large matures and mega spawners, median size in the catch as percentage of maximum size, and SPR plotted from 2015 through 2020, for as far as data were available. Trends indicated by linear regressions when data series were available for at least 3 years.

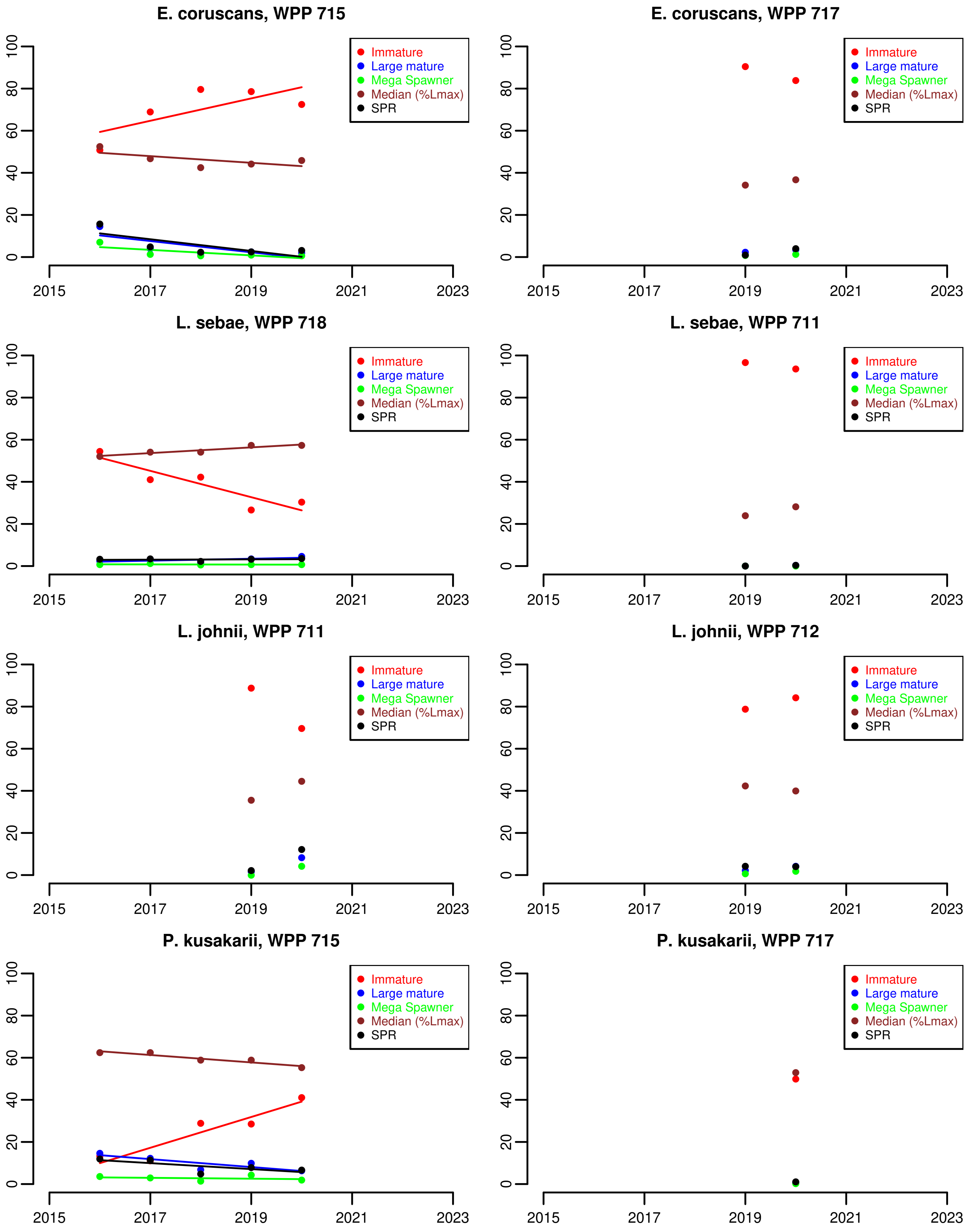


Figure 3.11: Time trends in length based indicators for the numbers 13 to 16 out of 16 species of snappers and groupers in the Indonesian deep demersal fisheries in their primary and secondary FMAs by 2020 production. With percentages immatures, large matures and mega spawners, median size in the catch as percentage of maximum size, and SPR plotted from 2015 through 2020, for as far as data were available. Trends indicated by linear regressions when data series were available for at least 3 years.

