# Developing Data-poor Assessments for Key Fin-Fish Species in Baja California Sur, Mexico

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# Introduction

This report has been prepared for the Programa De Conservación Marina Y Pesca Sostenible of Pronatura Noroeste A.C.'s 'Sustainable Fisheries in Northwest Mexico' project.

In 2017, the Marine Stewardship Council (MSC) approached Pronatura Noroeste to develop a partnership in the Fish for Good project, with the aim of working with local small-scale fisheries to improve their performance, and in some cases ready them to enter full assessment for certification. The fishery in the San Cosme – Punta Coyote Corredor (El Corredor), originally entered the Fish for Good project only with the red snapper portion of the catch, but later transformed into a multispecies finfish fishery, as described below, to better reflect the reality and needs of the fishery. The project has been working with fishers to address different gaps identified through a formal pre-assessment which was used to develop a work-plan and organize a pathway towards satisfying the requirements of MSC's standards.

## The San Cosme – Punta Coyote Corredor Fishery

The San Cosme – Punta Coyote Corredor is a series of 13 coastal communities found along the 150 km long coastline in the Gulf of California side of Baja California Sur, Mexico. Fishing is the main economic activity in the region, and it is conducted by an artisanal, small-scale fleet, traditional of most coastal finfish fisheries in Mexico. The fleet is composed of 23 ft open skiffs known as "pangas" with outboard engines of up to 115 hp, with a crew of two or three fishers that usually use handlines with hooks that vary in size depending on the species they target in a specific fishing spot. Some fishers in the region use gillnets and traps for certain species, but the fishery covered by this report only uses line and hooks. There may be however variations in the use of this gear as a single main line can have at the end, approximately, from 2 to 20 hooks in different arrangements.

In a regular fishing trip, fishers go to selected fishing grounds where known productive spots are probed for fish abundance. If acceptable, the fishers may spend several hours catching their preferred targets, however, other species may be caught in the same spot while hoping to get one particular species. This definition is relative because if the preferred target is the red snapper, other species that appear in the hooks may be equally valuable or close enough to be kept and landed. This makes the finfish fishery of the Corredor multi-specific in nature (the MSC has labeled this as a "mixed species fishery"). Although in a single trip more than one species may be caught, fishers have the possibility to decide what species they will try to target in a fishing trip depending on factors such as season, weather, bait available, and the trend in the catch observed in previous days in their own catch and that of fellow fishers. Because of the multi-specific nature described in the previous paragraph, the fishery has been evaluated under the MSC standard for mixed species which is still in developmental stages. The MSC approach follows the principles in Newman et al. (2018) to identify *stock complexes* that include several species regularly caught in a fishery. However, instead of attempting the evaluation of all species in the complex, one or few are chosen as index species, representative of the complex and to be assessed. Management actions are decided on the index species and it is assumed that the status of the index species is representative of the rest of the complex suit of species.

In the Corredor, three complexes were identified (. Table 1), the shallow reef species, the deep demersal species, and the pelagic species (coastal migratory species). The shallow reef species complex is represented by the trigger fish (*Balistes polylepis*) and the leopard grouper (*Mycteroperca rosasea*) as index species. The deep demersal complex includes only the red snapper (*Lutjanus peru*) as index species, whereas the pelagic complex includes only a single species which is therefore the index species, the yellowtail (*Seriola lalandi*). In terms of the MSC definition of a Unit of Assessment (UoA), these three complexes determine the UoA as caught in the same region, by the same fishers, using the same gear, and will be considered the target species that are evaluated under the MSC Principle 1. Together with the species in each of the three suits in the UoA other species are also caught, however those species appear less than 1% in the total catch of the fishery and are considered incidental catch which is mostly kept, landed and sold, these species are evaluated under the MSC Principle 2, mainly under the category of "unmanaged" species.

| **Shallow reef** | **Deep demersal** | **Pelagic species** |
|---|---|---|
| **Cabrilla sardinera (*Mycteroperca rosasea)*** | **Huachinango *(Lutjanus peru)*** | **Jurel (*Seriola lalandi)*** |
| **Cochito (*Balistes polylepis)*** | Pierna *(Caulolatilus princeps)* | Sierra (*Scomberomorus sierra)* |
| Cadernal (*Cephalopholis colonus)* | Estacuda (*Hyporthodus niphobles*) | Pez fuerte (*Seriola rivoliana)* |
| Pargo amarillo (*Lutjanus argentiventris)* | Guarepa (Caulolatilus affinis) | Dorado (*Coryphaena hippurus)* |
| Pargo mulato (*Hoplopagrus guentherii)* | Baqueta (*Hyporthodus acanthistius*) | Cabicucho (*Cynoscion reticulatus)* |
| Vieja (*Bodianus diplotaenia)* | Zorrillo (*Paralabrax auroguttatus*) | Curvina (*Cynoscion sp.)* |
| Cabrilla piedrera (*Epinephelus labriformis)* | Cabrilla pinta (Epinephelus analogus) | Medregal (*Seriola peruana)* |
| Pargo colorado (*Lutjanus colorado)* | Pargo lunarejo (Lutjanus guttatus) | |
| Pargo colmilludo (*Lutjanus jordani)* | Cabrilla aserrada (Mycteroperca prionura) | |
| Pargo liso (*Lutjanus aratus)* | Rocot (*Sebastes mystinus)* | |
| Pargo cenizo (*Lutjanus novemfasciatus)* | Vieja colorada (*Semicossyphus pulcher)* | |
| Mero (*Cirrhitus rivulatus)* | Lengua (*Brotula clarkae)* | |
| Curricata (*Paralabrax maculatofasciatus)* | | |
| Botete (*Sphoeroides lobatus)* | | |

*. Table 1. List of species by complex in the finfish fishery at Corredor San Cosme – Punta Coyote region. Bold names indicate the index species for each complex.*

All these species are economically important for the local communities found along the Corredor, however, from the point of view of the state-level economy, the catch of finfish is not important enough to trigger a major interest from the government management and research institutions, therefore, basic passive measures are implemented for their management, mainly by controlling the number of permits and in some cases by establishing minimum size regulations.

## This Project

In common with many Mexican fisheries, one of the main deficiencies of the Corredor, is the lack of formal harvest strategies, which, within the framework of the MSC standard, should include an information and monitoring system, a stock assessment procedure, and a decision-making process to prevent overfishing and overharvesting. The fishery has been monitored for several years by a collaboration between Niparajá and Pronatura Noroeste, data on catch composition and size has been obtained for several species, most importantly the red snapper, and several attempts have been made to get some measure of effort with variable degrees of success. In the last 20 years, at least two different assessments have been produced using the limited available data. The first assessed red snapper status in the southwestern Gulf of California using a simulation framework to obtained indicators of stock status by using assumptions about population parameters and calibrating the model to catch data (Díaz-Uribe *et al*. 2004). While a second also assessed red snapper using a variety of procedures, including fitting a surplus production model in a likelihood framework (Alvarez-Flores 2005).

Under the partnership between Niparajá and Pronatura, it was decided to explore assessment methods specifically developed for application to data limited fisheries and this collaboration with Dr. Jeremy Prince was developed to apply the Length Based Spawning Potential Ratio (LBSPR) methodology. This investigation had three main objectives, most importantly, to use LBSPR to determine status of at least the index species of the three suits described above and if possible, explore status of some or all the other species. Second, to provide advice about improvements in the quality of data to obtain more reliable LBSPR results and look forward to other methodologies. And last but not least, to train researchers associated to the project in the use of the methodology.

To these ends, a workshop was conducted by zoom 23-26 March 2001 inclusive, followed up by two further days on 13-14 April 2001. This report documents the exploratory analyses developed initially by Dr Prince working with Juan Carlos Castro Salgado prior to the workshops, as well as the analyses and discussion that occurred during, and subsequent to those workshops. The data illustrated in this report have been taken directly from analyses Juan Carlos prepared for this purpose (Castro Salgado 2020) and for which he is acknowledged and thanked.

## Length-based Spawning Potential Ratio Assessment

Length-based spawning potential ratio (LBSPR) assessment, is a relatively new technique developed specifically for fish stocks for which only data on catch size composition can feasibly be collected (Hordyk et al. 2015a, b; Prince et al. 2015a). As such it provides both a methodology and a logical framework for evaluating the scant information that exists for a fish stock. Since being published in 2015 it has become one of the most commonly used length-based methods of assessment (Canales et al. 2021).

The LBSPR methodology estimates the spawning potential ratio (SPR) of fish population, which is a metric developed during the 1980s to indicate the risk of recruitment declining and so whether stocks are likely to be declining, stable or increasing (Mace & Sissenwine 1993). Left unfished, fish complete their full life span and complete 100% of their natural reproductive (spawning) potential. Fishing reduces the average life span of fish reducing their reproductive, or spawning, potential below natural unfished levels (<100%), SPR is the proportion of the natural unfished spawning potential remaining in a population that is being fished. The concept of SPR for fished stocks is similar to the Human Reproductive Index (HRI) for human populations which is the average number of children per couple that survive to adulthood. With 2.1 children surviving through to adulthood, human couples replace themselves and those around them without children, ensuring population stability. An HRI above 2.1 ensures population growth, below that populations decline. Studies from around the world have shown that in marine populations, 20% SPR is the equivalent of the HRI replacement level of 2.1 surviving children per couple; both are pivotal reference points around which populations of humans and fish either increase or decline. Down to around

20% SPR fish populations are expected to retain their capacity to rebuild after depletion, although the rate at stocks rebuild declines as SPR falls towards 20% (Mace & Sissenwine 1993). Below 20% SPR the risk of recruitment declining is expected to increase, while 10% SPR is commonly called ‘SPR crash’, because below this level populations are likely to decline rapidly towards local extinction.

The SPR concept has been incorporated into fisheries management legislation by many jurisdictions which use it as a metric to define Reference Points (RPs) for evaluating the management of fish stocks (e.g. Anon. 2007). In parallel MSC standards define the following broadly accepted default SPR RPs, to be applied unless there are scientific studies to indicate variation is justified;

- SPR = 20% is considered the point of recruitment impairment (PRI) and is used as a Limit Reference Point, below which a stock should not be permitted.
- SPR = 30-40% is considered a proxy for attaining the maximum sustainable yield (MSY), while
- SPR 48 - 50% is considered a proxy for attaining maximum economic yield (MEY)

We apply these default RPs in our evaluation of stock status in the Corredor fisheries, and suggest that a good target for management is to maintain stocks with the range SPR = 30-50%. Around levels that should optimize sustainable yields and economic returns, and keep stocks well above levels that risk impairing recruitment (SPR = 20%).

The LBSPR methodology compares the size of the fish being caught with the size at which they reach sexual maturity ($L_m$). If fish are all caught before reaching sexual maturity their populations will have little spawning potential (i.e. ~ 0% SPR). On the other hand, if there is little fishing effort, fish live close to their natural life spans, thus allowing them to grow larger than their size at maturity, with some attaining the natural average maximum size ($L_\infty$) of the population; when this happens, SPR is close to 100%. The LBSPR algorithms enable this information in catch size composition, relative to size at sexual maturity, to be quantified in terms of SPR and relative fishing pressure (F/M, where *F* is ‘fishing mortality’, and M is ‘natural mortality’).

For this analysis the algorithms needed to apply the LBSPR methodology were accessed at the freely available website: http://barefootecologist.com.au.

## Input Parameters

The data inputs required for the LBSPR methodology are:

1. Catch size composition data that are indicative of the size of the adult fish in a population. If the type of fishing being conducted fails to catch the largest size classes of a fish species, then the estimate of SPR produced for that species will be too small.
2. Estimates of the size at which fish become adults ($L_m$) which is defined by $L_{50}$ and $L_{95}$, the sizes at which 50% and 95%, respectively, of a population are observed to be mature.
3. The two life history ratios (LHR) that characterise differing taxa and which determine the relative shape of population size and age compositions (Hordyk et al. 2015a). The LHR are:
   a. the relative size of maturity; this is the size of maturity ($L_{50}$) divided by the average maximum size a species can naturally attain without fishing ($L_\infty$); and
   b. a species’ natural rate of mortality (M), which is the rate at which fish die due to natural causes, divided by the von Bertalanffy growth parameter K, which

is a measure of how quickly each species grows to the average maximum size ($L_\infty$).

The first two of these data inputs need to be estimated locally for each fish species because they vary from place to place; but, the LHR are best estimated generically from high quality age and growth studies available from the internationally published scientific literature.

### *Life History Ratios*

The LHR not only define the shape of size and age compositions, they also provide a complete system of logic that can be used to inform assessment, as well as to test the strength and veracity of the input parameters being relied upon. Fisheries scientists commonly find themselves assuming values for the life history parameters (LHP: M, K, $L_m$ & $L_\infty$) of data-poor assessments based on studies conducted on other populations, or correlations based on other attributes, developed through meta-analysis. This is called the 'Robin-Hood' approach to data-poor stock assessment; whereby information is borrowed from well-studied species in 'data-rich' fisheries and applied to the parameterization of data-poor stock assessments.

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

Aiming to definitively settle this issue, data from more than 2000 published age, growth and maturity studies have been collected and re-digitized allowing rigorous standardization and quality control procedures to be applied and a database developed of 1576 and 861 high quality estimates of M/K and $L_m/L_\infty$, respectively. With this database two parallel analyses were conducted independently (Prince et al. in prep. a). A cross-validation study of the predictability of M/K by taxonomic category, and an evaluation of alternative models of the relationship between the LHRs using Akaike information criteria. These analyses provide a robust basis for assuming LHR values for previously unstudied populations, species, genera and even entire families. Previously unstudied species and genera can be assumed to share similar LHR to other species in the same family or genera (Figure 1). In most cases, due to the low number of high-quality LHP estimates available for species, average LHR values estimated from many high-quality studies across an entire genus, or family, will prove to be more accurate than, and should be used in preference to, LHR values derived from one or two local studies of a stock being assessed. This is because accurately estimating the LHP of any stock is far more complicated than most researchers realize, and many published LHP estimates are impacted by truncation through fishing of size and age compositions, the size selectivity of sampling not being corrected for, or an inaccurate estimate of the length at which growth starts, which results low quality LHR estimates. To circumvent reliance on locally derived LHR estimates of highly variable quality, Prince et al. (in prep) have completed a meta-analysis of ~ 2000 studies of fish LHP and compiled a data-base of standardized LHR estimates from which high quality average LHR estimates have been derived for 77 families of fish, including the families of all the species assessed in this study. Much use is made of these estimates in this study.

Our meta-analyses also suggest that the LHRs of taxa can be related to nutritional richness or balance of the food-webs that taxa typically exploit, referred to as their stoichiometric niches. Opportunistic species adapted to exploit highly variable nutrient rich niches typically have higher M/K and lower $L_m/L_\infty$ and conversely taxa adapted to exploit the equilibrium of stable but nutrient sparse niches predictably have lower M/K and higher $L_m/L_\infty$. The implication of these principals is that ecologically and physiologically similar taxa can be predicted to have similar LHR, so that detritovores that exploit bacterially enriched ecological niches tend to have high M/K and low $L_m/L_\infty$, while grazers of macro-algae and coral polyps tend to have low M/K and high $L_m/L_\infty$. This provides a coherent logical basis for predicting the LHR of unstudied taxa. In the context of this report, we use this principal to inform our analysis of cochito. Our meta-analysis of the taxa contains only 7 high quality estimates of M/K for Balistidae and no estimates of $L_m/L_\infty$, however, for the ecologically similar Monacanthidae it contains 8 high quality estimates of M/K and 5 estimates of $L_m/L_\infty$ which can also be used to provide an indication of the LHR that characterize these types of taxa.

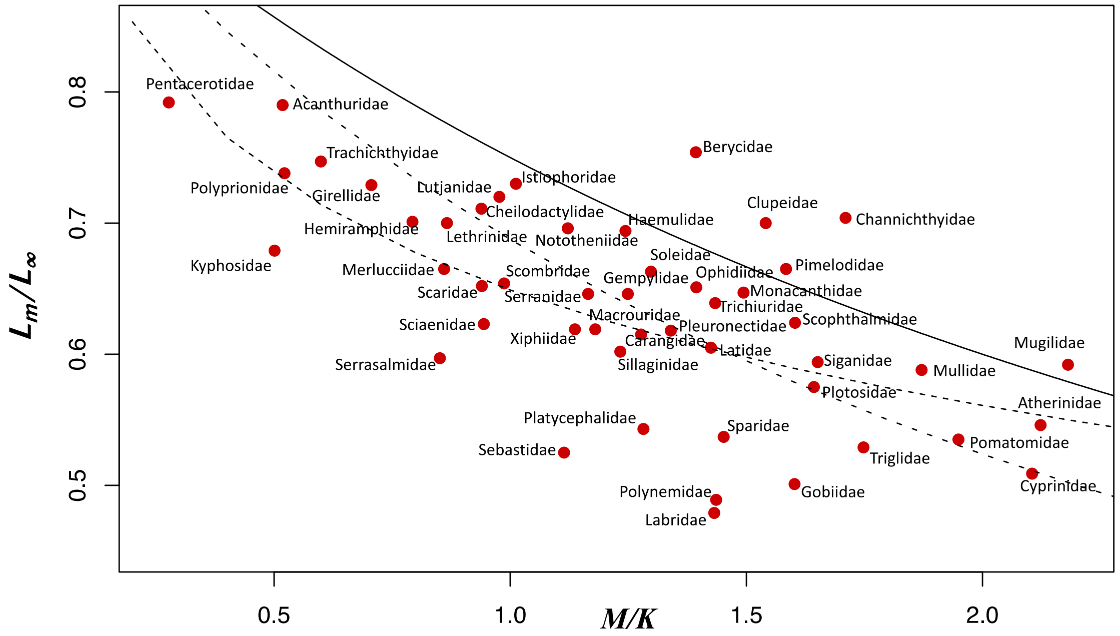


*Figure 1. Taken from in Prince (in prep. a), plotted average values of $L_m/L_\infty$ as a function of average M/K for families of fish with $\geq$ 5 high quality standardized estimates of M/K and $\geq$ 4 of $L_m/L_\infty$. The solid curve shows the relationship between $L_m/L_\infty$ and M/K deduced by Beverton (1992) assuming Weight $\propto$ Length$^3$, the dash-dot curve provided for scale assumes Weight $\propto$ Length$^{2.2}$, while the dashed curve depicts the relationship fitted with GLM Prince et al. (in prep. a),*

The LBSPR framework of logic also makes it possible to evaluate the robustness of local LHP estimates, by comparing the LHR implied when local LHP estimates are combined, with the average LHR estimates derived from the complete body of high-quality international studies. Such comparisons reveal where local LHP estimates when combine produce LHR estimates which are compatible with the broader body of biological studies, or incongruent.

The former case building our confidence in the quality and reliability of the local studies, while the latter causes us to question whether there is some bias in the local LHP estimate, or some entirely novel form of biology being discovered.

### Body Size

One of the principles involved with LBSPR is that, because the LHR define life history strategies and adapt taxa to their stoichiometric niches, they remain relatively consistent for species through their ranges, and also across species within genera and families. This is in contrast to the individual LHP which vary considerably across species' ranges, mainly in relation to water temperature (Brown et al. 2004; Pauly 2010). It follows from these principles that, we expect to observe latitudinal gradients in body size ($L_m$ & $L_\infty$), gradients in size that are shared by all the species in an assemblage. So that all the species in an assemblage will have proportionally larger body sizes at a site with cooler water and proportionally smaller body sizes at warmer sites. This expectation that the body sizes of species will co-vary together and remain proportional to each other can allow us to identify specific LHP estimates that incongruently varies as probably being less accurate than others which confirm to the broader ecological and physiological logic.

### Size of Maturity

A final short-cut which will also be applied repeatedly to inform these assessments is the estimation of $L_m$ or $L_{50}$ directly from size composition data. This is another topic that I and some colleagues have been conducting research into. Research that will be finalized for submission to journals once this current report has been acquitted and for which there is only space here for a short explanation (Prince et al. in prep. b). In many (but not all) fishery it is primarily the adult fish which are caught, because for various reasons only adults, or maturing sub-adult fish, behave in a way that makes them vulnerable to the fishing method. Our research in Palau, comparing the size of maturity in ~ 20 species of coral reef fish, with the size composition of catches and spawning aggregations, verified with simulation model, demonstrates that if catches can be assumed to be comprised entirely of mature individuals, then a point half-way up the left-hand side of the main mode in length-frequency histogram approximates size of maturity ($L_{50}$), a principle that will be used or referred to with various of the assessments developed below.

Our research also reveals an issue arising from incompatible definitions of the size of maturity that will also be encountered in our discussion of these species. The assumption for stock assessment is that $L_{50}$ is the size at which 50% of a stock become fully functioning adults which produce gametes and zygotes in proportion to their adult body-weight (Beverton & Holt, 1957). In contrast most published estimates of $L_m$ are produced using histological techniques which define maturity as beginning when 50% of individuals first become capable of producing a few viable gametes (e.g. Brown-Peterson et al., 2011). This definition was developed for histological purposes because it can be clearly and repeatedly detected by histologists, but really best defines the point at which the juvenile phase of life ends, and the sub-adult phase of maturation begins, rather than the size at which fish become fully functional adults. In our Palauan studies the histological measure of $L_m$ often coincides with the 50th percentile of the left-hand side of the catch size composition, but with the smallest individuals found in the spawning aggregation (Figure 2 2). The 50th percentile of the left-hand side of the spawning aggregation size composition, which we infer defines the size at which 50% of individuals become fully functional adults, tends to be 15 - 20% larger than the histologically defined $L_m$. This mis-match in definitions and discrepancy in sizes is mentioned here, as it may well help explain some of the issues confronted in our evaluation of local size of maturity estimates discussed is some species assessments.

## Critical Assumptions

### *Equilibrium assumption*

As with many forms of data-poor stock assessment the LBSPR methodology is based on the assumption that populations are in some sort of equilibrium. That is, they have experienced something like the existing level of fishing pressure, and rates of recruitment for several generations bringing them to some sort of ‘steady-state’ or equilibrium. Similarly, predictions of stock status based on equilibrium assumptions, predict the steady-state stocks would end up in, if the fishing pressure used to make that prediction, is applied constantly over several generations.

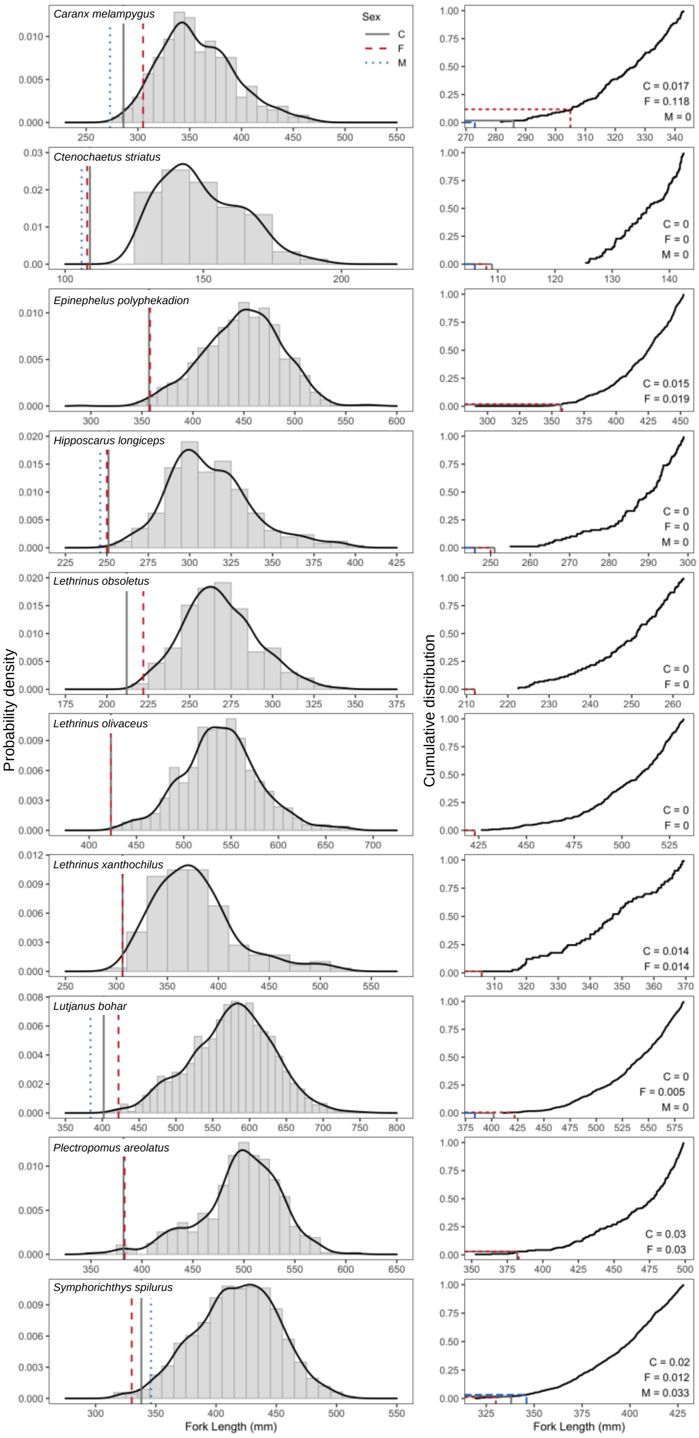


*Figure 2. Length frequency data from the spawning aggregations of 10 species of reef fish in Palau taken from Prince (in prep. b). The left-hand panels show the length frequency histograms overlayed with kernel density estimates. Vertical lines represent the $L_{50}$ based on the conventional histological classification criteria with a solid line for sex combined (C), dashed line for female (F) and dotted line for male (M) fish. Right-hand panels present the cumulative relative frequency (CRF) formed by the size classes leading up to the main modal size. Simulation modelling shows that the size at which 50% of adults begin participating in spawning aggregations is indicated by the 50th percentile of the CRF. The values from where the $L_{50}$ estimates intersect the CRF are provided in the bottom right corner of each plot. This demonstrates that histologically derived estimates of maturity determine the size at which maturation begins, rather than the size at which adult behaviour begins which is 15-25% larger.*

The equilibrium assumption is widely used in data-poor methodologies because it provides a way of ignoring all the fluctuations that actually impact stocks, greatly simplifying the information required and the computation involved. This simplification is also the reason that dynamic age-based assessment models were developed to track variations in fishing pressure and recruitment, and were hailed as a major advance in fisheries science during the 1980s. That dynamic age-based modelling is more realistic and sophisticated is not open for debate. The issue here, is that we rarely have all the information and data needed for that level of sophistication, and consequently must fall back on the simplifying assumption of equilibrium, despite the fact that we will confront evidence that some of the stocks being assessed have experienced pulses of recruitment, or recent depletions, and thus strictly speaking, are not at equilibrium. Rather we must develop ways of working around, or with, violations of this assumption.

Our own sensitivity testing of the LBSPR methodology shows that the assumption of equilibrium does not need to be too strictly observed, but the results of assessments will be impacted and this needs to be anticipated. Assessment results should be expected to oscillate around actual levels as perturbations, such as recruitment pulses, pass through stocks (Hordyk et al. 2015b).

### Size-Selectivity

Size selectivity refers to the size range of fish that is caught by fishing, and is sometimes referred to as the size of first capture. Size selectivity results from a combination of the type/s and size/s of the fishing gear being used, as well as the timing and location of fishing, along with the behaviour of the species being targeted. Generally larger hooks and mesh size catch larger fish, but if used exclusively in nursery areas, or on spawning aggregations, will primarily catch juveniles or adults respectively, more or less regardless of the size range the gear is optimised for. In the basic form used here the LBSPR methodology assumes a ‘logistic’, or S-shaped, transition between smaller size classes on the left of the length frequency histograms (LFH) that are not (0%) vulnerable to be caught, and larger size classes on the right of the LFH that are 100% vulnerable to being caught if they interact with fishing gear. Dome-shaped selectivity, is an alternative form of size-selectivity by which both the smallest and largest size classes are in-vulnerable (0% selected) to the fishing gear; so that the size-selective function describing vulnerability by size class is ‘domed’ shaped. The mesh size and the size of trap entrances, tend to mean dome-shaped selectivity is common in fisheries using those gear types.

The basic form of LBSPR assessment applied here assumes logistic size-selectivity and fits a S-shaped size selectivity curve to the left-hand side of the size composition histograms. To the extent that dome-shaped selectivity exists and causes the largest size classes of fish in a stock to be under-represented in samples, estimates of SPR will be biased low, and F/M biased high.

Hook and line fisheries in which a specifically narrow range and type of hooks are prescribed may also tend to exhibit dome-shaped selectivity, but where hook size is left unregulated, the tendency over time is for a range of hook sizes to be used, being adapted to the size of the largest individuals remaining in a stock at any time. For these fisheries the assumption of logistic, or S-shaped, selectivity is generally reasonable. Although in some groups of species, including species of interest here, we observe that the larger size classes moving out into deeper water, so that to the extent fishing only occurs in the shallower part of the species depth range, smaller and middling size classes of fish tend to dominate catches. So that the depth profile of fishing can also potentially result in ‘dome-shaped’ selectivity. The converse is that gear with dome-shaped selectivity may in some cases only have a ‘logistic-shaped’ impact on a stock. This can occur if fishing pressure is heavy enough to prevent fish living long enough to attain the range of sizes protected by the right-hand side of the ‘dome-shaped’ selectivity curve. When fishing pressure is heavy enough, the fish only experience the left-hand, S-shaped, side of the dome-shaped selectivity curve.

### Length-Frequency Histograms Accurately Reflect Adult Size Compositions

The LBSPR assessment methodology analyses the shape of the length-frequency histogram of adults. Only adults have reproductive potential, and it is how large the adults get to be which primarily determines SPR, and how truncated, or cut-off, is the size range of adults, the shape of the juvenile size ranges to the left of the length frequency histogram is also informative, but to a lesser extent.

Under the assumed equilibrium conditions, and with logistic size-selectivity, the combined processes of growth and mortality ensure that size composition of catches are comprised of one relatively bell-shaped, modal size classes of fish. If the mix of fishing gears remain stable over time, the length frequency histograms will also remain stable over time, simply eroding away from the right (bigger size classes) with increasing fishing pressure over time. To estimate SPR the LBSPR method primarily relies on the relative shape of the mode. The slope of the right-side informs the estimation of relative fishing pressure (F/M), while the size of the largest individuals, relative to $L_\infty$, strongly influences the SPR estimate. From the left-side of the mode the LBSPR methodology estimates the logistically shaped size-selectivity curve and with that estimate determines the relative fishing pressure (F/M) that would produce the estimated level of SPR. Because the estimate of SPR is primarily determined by the right-hand side of the mode, in order to derive the most accurate estimate of SPR possible, it is critically important that the model accurately fits to the right-side of the size composition data.