Apart from differences in the details of catch size frequency distributions between FMAs with similar status and trends, there are also important details in the trend graphs for the various indicators (Figures 3.8 to 3.11), worth further analysis. For example, in the trend graph for *L. malabaricus* in WPP 712, we see an overall decline over the full available time series, but trends may have been reversed to some recovery in the most recent years, which may have coincided with the movements of fleets to the East of the country or other factors not currently well understood. Also for the somewhat smaller *L. erythropterus*, some improvement seems evident in recent years in WPP 712, but SPR and other indicators are coming from very low levels and the percentage of immatures in the catch was very high for this species in WPP 712 in 2020. Overfishing in Western Indonesia, especially in WPP 712 (the Java Sea), is of major concern, also to the Indonesian Government. There may be some more scope to turn things around in the East of the country, for example in WPP 718 (the Arafura Sea), where risks are high and several major stocks are deteriorating, but where the decline thus far is less severe than in the West. With the fisheries in FMA 718 connecting to Australian fishing grounds, management effectiveness across those boundaries may be contributing to some buffering of the stocks.

4 Conclusions and Discussion

4.1 CODRS and image-based size- and species-specific data

Snappers and groupers are highly prized species, supporting important marine fisheries in tropical regions around the world, despite life-history traits that make them vulnerable to overfishing (Newman et al., 2016; Cawthorn and Mariani, 2017; Dimarchopoulou et al., 2021; Ault et al., 2022). With few exceptions, snapper and grouper fisheries worldwide are poorly managed and data poor, particularly in the small-scale multi-species fisheries in developing countries, with Indonesia no exception to this problem (Blaber et al., 2005; Cawthorn and Mariani, 2017; Wibisono et al., 2022). There is little methodology in place to trace snappers and groupers by species to their source fisheries, or to monitor the volumes and values entering international trade (Cawthorn and Mariani, 2017).

In the deep demersal snapper and grouper fisheries in Indonesia, the high diversity of species that share common morphological characteristics, compared with limited capacity and inadequate enumeration methods, has until recently impaired identification and reporting at the species level. This has resulted in poor resolution of official catch statistics, hindering the application of traditional stock assessment methods. Using the speciesspecific image-based data collected through the CODRS over the past five years, however, in combination with updated life-history characteristics for the main target species (Dimarchopoulou et al., 2021), it is now possible to apply length-based stock assessment methods to these fisheries. This study presents the results of a holistic length-based stock assessment, using a data base consisting of images collected by fishers participating in the CODRS from 2015 through 2020, covering the Top 16 snapper and grouper species in the deep demersal fisheries in Indonesia.

The CODRS proved to be an accurate and efficient system to collect high-definition catch and effort data, including species and size distribution of catches, exact fishing grounds, and detailed information on fleet size, gear types and fleet dynamics. Within 5 years the CODRS approach has lifted the widely dispersed Indonesian deep demersal fisheries out of the realm of complete data deficiency, into one of the best documented fisheries of its kind in the world. As a result, within the same 5 years, Government agencies and fisheries managers have been enabled to start developing a National Management Plan and Harvest Strategies for individual FMAs, while industry partners have been encouraged to join a Fisheries Improvement Program (FIP) that is committed to making the fisheries sustainable, using actionable information by species, and ambitiously aiming at MSC certification of at least some segments of the fisheries within the next 5 years.

In addition to collecting high-volume and high-resolution data, the CODRS approach is working to enhance collaborative fishery management by engaging fishers in data collection and providing open communication channels. At the same time, the great quantity and quality of verifiable image-based length measurements by species in the catch enabled us to update important life-history parameters based on maximum attainable sizes by species, perform length-based stock assessments and ultimately generate actionable management advice. Issues with offloading at sea, reporting of “commercial” catch only, vs. catch sold on the local market, consumption by crew, use as bait, etc., did not affect CODRS data, whereas these would have had serious implications for port sampling programs. This further highlights the importance of an on-board data collection system for these fisheries as opposed to post-landing data collection methods.