Unfortunately, nature is more complex than assumptions used for data-poor assessment can always allow for, and in many cases bi-modal or even multi-modal size composition data are encountered. Where there is more than one mode the one/s on the left side of the size composition are usually (but not always) numerically smaller, and are normally comprised of juveniles, while the larger sized, and numerically more abundant mode on the right will be comprised of adult, and maturing sub-adults to varying degrees. This situation arises because of another simplifying assumption that is used almost universally in every type of stock assessment. Which is that all size and age classes experience similar levels of natural mortality (M), with LBSPR the equivalent assumption is that M/K is similar across size classes. This assumption can become problematic for LBSPR assessment. The rate of natural mortality (M) is the most difficult life history parameter to measure, and has mainly been estimated for the commercially exploited adult portion of marine stocks. Consequently, the simplifying assumption of constant M is both widely used due to necessity, and acknowledged as not been strictly correct. Almost universally smaller size classes suffer higher rates of mortalities. Fortunately, most stock assessment methodologies focus on modelling adults, or spawning biomass, for which the constant M assumption is most valid. Biomass equations relate spawning biomass to recruitment, the abundance of cohorts as they ‘recruit’ into the adult-biomass being fished. With conventional biomass modelling this definition of recruitment to the fished size classes neatly avoids needing to accurately compute numbers in the ‘pre-recruit’ juvenile cohorts.

The implication for LBSPR assessment, of this violation of the simplifying assumption of constant M, is that when fisheries effectively target juvenile size classes, the juvenile size classes become more abundant in samples than the LBSPR algorithms can accurately account for. Subject to higher M smaller size classes of fish are, in reality, far more abundant than estimated, using the assumption of constant M. But when more than one modal size class occurs in the size frequency data, the LBSPR with its underlying assumptions, is constrained to describe the size composition as consisting of a single modal size group. It will always attempt to group all the size classes into that one mode, and this will normally be at the expense of it accurately fitting to the right-side of the size composition which contains the principal information about SPR and F/M. When the relative proportions of the smallest sizes classes are ‘over-represented’ in this way, SPR will be under-estimated, and relative fishing mortality (F/M) over-estimated.

Working with South Atlantic small pelagic fisheries Pons et al. (2020) found that focussing LBSPR assessment on the catch composition that most accurately reflected the adult composition of the population produced the best estimate SPR estimates. Although using a sub-set of data in this way must inevitably result in both size selectivity and F/M being biased proportionally.

## Implementing Adaptive Fisheries Management with Harvest Control Rules

Known as ‘Adaptive Management’; the capacity to adapt and adjust the management of fisheries should be designed into all fisheries management plans. So that management can be incremental adjusted in response to stock abundance changing due to fishing pressure and environmental variation. And to incorporate learning derived over time through the experience of managing.

Plans for Adaptive Management plans are formalized as ‘Harvest Strategies’ the elements of which are:

A. Management objectives.
B. Indicators of fishery status against which stocks will be assess, and which will be routinely monitored to enable regular re-assessment.
C. A methodology for assessing the fishery based on the indicators being monitored.
D. A framework of management regulations that can be incrementally adjusted in relation to the assessed status of the fishery.
E. Harvest Control Rules which define the extent to which management regulations are incrementally adjusted in response to assessment results so as to achieve management objectives.

The aim of Harvest Strategies is to keep the process of adjusting management disciplined and transparent and as free as possible from influence by political processed driven by vested interest groups. For this purpose, Harvest Strategies should be designed and agreed by stakeholders outside the process of making actual decisions about changing management regulations.

Central to the Harvest Strategy are the Harvest Control Rules (HCRs), that connect numerical stock assessment results to incremental regulated management adjustments. The final aim of this project, is to initiate the process of developing the Harvest Control Rules (HCRs) for this assemblage of fisheries. To this end the final section of this report presents schematically several frameworks of fisheries logic and indicators that could be applied as HCRs for these fisheries with current streams of fisheries monitoring data. The frameworks presented can be developed and codified, and then tested with management strategy evaluation (MSE) for implementation. And it is hoped that a parallel project with Dr Tom Carruthers and MSC will enable this to happen.

## Balistes polylepis – Cochito - Triggerfish

### Life History Ratios

To date relatively few high-quality age and growth studies have been collected to estimate M/K for the Balistidae family through meta-analysis (Prince et al. in prep.a).

M/K = 1.21; n = 7

Based on the correlation between the two LHR (Prince et al. in prep.a) it can be inferred that;

$L_m/L_\infty = 0.63$; n = 0

As noted in the introduction, the theory behind the correlation of the two LHR and the taxonomic variability of the LHR, leads to the supposition that ecologically and physiologically similar species have similar LHR. In that context it is relevant that the LHR of the ecologically similar Monacanthidae family are better documented, and as expected, similar to our initial estimates for Balistidae, the M/K being just a little higher, while the Monacanthidae estimate of $L_m/L_\infty$ based on 5 high quality published estimates is very close to that inferred through correlation:

M/K = 1.47; n = 8

$L_m/L_\infty = 0.647$; n = 5

### Life History Parameters

For cochito, growth has been studied at Mazatlan by Barroso-Soto et al. (2007) who estimated $L_\infty = 55.8$ cm. When the data from that study were digitized and standardized growth estimates produced using the methodology of Prince et al. (in prep. a) an estimate of $L_\infty = 55.0$ cm was produced, which assuming $L_m/L_\infty = 0.63$, infers $L_m = 34.6$ cm. The age and growth data of Barroso-Soto et al. (2007) do not clearly define asymptotic size as there are almost no data around of around asymptotic size. This may not be as much of an issue as it is with some of the species in this analysis, as the relatively high M/K of this taxa implies even without fishing pressure relatively few individuals would survive to achieve asymptotic size.

The estimate of $L_m$ = 33.8 cm by Camacho Mondragon et al. (2019) from a study conducted in El Corredor is similar to the $L_m$ = 34.6 cm we infer from the Barroso-Soto et al. (2007) study ($L_\infty$ = 55.8 cm) and $L_m/L_\infty$ = 0.63. Given that Mazatlan, where that growth study was conducted is at a similar Latitude as La Paz, and probably relatively similar water temperature regimes, we would expect this consistency, suggesting these estimates are of reasonable quality, or at least internally consistent. So that, while we have relatively little in the way of detailed biology for cochito in El Corredor, the internally consistency of our estimates gives us some confidence in what we have.

## Size Composition Data

The catch size composition of cochito consistently produces uni-modal bell-shaped size histograms which conform to the assumptions of LBSPR assessment (Figures 3 - 6). There is apparently little variation in size composition spatially (Figure 4), with depth (Figure 5) or over time (Figure 6).

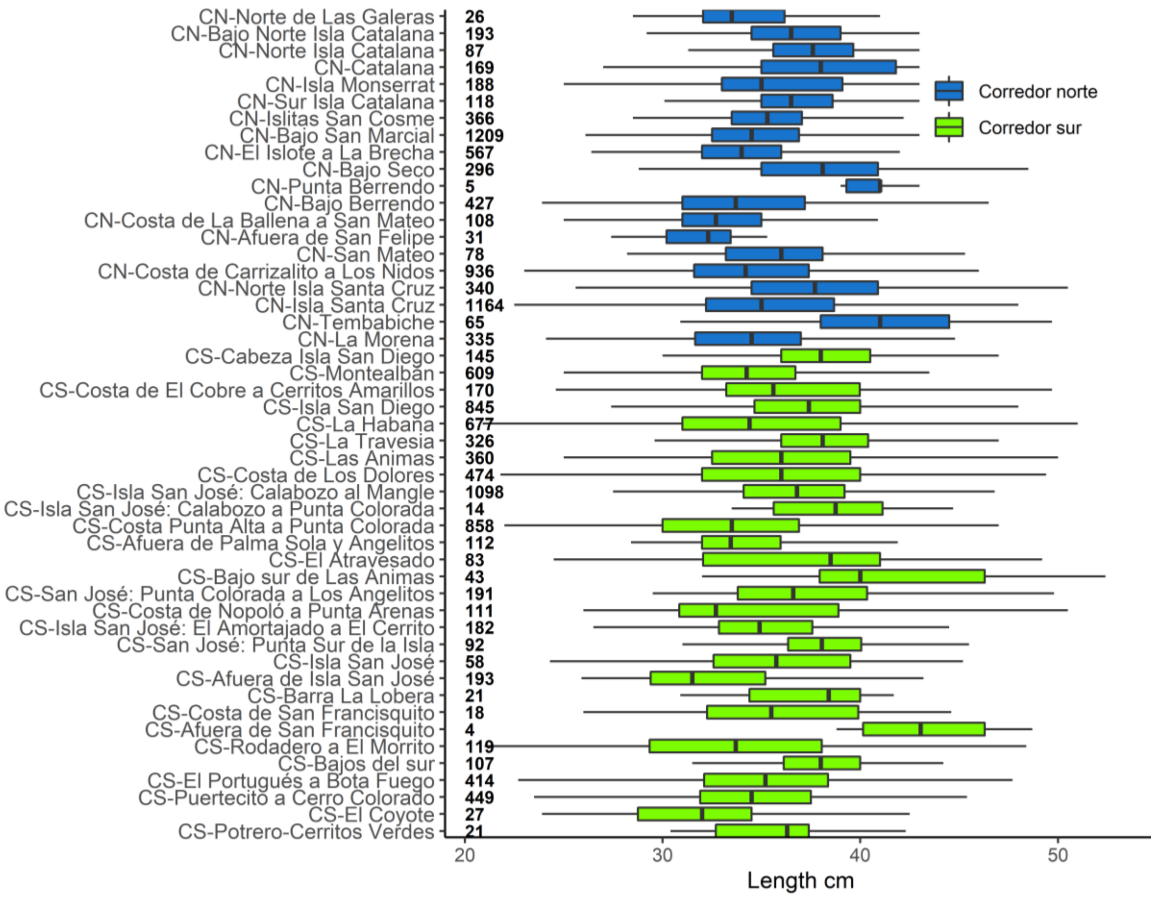


*Figure 3. Percentile length-frequency data for cochito aggregated across all years (2009-2019) and depth categories; plotted by fishing areas sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

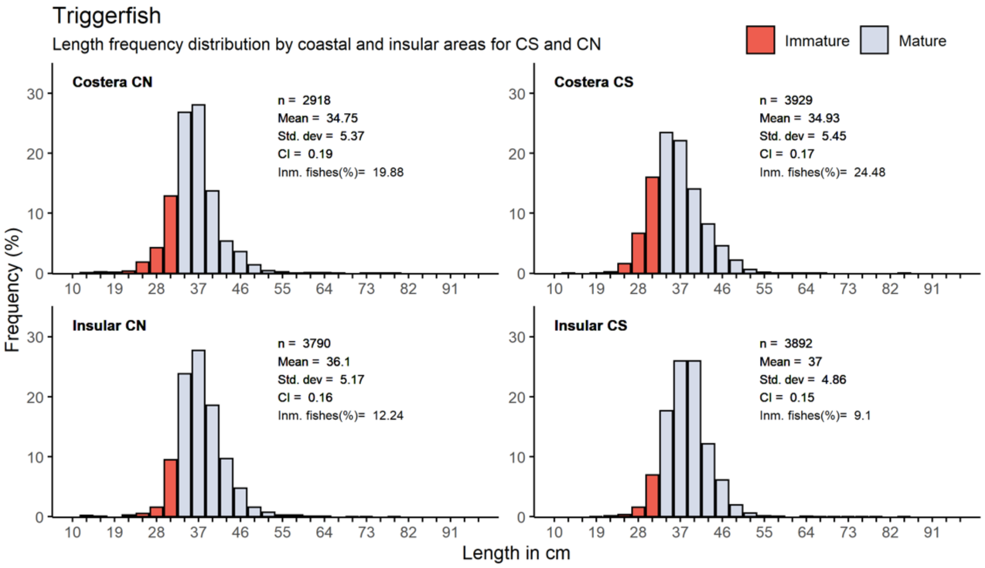


*Figure 4. Length-frequency data for cochito aggregated across all years (2009-2019); plotted by coastal (costera) and offshore (Insular) in the north and south of El Corredor. Size at maturity (33.8 cm) according to Camacho Mondragon et al. (2019) indicated by darker colouring.*

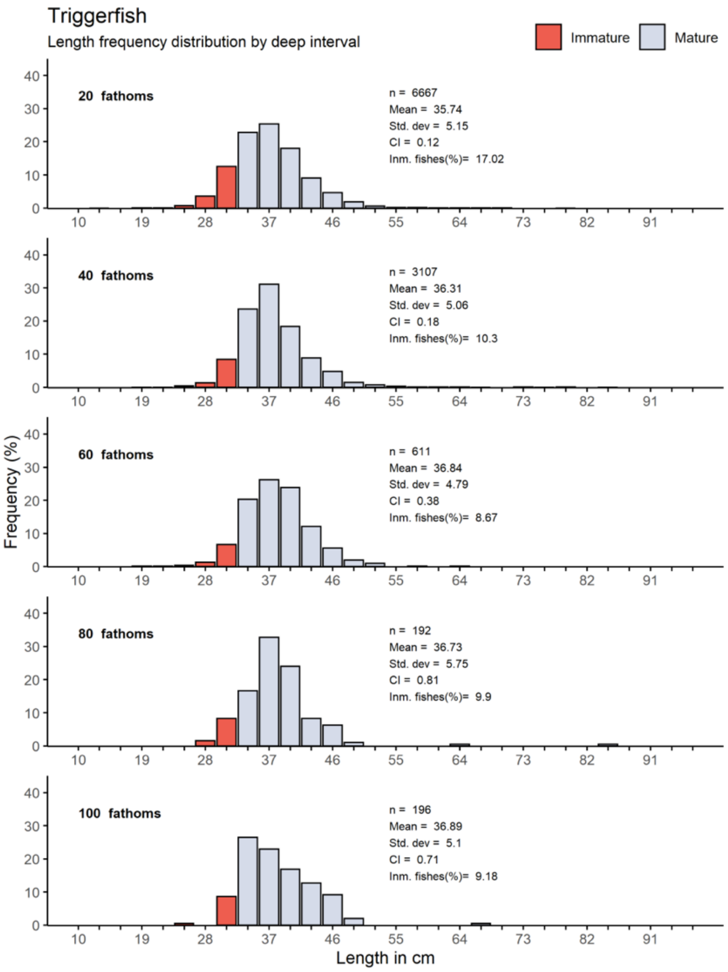


*Figure 5. Length-frequency data for cochito aggregated across all years (2009-2019) and fishing locations; plotted by depth category. Size at maturity according to Camacho Mondragon et al. (2019) indicated by darker colouring.*

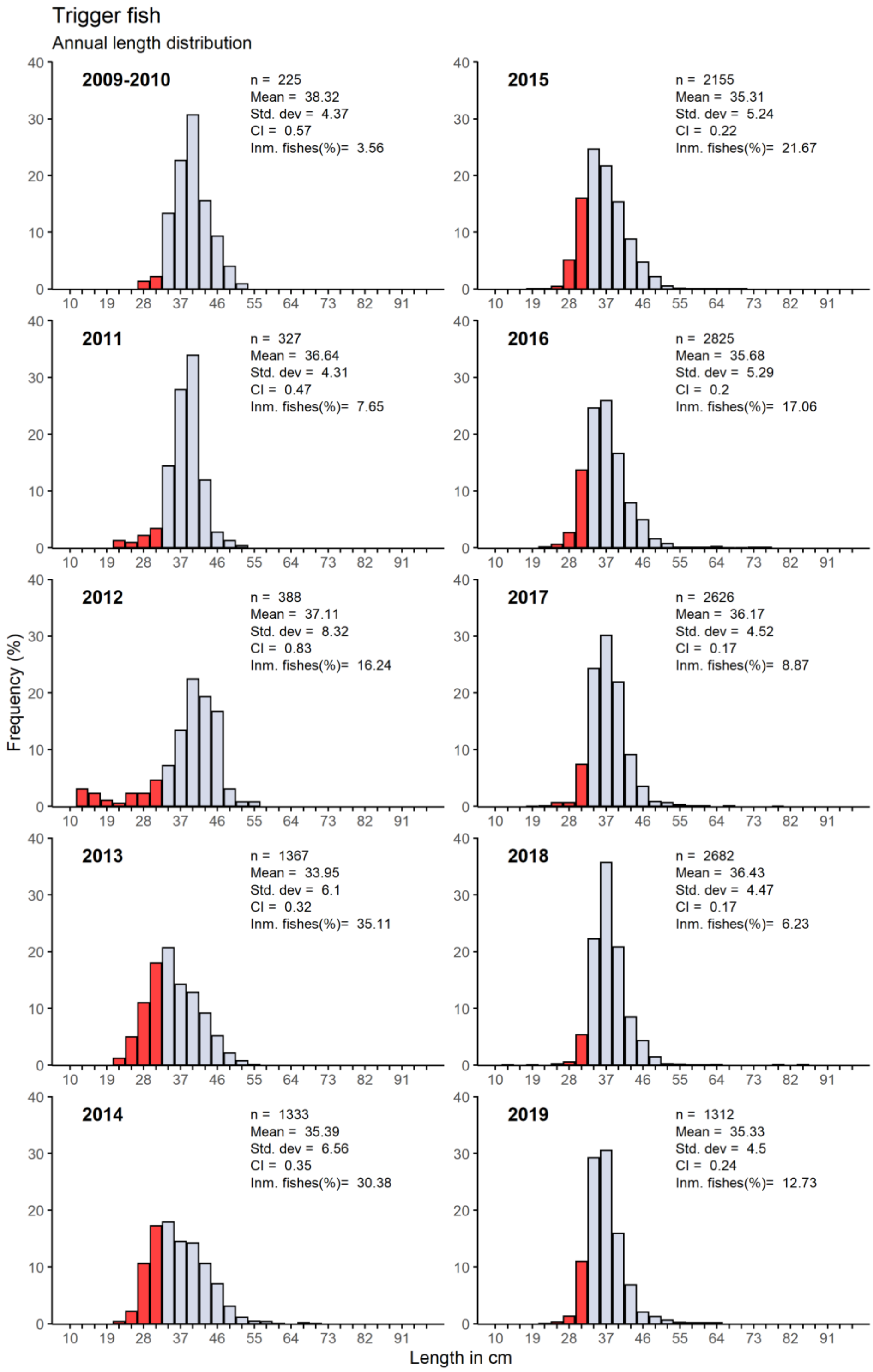


*Figure 6. Length-frequency data for cochito aggregated across fishing areas and depth categories; plotted by year/s. Size at maturity according to Camacho Mondragon et al. (2019) indicated by darker colouring.*

## Catch Per Unit Effort Data

The cochito CPUE data suggest some spatial variability between fishing locations within the two zones, which might be suggestive of high/low exploitation areas or more probably the extent to which cochito are caught with either traps, or hook and line fishing in the different fishing locations (Figure 7). The highest and most variable catch rates are apparently recorded in the shallows <20 fathoms (Figure 8) which may again indicate that most of the fishing with traps occurs in those depths, as well as a lot of hook and line fishing during which other species are also being caught, and the catch rate of cochito is lower. The aggregate CPUE appear to have been relatively stable over time (Figure 9), but this may be due to the aggregation of data, which might mask more complex trends in different parts of the fishery, or for the different gear types. It is to be expected that the transition to targeting with traps has increased the effectiveness of fishing, and served to stabilise the trend in aggregate average catch per fishing trip. In a subsequent analysis of CPUE these data should be dis-aggregated by depth, region and gear type.

Some 1170.97t of cochito was recorded being landed during the period 2006-2017 of which more than 50% was landed in the final three years of the time series (Figure 10), probably due to increasing use of traps. Suggesting fishing pressure was increasing rapidly towards the end of this time period.

The vast majority of the catch records in the database contain <25% cochito, although a reasonable proportion are comprised of >95% cochito (Figure 11). This is consistent with the species being targeted relatively selectively with traps, as well as being caught with hook and line as part of a broader assemblage of species.

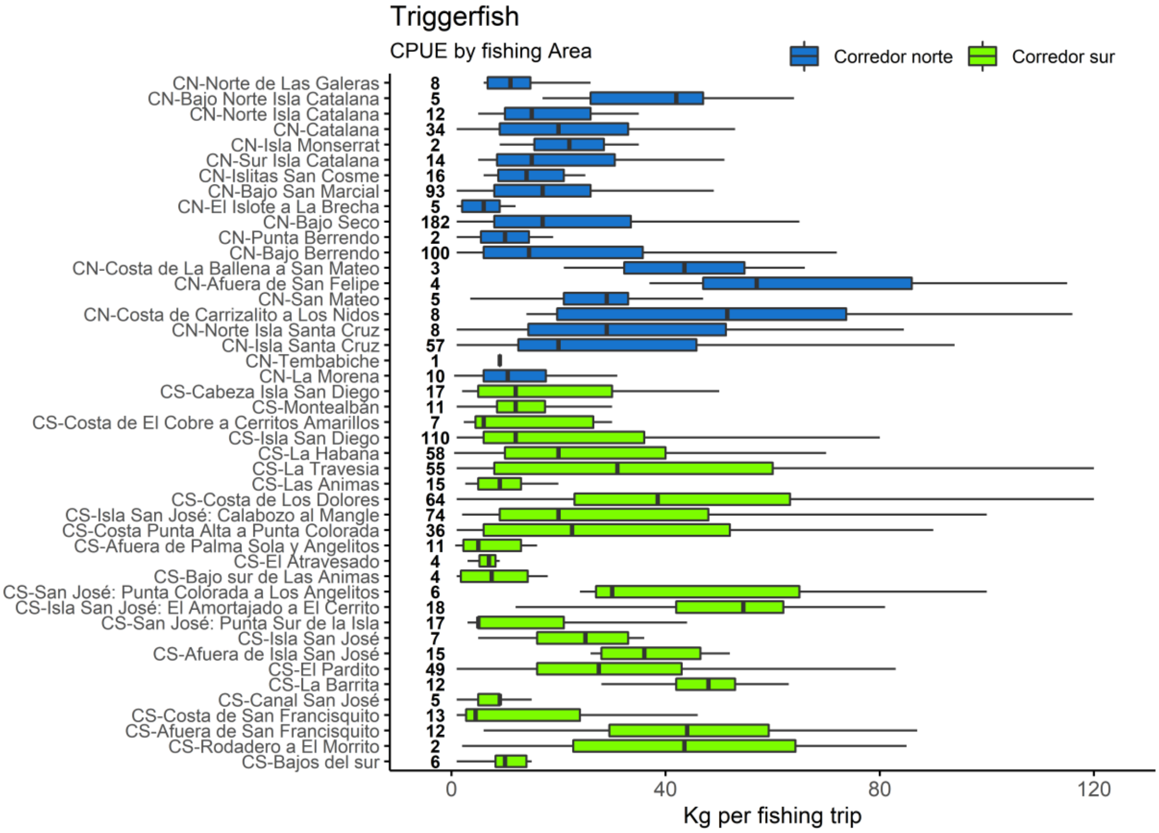


*Figure 7. Percentile catch-per-unit-effort data for cochito aggregated across all years (2009-2019) and depth categories, plotted by fishing area sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

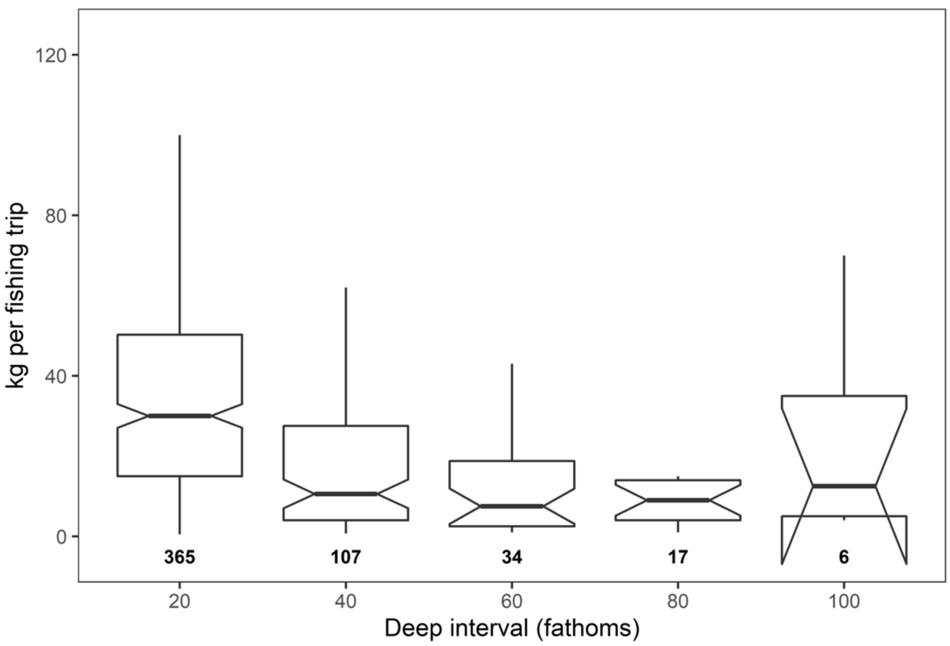


*Figure 8. Catch-Per-Unit-Effort data for cochito aggregated across all years (2009-2019) and fishing locations; plotted by depth category. Bold values mark sample size for depth category, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range. The unusual shape of the last boxplot indicates the low sample size.*

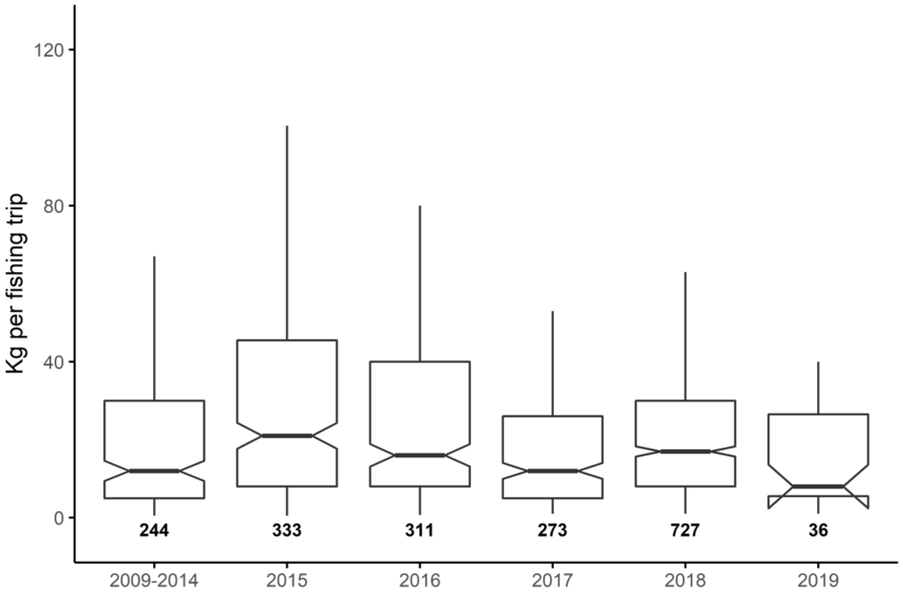
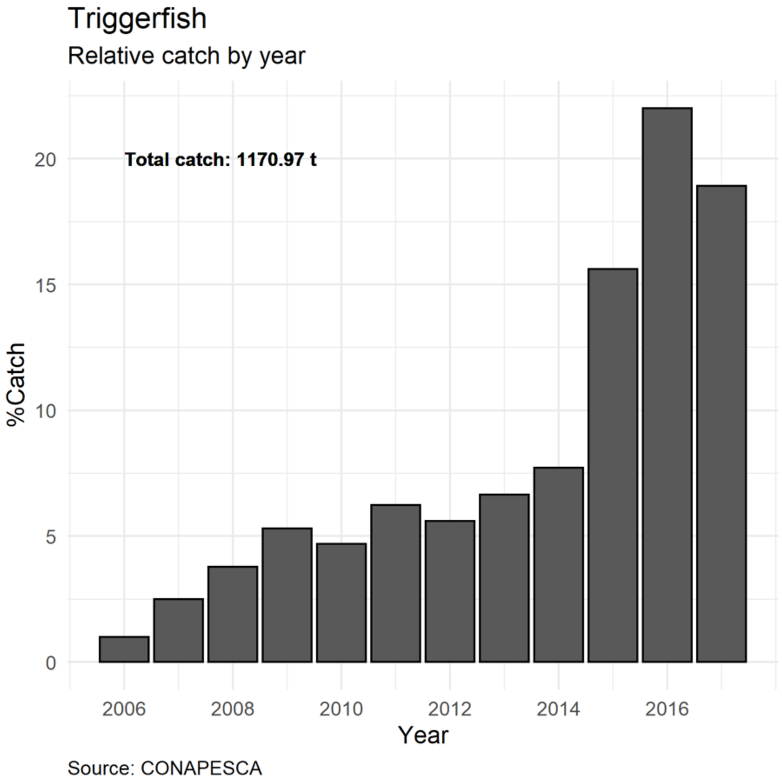


*Figure 9. Catch-Per-Unit-Effort data for cochito aggregated across all depth categories and fishing areas, plotted annually or time period. Bold values mark sample size for depth category, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range. The unusual shape of the last boxplot indicates the low sample size.*


Triggerfish

Relative catch by year

Source: CONAPESCA

*Figure 10. The proportion of total recorded catch of cochito from 2006-2017 (1170.97t) that was recorded in each year of that time series. This figure shows that >50% of the recorded cochito catch was taken in the final three years of the time series.*

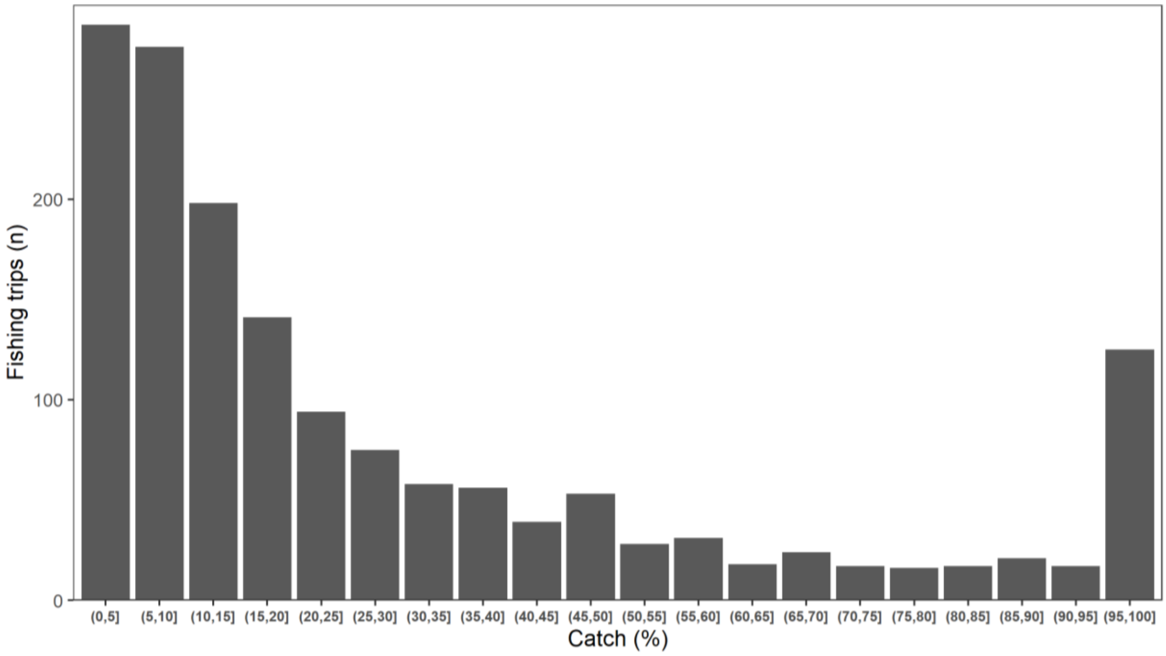


*Figure 11. Cochito catch data aggregated across all years (2014-2019), depth categories and locations; plotted as the number of sampled trips in which cochito comprised each percentage range of the catch. This*

*figure shows that most catches contain a low proportion of cochito, but that >100 catches (on the extreme right) were >95% cochito.*

## Initial LBSPR Assessment

In completing the initial LBSPR assessment of the aggregated dataset (all years, depths and fishing locations) we initially assumed the Balistidae family average M/K = 1.21 that had been derived through meta-analysis (Prince et al. in prep. a), together with $L_m/L_\infty = 0.63$ derived from the correlation between the two LHR estimated by that study. We also initially assumed the standardized Mazatlan estimate of $L_\infty$= 55 cm and $L_m/L_\infty = 0.63$ to infer $L_{50}$ = 34.6 cm with $L_{95} = L_{50} \times 1.1$ for the Corredor.