One aspect of the CODRS method which is particularly useful and unique in small scale fisheries monitoring, is the detailed effort data it records for each fishing trip with the basic onboard GPS tracker. Using CODRS datasets, researchers can match GPS coordinate dates from the tracking device to the date on CODRS images, verifying time and location of catch. These parameters helped to standardize catch per unit effort by active fishing day. Researchers can also filter GPS coordinates to map fishing areas in great detail, determine the spatial distribution and habitat preference (using bathymetry) of fish species, analyze vessel dynamics, and determine potential management implications related to fleet movement patterns. Logbooks, observers, and CODRS all require fishers to voluntarily provide or give access to unbiased, accurate information, so this caveat is not exclusive to any one method.

4.2 Holistic length-based stock assessment of the fisheries

The total volume of the Top 100 species in the catch by the deep water fisheries for snappers and groupers in Indonesia in 2020 was estimated at nearly 119,000 Metric Tons (MT), closely resembling estimates for Indonesian production of “snappers” alone in the period 2006 to 2013 (Cawthorn and Mariani, 2017; Anggraeni, 2012). It is unclear if this discrepancy is a result of problems with species identification in previous studies, or represents in a drop in the total catch of snappers in recent years. The deep water fisheries for snappers and groupers in Indonesia are yielding a highly diverse spectrum of species from a range of families, but snappers and groupers did clearly dominate with 81% of the catch in 2020. Snappers contributed by far the biggest volume with 69% of the total catch, while groupers were an economically important second group with 12% of the volume. A selected group of the Top 16 snapper and grouper species were by far the most important, representing 71% of the total catch and 83% of the global end value in 2020. This study therefore concentrated on stock assessments for these Top 16 species of snappers and groupers, in the two main FMAs for each species by production in 2020. This selection of species and FMAs represents almost half of the catch for 2020.

Length based stock assessments for 2020 showed very high risk against a range of sustainability indicators for the Top 16 snapper and grouper species in the deep demersal fisheries in Indonesia. Out of 128 combinations of species, FMAs, and indicators, no less than 116 combinations (>90%) showed a high risk of overfishing. Almost all of the major target species of snappers and groupers show a rapid decline in numbers above the size where the species becomes most vulnerable to the fisheries. This rapid decline in numbers indicates a high fishing mortality for the vulnerable size classes. In 2020 the deep demersal fisheries for snappers and groupers not only showed clear signs of overexploitation, but time series up to that year also showed a deteriorating trend in the stocks of most species, across the most important fishing grounds in Indonesia. In total 53 of the available 76 time series (70%) for sustainability indicators, related to specific combinations of species and FMAs, showed a deteriorating situation in these important fisheries, with a very high level of risk for just about all major target species and in all major FMAs at the end of these time series in 2020.

There are major differences between FMAs, but in general it is clear that an effective management strategy is urgently needed across the Indonesian archipelago, and that harvest strategies need to be implemented in each of the most important FMAs to prevent collapse of these valuable fisheries. Fishing mortality among the main target species is unacceptably high, while the catches of the main target species include large percentages of relatively small and even immature specimen. For several species of snappers, relatively small sizes are even specifically targeted, and these species are traded well below the size where they reach maturity. Almost all of the larger species are harvested well below the optimum size, and bigger specimens (mega spawners) of the largest target species are now extremely rare in our region.