These assumptions produced a reasonable fit with size selectivity in the catch estimated to be similar to the size of maturity (Figure 12). The results of that version of the assessment suggests moderately low level of SPR = 24% and relatively high fishing pressure F/M = 2.3. Analysed by year with that initial set of input parameters, suggests that SPR is declining slowly over time as F/M increases more rapidly (Figure 13; Table 2). This interpretation of the data implies that the SPR remains relatively stable because the fishery is targeting adults while the juveniles are protected from fishing pressure by the size selectivity being similar to the size of maturity. Considering that the targeting of cochito with traps has developed relatively recently the workshop participants considered that the high level of fishing pressure, suggested by this initial version of the assessment to have existed since the earliest part of the time series, to be unrealistically high. Consequently, we also explored a plausible alternative set of input parameters.

From meta-analysis, we also have available the LHR estimates for Monacanthidae (M/K = 1.47, n=8; $L_m/L_\infty = 0.647$, n=5), which are based on a bigger sample of high-quality international studies than our Balistidae LHR estimates (M/K = 1.21, n=7; no estimates of $L_m/L_\infty$). Being morphologically and ecologically similar taxa, it can be argued that the bigger sample of Monacanthidae LHR might provide a more reliable approximation of the actual LHR of Balistidae, or at least help define a plausible range. For this alternative analysis we also assumed the smaller local estimate of $L_m$ = 33.5 cm (Camacho Mondragon et al. 2019), from which assuming $L_m/L_\infty = 0.647$, we can infer a smaller $L_\infty$ = 52 cm.

With this selection of input assumptions, higher estimates of SPR and lower F/M are produced which conforms more closely to workshop's expectations that heavier exploitation has developed relatively recently (Figures 16 – 18; Table 3). This version of the assessment suggests SPR has declined from ~60% to ~40% during the time series while F/M has increased from ~ 0.4 to >1.5.

| SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|
| 0.24 (0.23 - 0.25) | 33.46 (33.27 - 33.65) | 39.92 (39.6 - 40.24) | 2.3 (2.2 - 2.4) | 1.21 | 55 | 34.6 | 38 |

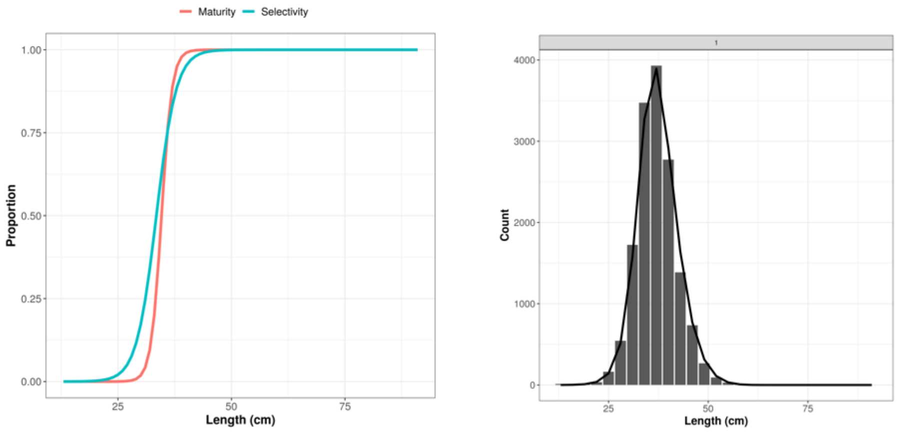


*Figure 12. Initial LBSPR assessment using size composition of the catch data aggregated across all years, fishing areas and depths. The table shows derived estimates of spawning ratio potential (SPR) and the size of 50% and 95% selectivity ($SL_{50}$ & $SL_{95}$) and relative fishing pressure (F/M). The estimated 95% confidence intervals around these mean estimates are shown in brackets. The input parameters assumed are indicated to the right; life history ratio M/K, asymptotic size ($L_\infty$), size at 50% and 95% maturity ($L_{50}$ & $L_{95}$). The left-hand panel presents plots of assumed size of maturity ogive (red) and the estimate size of selectivity (blue). The right-hand panel plots the size composition data analysed (black bars) and the LBSPR modelled fit to those data.*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2013 | 0.25 (0.2 - 0.3) | 30.29 (28.71 - 31.87) | 38.54 (35.87 - 41.21) | 1.52 (1.14 - 1.9) | 1.21 | 56 | 35 | 39 |
| 2014 | 0.34 (0.29 - 0.38) | 30.47 (29.6 - 31.34) | 36.16 (34.56 - 37.76) | 1.08 (0.87 - 1.29) | 1.21 | 56 | 35 | 39 |
| 2015 | 0.23 (0.21 - 0.25) | 31.65 (31.15 - 32.15) | 36.92 (36.03 - 37.81) | 1.89 (1.67 - 2.11) | 1.21 | 56 | 35 | 39 |
| 2016 | 0.22 (0.21 - 0.24) | 32.12 (31.74 - 32.5) | 36.93 (36.25 - 37.61) | 2.03 (1.84 - 2.22) | 1.21 | 56 | 35 | 39 |
| 2017 | 0.21 (0.19 - 0.22) | 34.45 (34.06 - 34.84) | 39.73 (39.06 - 40.4) | 3.06 (2.75 - 3.37) | 1.21 | 56 | 35 | 39 |
| 2018 | 0.22 (0.2 - 0.23) | 34.64 (34.31 - 34.97) | 39.08 (38.5 - 39.66) | 3.02 (2.72 - 3.32) | 1.21 | 56 | 35 | 39 |
| 2019 | 0.2 (0.18 - 0.22) | 33.23 (32.76 - 33.7) | 38.71 (37.9 - 39.52) | 2.68 (2.35 - 3.01) | 1.21 | 56 | 35 | 39 |
| 2020 | 0.18 (0.15 - 0.22) | 34.94 (33.87 - 36.01) | 40.49 (38.74 - 42.24) | 3.87 (2.83 - 4.91) | 1.21 | 56 | 35 | 39 |

*Table 2. Initial LBSPR assessment of cochito using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_\infty$ = 56 cm and $L_{50}$ = 35 cm. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

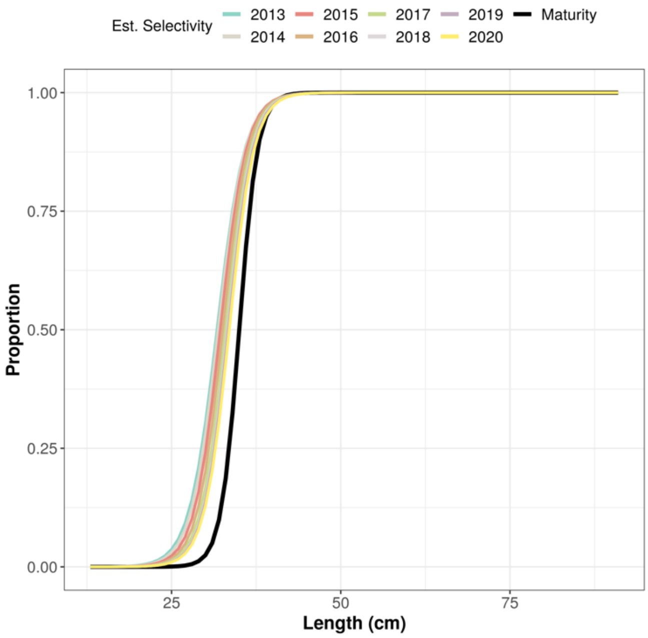


*Figure 13. Results of initial LBSPR of cochito using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_\infty$ = 56 cm and $L_{50}$ = 35 cm. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

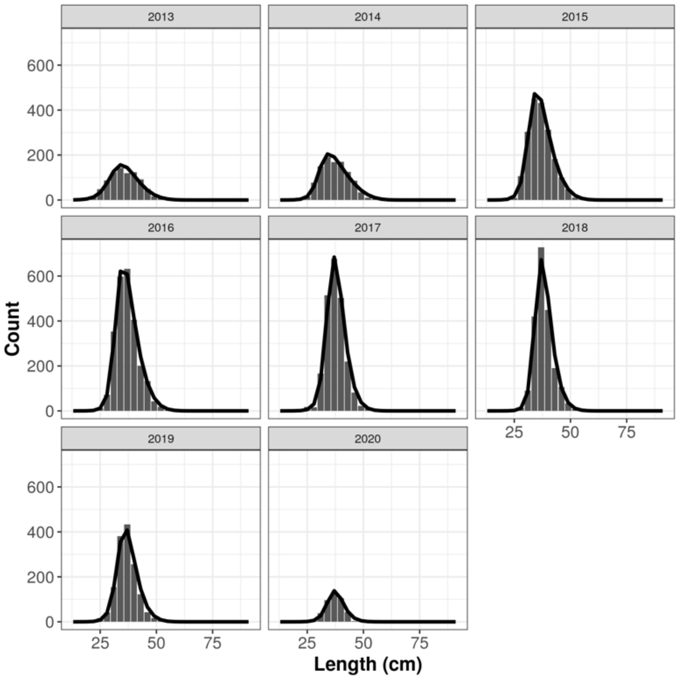


Figure 14. *Initial LBSPR assessment of cochito using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_\infty$ = 56 cm and $L_{50}$ = 35 cm. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

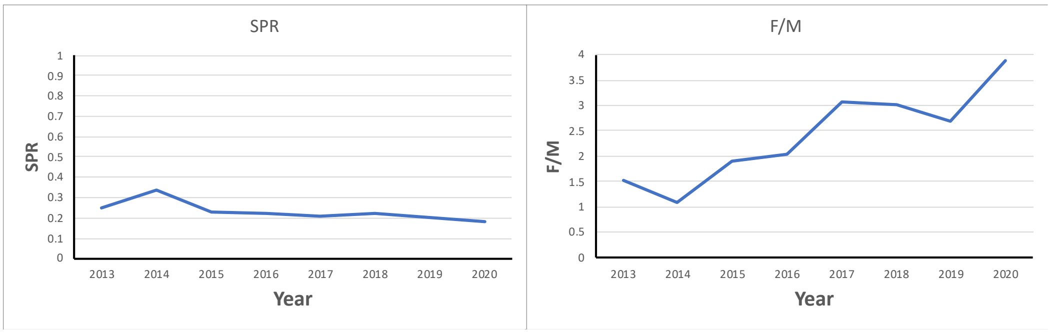


*Figure 15. Initial LBSPR assessment of cochito using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_\infty = 56$ cm and $L_{50} = 35$ cm. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2013 | 0.57 (0.46 - 0.67) | 29.24 (27.78 - 30.7) | 36.48 (34.01 - 38.95) | 0.48 (0.28 - 0.68) | 1.47 | 52 | 33.5 | 37 |
| 2014 | 0.7 (0.61 - 0.79) | 30.03 (29.17 - 30.89) | 35.22 (33.67 - 36.77) | 0.29 (0.16 - 0.42) | 1.47 | 52 | 33.5 | 37 |
| 2015 | 0.47 (0.43 - 0.51) | 31.43 (30.93 - 31.93) | 36.44 (35.57 - 37.31) | 0.82 (0.69 - 0.95) | 1.47 | 52 | 33.5 | 37 |
| 2016 | 0.45 (0.41 - 0.48) | 32.08 (31.69 - 32.47) | 36.77 (36.08 - 37.46) | 0.97 (0.84 - 1.1) | 1.47 | 52 | 33.5 | 37 |
| 2017 | 0.41 (0.38 - 0.44) | 34.35 (33.95 - 34.75) | 39.48 (38.81 - 40.15) | 1.52 (1.33 - 1.71) | 1.47 | 52 | 33.5 | 37 |
| 2018 | 0.42 (0.4 - 0.44) | 34.64 (34.31 - 34.97) | 39.01 (38.43 - 39.59) | 1.56 (1.37 - 1.75) | 1.47 | 52 | 33.5 | 37 |
| 2019 | 0.39 (0.36 - 0.42) | 33.29 (32.79 - 33.79) | 38.71 (37.89 - 39.53) | 1.4 (1.18 - 1.62) | 1.47 | 52 | 33.5 | 37 |
| 2020 | 0.37 (0.31 - 0.43) | 34.84 (33.75 - 35.93) | 40.21 (38.46 - 41.96) | 2.03 (1.39 - 2.67) | 1.47 | 52 | 33.5 | 37 |

*Table 3. Initial LBSPR assessment of cochito using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming Monocanthidae LHR (M/k=1.47; $L_m/L_\infty = 0.647$) and $L_m = 33.5$ cm as estimated for the Corridor and thus $L_\infty = 52$cm. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

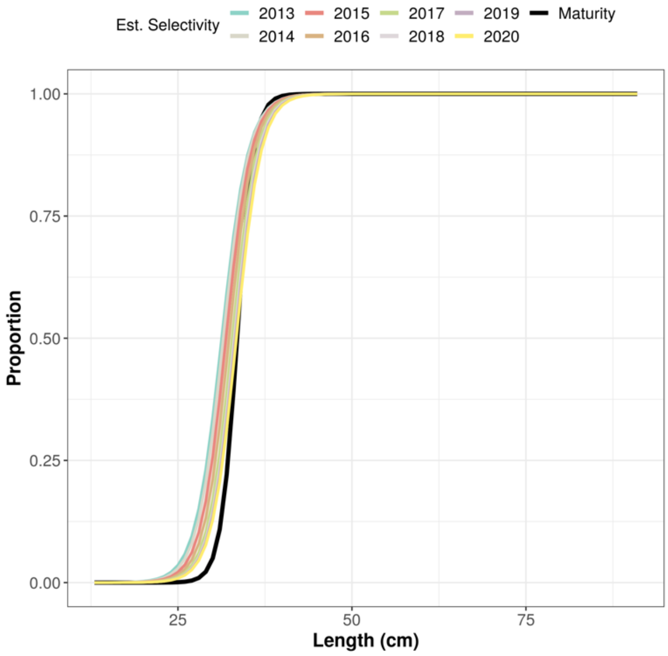


*Figure 16. Results of initial LBSPR of cochito using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming Monocanthidae LHR (M/k=1.47; $L_m/L_\infty = 0.647$) and $L_m = 33.5$ cm as estimated for the Corredor and thus $L_\infty = 52$cm. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