Only the smallest snapper in the Top 16 (*P. sieboldii*) is currently less vulnerable to overfishing of the juveniles. The three species of groupers are also less vulnerable to targeting of the juveniles - in the deep demersal fisheries. Groupers mature as females at a size relative to their maximum size which is lower than for snappers. This strategy enables them to reproduce before they are being caught, although fecundity is still relatively low at sizes below the optimum length. Fecundity for the population peaks at the optimum size for each species, and this is also the size around which sex change from females to males happens in most groupers. Some grouper species have already reached their optimum harvest size when they are caught by the deep demersal fisheries. For grouper species which spend all or most of their life cycle on the deep demersal fishing grounds, a relatively low vulnerability to overfishing of juveniles is good news. For other grouper species which spend major parts of their life cycle in shallower habitats, like coral reefs or mangroves or estuaries, the reality is that their populations in general are in very bad shape due to excessive fishing pressure by small scale fisheries in those shallower habitats.

4.3 Accuracy of parameter value estimates and sensitivity of conclusions

Conclusions on status of the stocks are dependent on accuracy of life history parameter value estimates, while conclusions on trends are much less sensitive to accuracy of individual data points, as long as estimation methods of indicator values are consistent. Life history parameter values for Lmat and Linf are subject to much discussion, and conclusions on stock status from length-based assessments are sensitive to variation in these values. We chose to compare our Lmat estimates from the life history invariant approach (Newman et al., 2016) with available literature, because biological studies on maturation have been reported to be more robust than studies on Linf (Brown Peterson et al., 2011), and Linf estimates are very well predicted by known values of Lmax (Nadon and Ault, 2016). For several important species our estimates for Lmat from life history invariants resulted in values within the range of published values, while we note that there is a lack of consistency in Lmat values across studies over the range of our target species. Lmat studies of *P. filamentosus* from latitudes near the equator tend to estimate larger values than those published for higher latitudes and the opposite trend seems to occur in Lmat estimates for *L. sebae*, *L. malabaricus*, and *L. erythropterus*. There was no consistent trend in how our estimates for Lmat compared to literature studies either within or outside the Indonesian latitude range (Wibisono et al., 2022). The broad range in published values for Lmat within species does highlight the need for caution before referring to any particular study.

Correct species identification remains an issue when samples are collected for maturity studies. Moreover, the costs and difficulties of acquiring samples across the full size of each species, throughout all seasons, and over the range of all fishing grounds, are sometimes prohibitive. It is extremely difficult to obtain enough of the largest fish, throughout the season, to conduct fishery dependent maturity studies in dispersed small-scale multispecies fisheries. Some fisheries may not be active during spawning seasons, when these coincide with monsoons. In other cases, large mature specimen, needed for gonad studies, are just too rare in catches from heavily fished stocks. Maturity studies are completely lacking for *A. rutilans*, *P. typus*, and *Paracaesio kusakarii*, despite their prevalence in the catches. For other species some studies may be available, but inconsistent results need to be viewed with extreme caution due to potential issues with species identification, with methods applied to determine maturity, and with potential bias in the samples used. Many studies were hampered by incomplete samples, and worked with small numbers of fish, over a limited size range (lacking large mature fish), collected during specific sampling activities, which may not have coincided with spawning seasons.

4.4 Management options

There is some scope for industry led fisheries improvements where traders are willing and able to implement size-based purchasing limits, either complete or with price incentives to fishers for specific size classes, based on the size at maturity for each traded species. Many of the larger snapper species are traded at sizes that are too small, which impairs sustainability. By refusing undersized fish in high value supply lines, the market can provide incentives for captains of fishing boats to target only the larger specimen in the population. Captains can do this by using their day-to-day experiences, selecting locations, fishing depths, habitat types, hook sizes, etc. Literature shows habitat separation between size groups in many of our species (Misa et al., 2013; Takahashi et al., 2020), as well as size selectivity of specific hook sizes. Captains know about this from experience. Market preference for certain (small) size classes (like "plate size" and "golden size") could potentially be adjusted by awareness campaigns that clarify to the public that such sizes for many species actually represent immature juveniles and that targeting these specifically will impair fisheries sustainability.