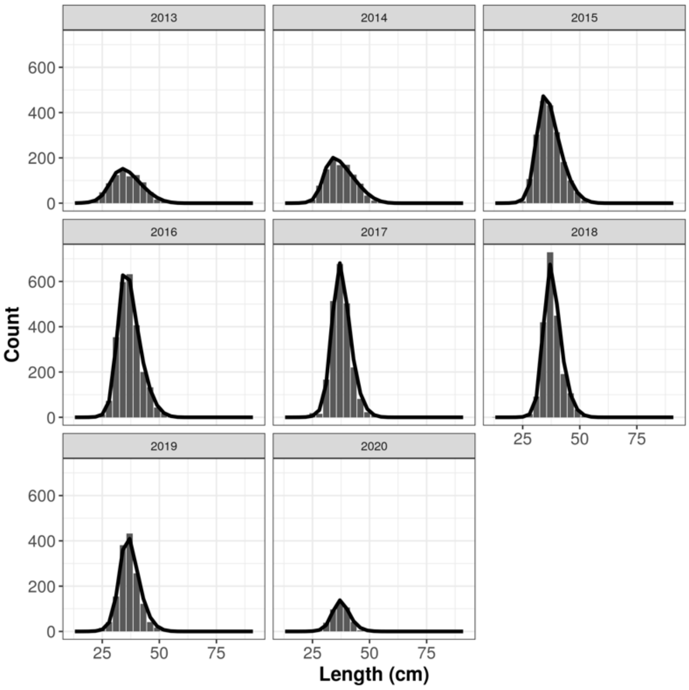


*Figure 17. Initial LBSPR assessment of cochito using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming Monocanthidae LHR (M/k=1.47; $L_m/L_\infty$ = 0.647) and $L_m$ = 33.5 cm as estimated for El Corredor and thus $L_\infty$ = 52cm. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

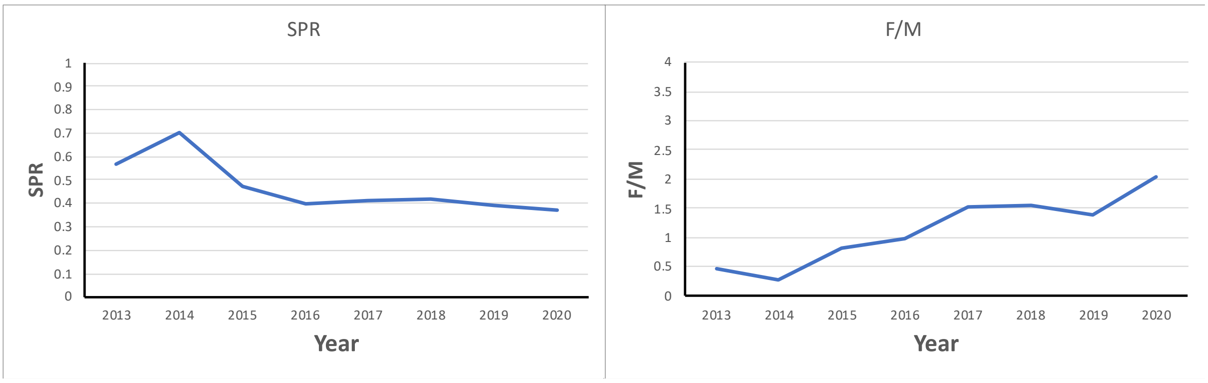


*Figure 18. Initial LBSPR assessment of cochito using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming Monocanthidae LHR (M/k=1.47; $L_m/L_\infty$ = 0.647) and $L_m$ = 33.5 cm as estimated for El Corredor and thus $L_\infty$ = 52cm. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

## Cochito Discussion

With a simple and consistent unimodal size structure the cochito catch size composition data should be conducive to relatively simple assessment with the LBSPR technique. The issue with this species is uncertainty around the choice of input assumptions, depending upon which, the resource is estimated to have relatively low (8-25%) or high (35-60%) levels of SPR. In either case SPR is estimated to be trending down and fishing pressure increasing.

There does not seem much prospect for quickly reducing this uncertainty around our assessments. The two estimates of size of maturity ($L_m$) from Mazatlan and the Corredor are from a good quality histological studies, and comparable as might be expected from their similar latitude origin, and presumably ambient water temperature which via dissolved oxygen levels largely determines fish growth (Pauly 2010). So that conducting another study of size of maturity with the same technique would be expected to simply confirm the existing estimates. If further studies of size of maturity were to be conducted we would recommend applying a range of methodologies to enable some comparisons to be made between techniques. This topic is be discussed more generally in the concluding discussion of this report.

An age and growth study from the Corredor would be useful if it produced accurate estimates of the growth parameters, however it would take time and resources, and because the age and size structures of the cochito population has already been truncated by fishing, accurately estimating asymptotic size will be challenging. If such a study is going to be conducted the focus should be on making sure adequate numbers of the largest size classes of fish are found and sampled. As also discussed more generally in the final discussion, this could be achieved if the sampling program for any age and growth study worked collaboratively with the Niparaja catch size composition sampling program.

In the absence of further field studies improving the sample size of studies included in the LHR meta-analysis for both Balistidae and Monocanthidae through further literature search and meta-analysis, could be the most immediate and cost-effective way of narrowing the current range of plausible parameters and assessments.

Some level of uncertainty around the input parameters will need to be accepted and incorporated into the LBSPR assessments with the boot-strapping methodology developed by Hordyk to estimate confidence intervals around the estimates of SPR and F/M to quantify the uncertainty.

The CPUE data should be disaggregated to examine the extent to which the disaggregated CPUE trends vary between fishing area, fishing gear and depth zone. Both the CPUE from hook and line, and trap fishing may provide useful indicators of stock abundance, only further exploration of the data will determine that.

## *Mycteroperca rosacea* - Cabrilla sardinera - Leopard Grouper

### Life History Ratios

There is a good-sized sample of high quality LHR estimates available for the family Serranidae from the meta-analysis of Prince et al. (in prep. a) which produce the average estimates;

$M/K = 1.16$; $n = 131$
$L_m/L_\infty = 0.65$; $n = 81$

### Life History Parameters

The growth and size of maturity of cabrilla sardinera have been estimated at Santa Rosalia producing the estimates of:

$L_m = 42$cm (Perez-Olivas 2016) and
$L_\infty = 69.2$ cm (Bermejo Miramontes 2018) or
$L_\infty = 65.8$ cm when standardized.

Using the standardized estimate $L_\infty = 65.8$ cm from Santa Rosalia, and the estimate of $L_m = 42$ cm results in $L_m/L_\infty = 0.638$ which is in close agreement to the estimate for the Serranid family of $L_m/L_\infty = 0.65$ derived from meta-analysis of high quality LHR estimates (Prince et al. in prep a). This comparison supports our confidence in the parameter estimates from Santa Rosalia as the life history ratios they infer are consistent with the averages produced from the large body of international age and growth studies. However, being from Santa Rosalia, further north into the Gulf, and we infer further from cooler deep oceanic influences, we expect slightly warmer ambient water temperatures and slightly lower dissolved oxygen levels in El Corredor; environmental conditions expected to result in smaller body sizes in fish. So that our expectation is that the body size of this species will be smaller in Santa Rosalia than in El Corredor.

Growth of cabrilla sardinera has also been studied around La Paz, which resulted in an estimate of $L_\infty = 122.6$ cm (Diaz-Uribe et al. 2001). When I re-digitised these data and standardized it produced a growth estimate of $L_\infty = 104.7$ cm. However, the age at size data of Diaz-Uribe et al. (2001) contains relatively few individuals around asymptotic size, suggesting that age and size structure of the sampled population had already been truncated by fishing. The unfortunate consequence of that truncation is that these estimates of $L_\infty$ are not well informed by data, and so the estimates of $L_\infty$, and of the inferred $L_m$, are most probably biased high. Never-the-less based on that standardized estimate of $L_\infty$ from that study and assuming the average LHR for Seranids ($L_m/L_\infty= 0.65$) we imply that in El

Corredor $L_m$ ~ 68 cm, some 26 cm larger than estimated at Santa Rosalia by Perez-Olivas (2016).

## Size Composition Data

The catch size composition data for cabrilla sardinera consistently produce simple relatively normal looking bell-shaped size histograms (Figures 19 - 23) consistent with the assumptions underlying the LBSPR algorithms. There is little if any evidence of any consistent variability (data-structure) by location (Figure 20) or depth strata (Figure 21). Although the size data suggest some truncation of the largest size classes in later years (Figure 22).

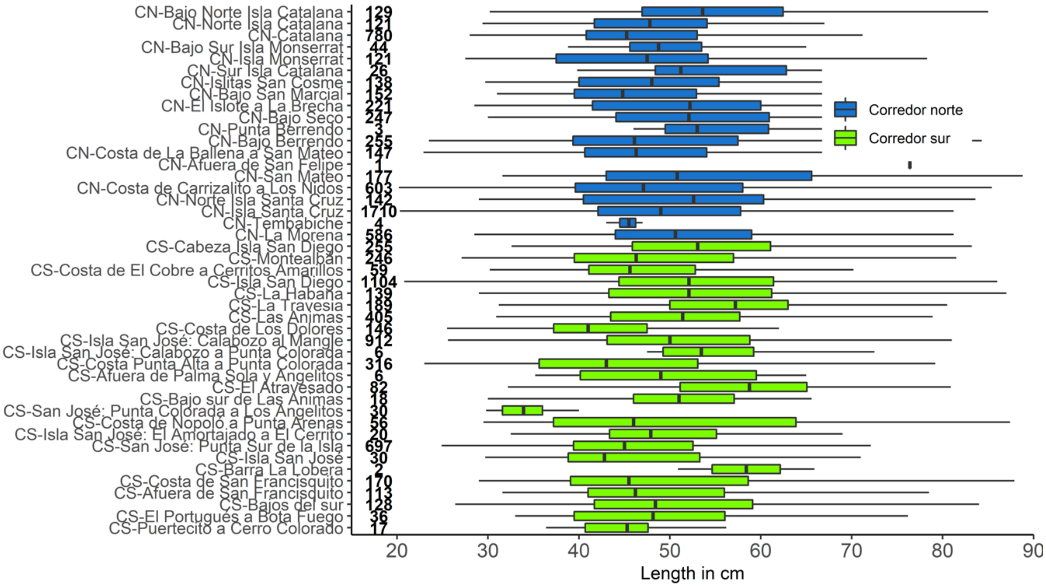


*Figure 19. Percentile length-frequency data for cabrilla sardinera aggregated across all years (2009-2019) and depth categories; plotted by fishing areas sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

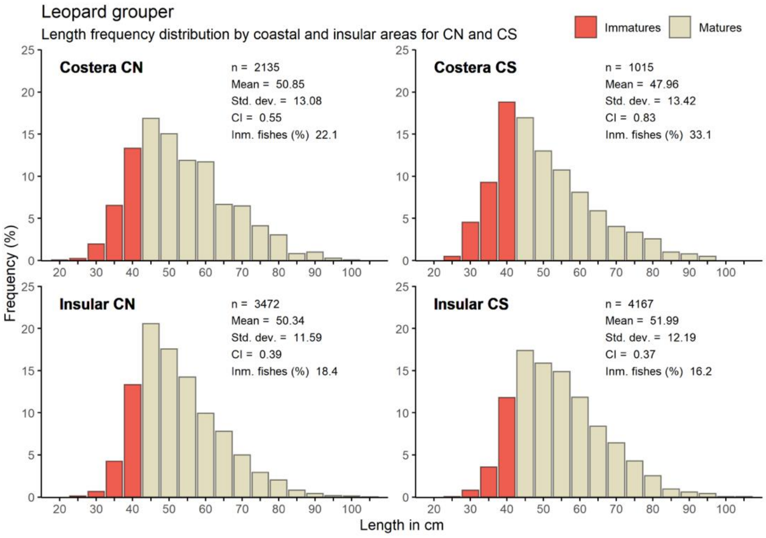


*Figure 20. Length-frequency data for cabrilla sardinera aggregated across all years (2009-2019); plotted by coastal (costera) and offshore (Insular) in the north and south of El Corredor. Size at maturity according to Perez-Olivas et al. (2018) indicated by darker colouring.*

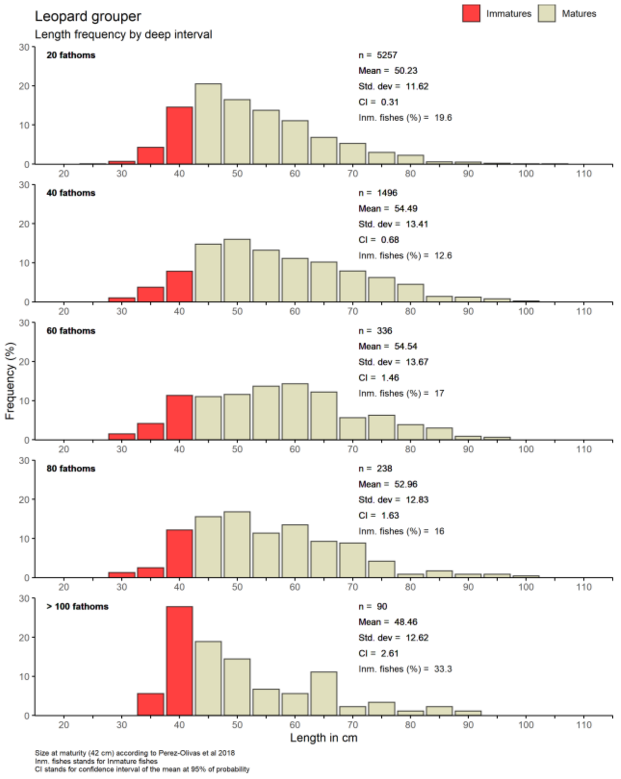


*Figure 21. Length-frequency data for cabrilla sardinera aggregated across all years (2009-2019) fishing locations; plotted by depth category. Size at maturity according to Perez-Olivas et al. (2018) indicated by darker colouring.*

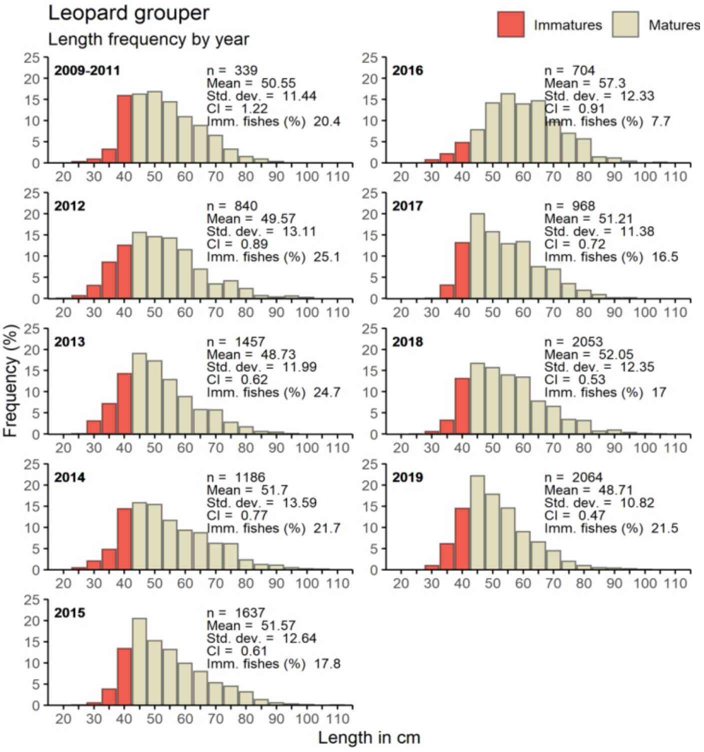


*Figure 22. Length-frequency data for cabrilla sardinera aggregated across all years (2009-2019) and depth categories; plotted by time period. Size at maturity according to Perez-Olivas et al. (2018) indicated by darker colouring.*

## Catch and Catch Per Unit Effort Data

Similarly, the CPUE data for cabrilla sardinera appear to be relatively consistent spatially (Figure 23), across the depth strata (Figure 24) and temporally (Figure 25), supporting the inference that with cabrilla sardinera there is little population structuring.