Attempts to achieve certification by the Marine Stewardship Council (MSC) through Fisheries Improvement Programs (FIPs) will need to be realistic about what can be achieved, what is necessary to achieve management goals, where the best opportunities are, and what potential time tables could look like. It will be prudent to look at target species which are near a potential limit reference point of 25% SPR in specific FMAs, and which also show improvement in status of stocks over time. Implementation of an effective harvest strategy in that FMA would also help to tick the boxes in a full assessment of the fisheries there. Where some FMAs may be more likely candidates for MSC certification than others, certain species are also more likely to pass than others. These are mainly the smaller species such as for example *P. sieboldii* and *L. erythropterus* among the snappers and *E. areolatus* among the groupers. For some of the larger and commercially most important snappers like *L. malabaricus*, *P. multidens* and *P. typus*, and for the grouper *P. maculatus*, there may be some opportunities in selected FMAs if stocks could be re-built and if fishing practices and purchasing behavior could be adjusted to favor the trade of large mature specimen versus the smaller juveniles. Industry led fisheries improvements based on the size of maturity for target species can be supported by uncomplicated regulations using legal minimum sizes.

An effective National management plan and harvest strategies for all FMA are urgently needed in the Indonesian deep demersal fisheries. Even with limit reference points and target reference points in harvest control rules potentially being chosen around 20% SPR and 40% SPR respectively, difficult decision-making lays ahead for fisheries managers. Strategies for re-building of stocks need to be developed and implemented while there is little evidence at present that stock rebuilding is taking place across a wider range of species in any FMA at this time. Highly important fishing grounds in the Indonesian parts of the Arafura Sea and in the Timor Sea are heavily fished by boats targeting the snapper resources there. Possibly the main reason that the fishery is still perceived by captains to be in relatively good shape in those areas, is the huge amount of shelf habitat across the Australian marine boundary, which experiences much lower fishing pressure. The Indonesian boats are fishing the line here in the most literal sense, along the Sahul Banks, possibly profiting from a spillover effect from that Australian shelf area. The differences in stock densities and fish sizes on either side of the boundary are stark and very well known by captains. In the past this has led to IUU incidents and arrests of Indonesian boats on the Australian side of the boundary.

The total volume of the Top 100 species in the catch in 2020 was close to 119,000 Metric Tons (MT) annually, and no less than 64% of this total catch was produced by vessels smaller than 10 GT. This small-scale characteristic of the fisheries has very important consequences for management, as vessels below 10 GT are not licensed in Indonesia. TURF-Reserve approaches, including no take areas as well as restricted access fishing grounds (Mous et al., 2005; Gaines et al., 2010), may be needed to manage the small-scale fisheries which are currently not covered by the fisheries licensing system and which represent such a large part of the catch in the deep demersal fisheries. Only one third of the catch is landed by licensed medium to large sized boat, and thus effort regulations through the licensing system will only have limited effect on the status of the stocks. Relative importance of larger vessels does differ across FMAs and for some FMAs license-based regulations will therefore have more effect than in others. Either way, fishing effort by medium to large sized boats needs to be capped at the current level and fisheries managers will need to start looking at incentives for effort reductions. An improved licensing and effort control system based on Indonesia's mandatory Vessel Monitoring System, using accurate data fishing boat sizes, could be used to manage fishing effort by medium to large sized vessels. Continuous monitoring of trends in size-based sustainability indicators will show how the fisheries are developing and what the effects are of fisheries management in future years. Recommendations for policies in relation to the deep demersal fisheries include:

- Use scientific (Latin) fish names in fisheries management and in trade.
- Incorporate length-based assessments in management of specific fisheries.
- Develop species-specific length-based regulations for these fisheries.
- Implement a controlled access system for regulation of fishing effort by FMA.
- Increase public awareness on unknown species and preferred size classes by species.
- Incorporate traceability systems in fleet management by fisheries and by FMA.
- Explore options for TURF-Reserve approaches to small scale fisheries management.

Recommendations for specific regulations include:

- Introduce mandatory display of correct scientific names of all traded fish.
- Adopt legal minimum sizes for traded species, at their length of 50% maturity.
- Make mandatory for each fishing vessel of all sizes to carry a simple GPS tracking device that needs to be functioning at all times. Indonesia already has a mandatory Vessel Monitoring System for vessels larger than 30 GT, so could expand this requirement to smaller vessels.
- Cap fishing effort in the deep demersal fisheries at the current level and explore options to reduce effort to more sustainable levels.

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