As with many of the other species in this analysis the level of catch has been increasing in the more recent years. From Figure 26it can be seen that >60% of the 586.7t of cabrilla sardinera recorded caught in the 12 year time series (2006-2017) were taken in the final 5 years of the time series.

From Figure 27it can be seen that cabrilla sardinera is generally caught as a minor proportion (<50%) of a day’s catch, and is rarely the main component of a catch. Illustrating that this species is not a primary target for the fishery.

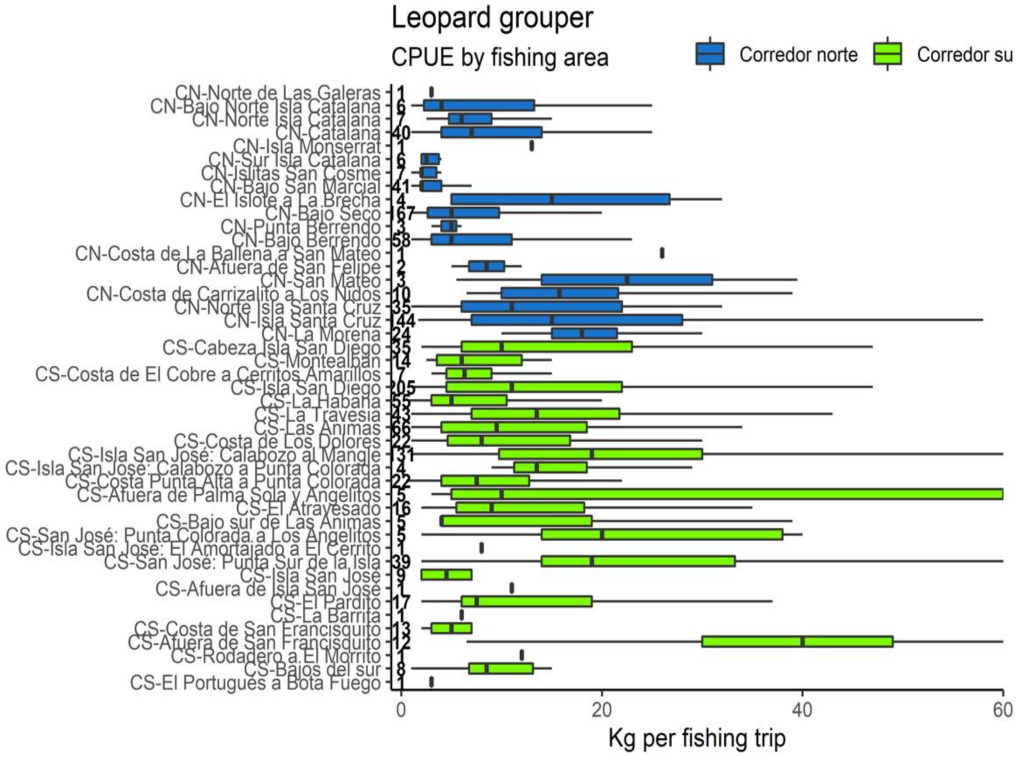


*Figure 23. Percentile catch-per-unit-effort data for cabrilla sardinera aggregated across all years (2009-2019) and depth categories, plotted by fishing area sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

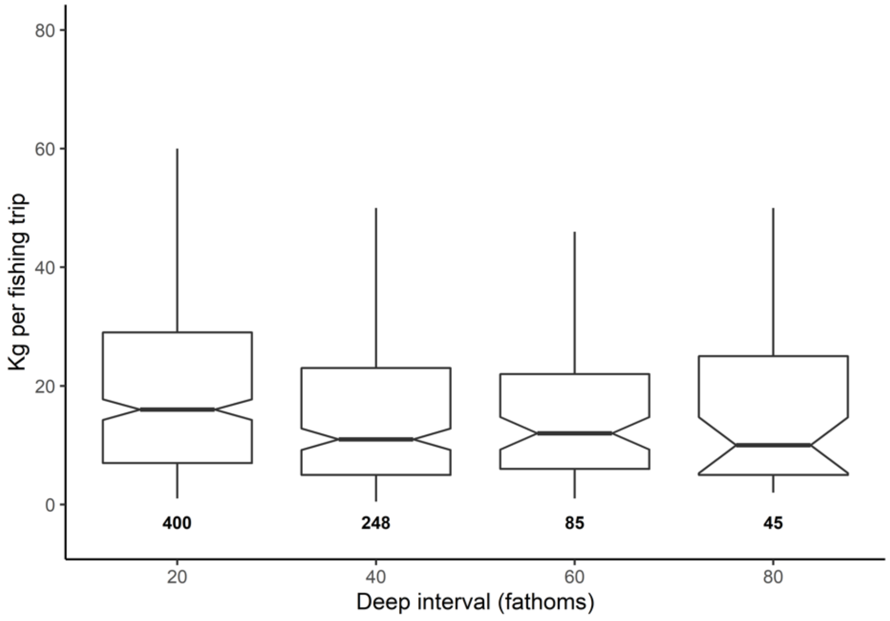


*Figure 24. Catch-Per-Unit-Effort data for cabrilla sardinera aggregated across all years (2009-2019) and fishing locations; plotted by depth category. Bold values mark sample size for each year, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*

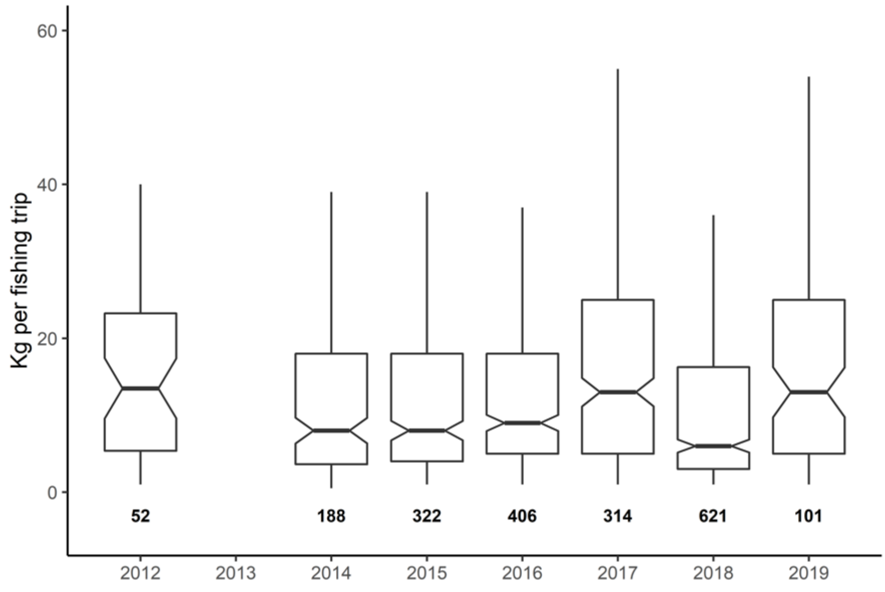
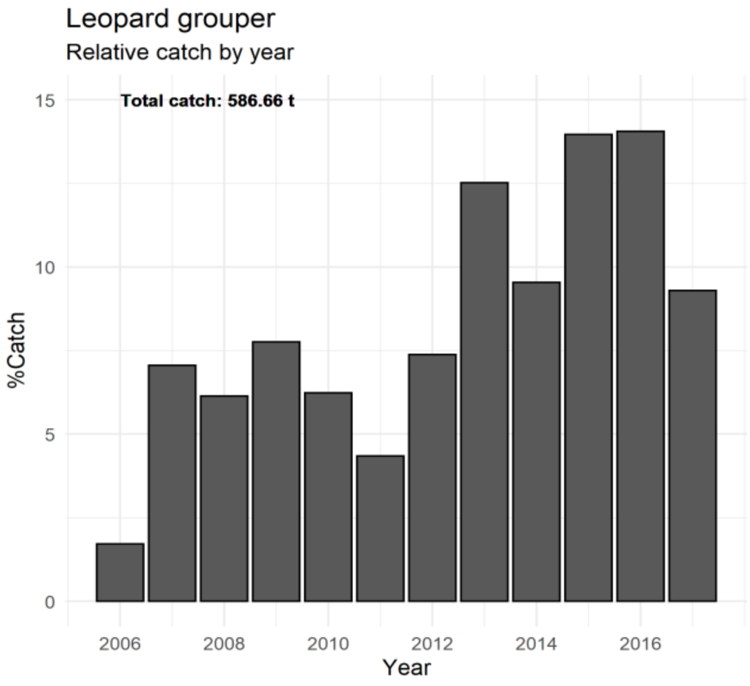


*Figure 25. Catch-Per-Unit-Effort data for cabrilla sardinera aggregated across all depth categories and fishing areas, plotted annually. Bold values mark sample size for each year, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*



Source: CONAPESCA

*Figure 26. The proportion of total recorded cabrilla sardinera catch from 2006-2017 (586.7t) that was recorded in each year of that time series. This figure shows that >60% of the recorded cabrilla sardinera catch was taken in the final five years of the 12-year time series.*

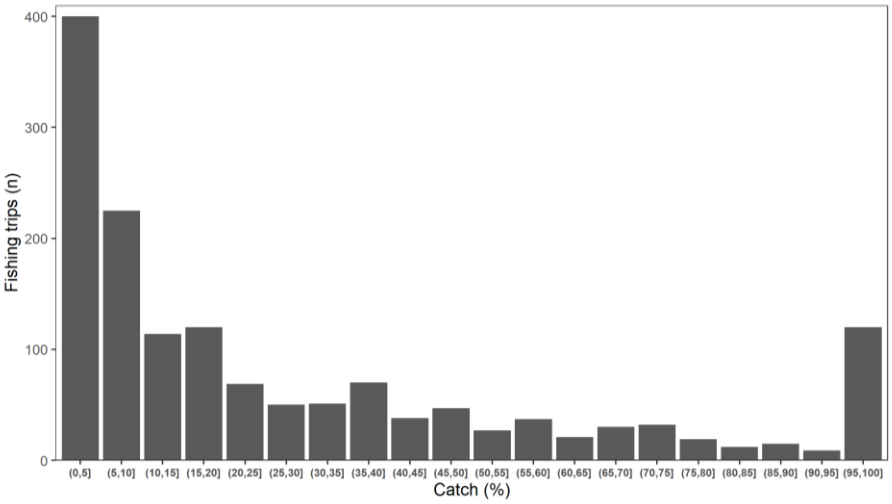


*Figure 27. Cabrilla sardinera catch data aggregated across all years (2014-2019), depth categories and locations; plotted as the number of sampled trips in which cabrilla sardinera comprised each percentage range of the catch. This figure shows that most catches contain a low proportion (<50%) of cabrilla sardinera but >100 catches on the extreme right were >95% cabrilla sardinera.*

## Initial LBSPR Assessment

In completing the initial LBSPR assessment of the aggregated dataset (all years, depths and fishing locations) we initially assumed our standardized estimate of $L_\infty$ = 104.7 cm from La Paz and the family average $L_m/L_\infty$ = 0.65 to infer $L_{50}$ = 68 cm for El Corredor with $L_{95} = L_m$ x 1.1.

This produced a plausible good-looking fit and estimated that the size selectivity of the catch is considerably smaller than $L_m$ (Figure 28) resulting is a very low initial estimate of SPR=8%, and a correspondingly high fishing pressure F/M = 2.0, which if believed has apparently been relatively stable over the time-period of assessment (Figure 29-31; Table 4). This assessment of SPR is very low but might be plausible considering the species relatively large body size, longevity and catchability, and the global propensity for the large Serranids to be over-exploited and depleted to the point of local extinction.

It is possible, however, that these initial estimates of $L_m$ and $L_\infty$ are too large, due to the sampled population around La Paz having been truncated by fishing before they were studied, causing our estimate of $L_\infty$ to be poorly constrained by the available data. Assuming smaller $L_m$ and $L_\infty$ produces progressively higher estimates of SPR and lower relative fishing pressure (F/M). However, if we assume the Santa Rosalia parameter estimates ($L_m$ = 42cm and $L_\infty$ = 65.8 cm) our assessment suggests 100% SPR and F/M=0 which is less plausible than our initial result.

| **SPR** | **SL50** | **SL95** | **F/M** | **MK** | **Linf** | **L50** | **L95** |
|---|---|---|---|---|---|---|---|
| 0.08 (0.07 - 0.08) | 40 (39.66 - 40.34) | 49.05 (48.39 - 49.7 | 2 (1.92 - 2.08) | 1.2 | 105 | 68 | 77 |

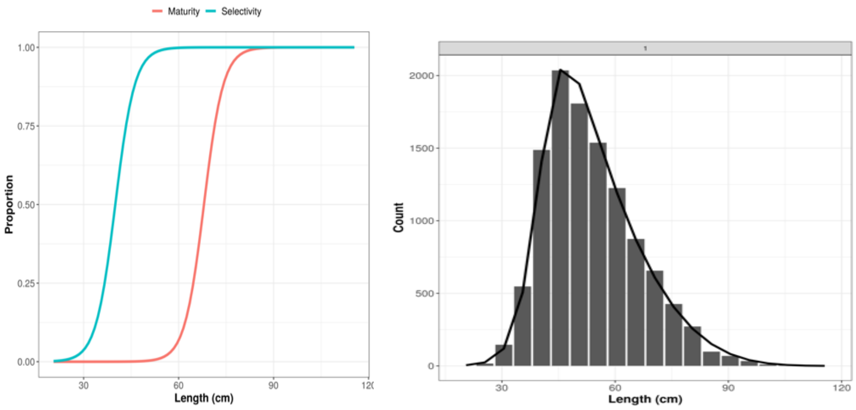


*Figure 28. Initial LBSPR assessment of cabrilla sardinera using size composition of the catch data aggregated across all years, fishing areas and depths. The table shows derived estimates of spawning ratio potential (SPR) and the size of 50% and 95% selectivity (SL50 & SL95) and relative fishing pressure (F/M). The estimated 95% confidence intervals around these mean estimates are shown in brackets. The input parameters assumed are indicated to the right; life history ratio M/K, asymptotic size (Linf), size at 50% and 95% maturity (L50 & L95). The left-hand panel presents plots of assumed size of maturity ogive (red) and the estimate size of selectivity (blue). The right-hand panel plots the size composition data analysed (black bars) and the LBSPR modelled fit to those data.*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.09 (0.03 - 0.16) | 44.05 (39.95 - 48.15) | 52.93 (45.09 - 60.77) | 1.99 (1.17 - 2.81) | 1.16 | 105 | 68 | 75 |
| 2011 | 0.04 (0.02 - 0.06) | 39.38 (37.22 - 41.54) | 47.64 (43.39 - 51.89) | 2.78 (2.09 - 3.47) | 1.16 | 105 | 68 | 75 |
| 2012 | 0.07 (0.05 - 0.09) | 38.95 (37.19 - 40.71) | 50.87 (47.61 - 54.13) | 2.11 (1.79 - 2.43) | 1.16 | 105 | 68 | 75 |
| 2013 | 0.05 (0.04 - 0.06) | 39.14 (38.11 - 40.17) | 49.25 (47.34 - 51.16) | 2.48 (2.22 - 2.74) | 1.16 | 105 | 68 | 75 |
| 2014 | 0.1 (0.08 - 0.12) | 38.79 (37.7 - 39.88) | 48.21 (46.11 - 50.31) | 1.7 (1.5 - 1.9) | 1.16 | 105 | 68 | 75 |
| 2015 | 0.08 (0.07 - 0.1) | 39.52 (38.82 - 40.22) | 46.46 (45.12 - 47.8) | 1.92 (1.74 - 2.1) | 1.16 | 105 | 68 | 75 |
| 2016 | 0.11 (0.08 - 0.14) | 50.23 (47.7 - 52.76) | 65.72 (61.4 - 70.04) | 2.15 (1.71 - 2.59) | 1.16 | 105 | 68 | 75 |
| 2017 | 0.07 (0.05 - 0.08) | 40.24 (39.34 - 41.14) | 46.72 (44.93 - 48.51) | 2.16 (1.9 - 2.42) | 1.16 | 105 | 68 | 75 |
| 2018 | 0.09 (0.07 - 0.1) | 40.34 (39.57 - 41.11) | 48.2 (46.67 - 49.73) | 1.92 (1.75 - 2.09) | 1.16 | 105 | 68 | 75 |
| 2019 | 0.04 (0.03 - 0.04) | 40.16 (39.45 - 40.87) | 48.54 (47.2 - 49.88) | 2.9 (2.66 - 3.14) | 1.16 | 105 | 68 | 75 |

*Table 4. Initial LBSPR assessment of cabrilla sardinera by year using size composition of the catch data aggregated fishing areas and depths and fitted by year. This table shows input assumptions (M/K, $L_{\infty}$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

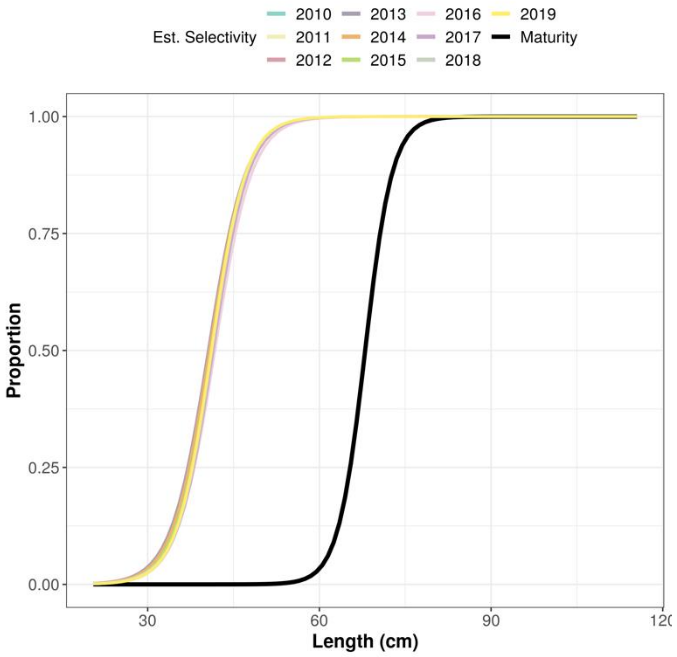


*Figure 29. Results of initial LBSPR assessment of cabrilla sardinera using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

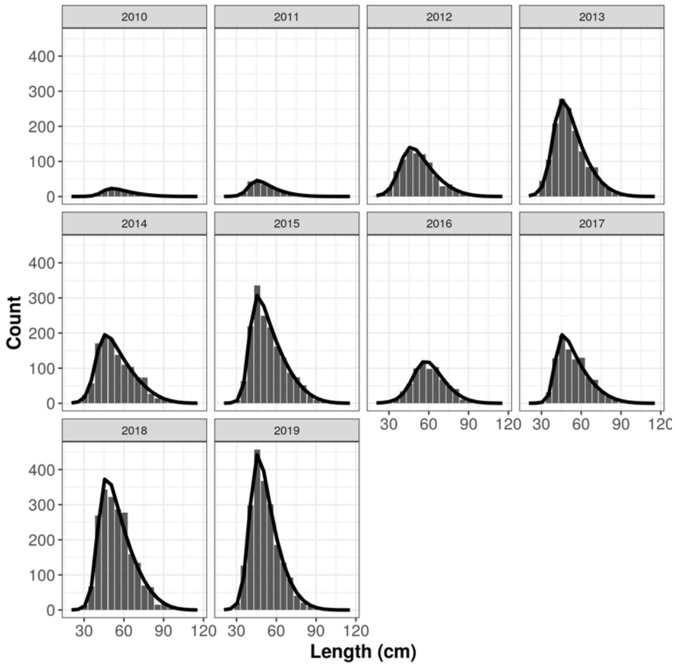


*Figure 30. Initial LBSPR assessment of cabrilla sardinera using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

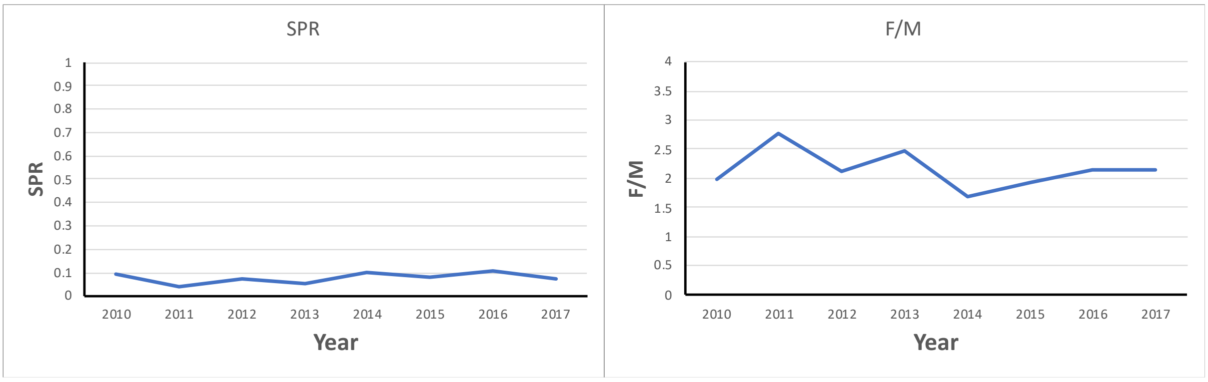


*Figure 31. Initial LBSPR assessment of cabrilla sardinera using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

## Cabrilla Sardinera Discussion

Being cleanly uni-modal, representative of the adult size composition, and relatively uniform across fishing sites and depths cabrilla sardinera, should be well suited for LBSPR assessment.

Our initial LBSPR assessment for this species is that SPR is very low and fishing pressure very high (SPR = 4-11%; F/M = ~2). This initial assessment would be consistent with the impact of fisheries on large bodied Serranids world-wide. However, we have reason to expect our estimates of $L_m$ and $L_\infty$ are biased high and at least partially responsible for this result.

More surety about the input parameters is needed to inform our interpretation of these data. At the level of family, the average LHR for this species are well estimated by meta-analysis, and studies of both $L_m$ and $L_\infty$ conducted at Santa Rosalia suggest the species conforms with those family averages. However, our input estimates of $L_m$ and $L_\infty$ are imprecise, $L_m$ has not been estimated in La Paz or El Corredor, and the estimate of $L_\infty$ was apparently based on a population already truncated by fishing in 2001 so that fish around $L_\infty$ were already rare.

Revising or confirming our estimates of $L_m$ and $L_\infty$ could either improve or confirm our initial analysis.

For this preliminary assessment $L_\infty$ = 104.7 cm has been assumed which is 30-55cm larger than, the apparently better-founded, estimates of $L_\infty$~70cm for Santa Rosalia. While it is to be expected that $L_m$ and $L_\infty$ of all species will be larger nearer sources of cooler, deeper oceanic sources of water. This margin of difference is somewhat larger than expected, strengthening the impression that the parameters used are too large. It would be interesting to make a systematic multi-species comparison of biological studies from La Paz, Santa Rosalia and Mazatlan, because being attributable to differentials in water temperature, the proportional margin between LHP estimates of the species in each place, should be similar for all species. Systematically studying regional differences in $L_m$ and $L_\infty$ for a range of species might make it possible to establish average relativities in body size between locations, and the deviations from, or conformity with, those average relativities, could be used to infer the reliability, or otherwise, of various LHP estimates.

Specifically for this assessment of cabrilla sardinera it would be very informative to estimate $L_m$ of around La Paz, and in El Corredor which could then be used with $L_m/L_\infty$= 0.65 to infer $L_\infty$ for comparison with the estimate assumed here. Since there is currently no estimate of $L_m$ for this region any estimate would have great value. As is discussed in the final discussion I recommend conducting parallel studies applying a range of methodologies (histology, fecundity and gonadosomic indices).

Repeating a complete length at age study is unlikely to add much value to the existing study of Diaz-Uribe et al. (2001) which was hampered by the lack of the largest size classes of fish, due to the truncation of the population by fishing. My suggestion would be to try and augment that pre-existing study by working with the fishery to locate over a period of time rare very large fish that must still very occasionally be caught. Finding, sampling and ageing a further 20-30 fish >80cm in length, and adding their data into Diaz-Uribe et al.'s data-set would substantially improve their estimates. Also as discussed in the discussion I recommend using Niparaja's catch size sampling program to find the increasingly rare very large (>800 mm) individuals.

## *Lutjanus argentiventrus* - Pargo Amarillo - Yellow snapper

### Life History Ratios

There is a good-sized sample of high quality LHR estimates available for the family Lutjanidae from the meta-analysis of Prince et al. (in prep. a) which can be used to derive the average estimates;

$M/K = 0.98$; $n = 88$
$L_m/L_\infty = 0.72$; $n = 30$

### Life History Parameters

There are studies of pargo amarillo growth from Mazatlan which estimated $L_\infty = 73.5$ cm (Garcia-Contreras 2009). Redigitizing those data and standardizing the growth estimates results in the substantially lower $L_\infty = 60.9$ cm. The reason for the large difference between published and standardized values is that Garcia-Contreras (2009) estimated an unrealistic $t_0 = -2.05$ years which implies that growth begins at ~15 cm when the size of settling lutjanid larvae is ~ 2 cm. Fixing the $t_0$ to a biologically realistic value results in a higher estimate of the growth rate (k) and lower estimate of $L_\infty$.

Assuming $L_m/L_\infty = 0.72$ and $L_\infty = 60.9$ cm suggests $L_m \sim 44$ cm.

Using histological techniques Barbosa-Ortega et al. the female $L_m = 37$ cm TL in samples collected in the La Paz area, although sexually mature females were found from 25.7 cm TL, and for males $L_m = 34$ cm was estimated. An estimate of ~34 cm coincides with the 50th percentile of left-hand side of the size composition, which is typical for small and medium bodied Lutjanid species for which hook and line catches are often comprised almost entirely of adult and sub-adult individuals, and juveniles are poorly represented.

### Size Composition Data

The catch size composition data for pargo amarillo, consistently produce simple relatively normal looking bell-shaped size histograms (Figure 32- 35), consistent with the assumptions underlying the LBSPR algorithms. The size composition data are relatively homogeneous. At this level of aggregation there is little evidence of consistent variance (data-structure) by location (Figure 33) or depth strata (Figure 34). Although the size data suggest some hollowing out of the right-hand side of the size composition in later years (Figure 35).

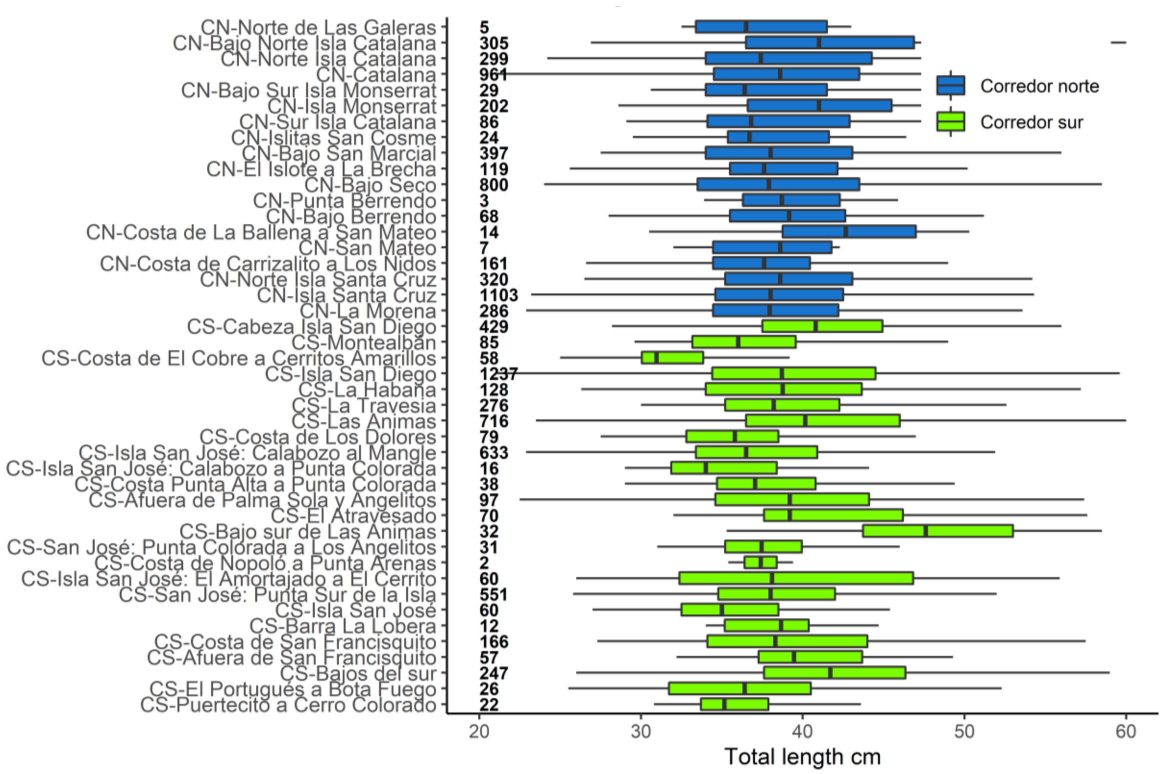


*Figure 32. Percentile length-frequency data for pargo amarillo aggregated across all years (2009-2019) and depth categories; plotted by fishing areas sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

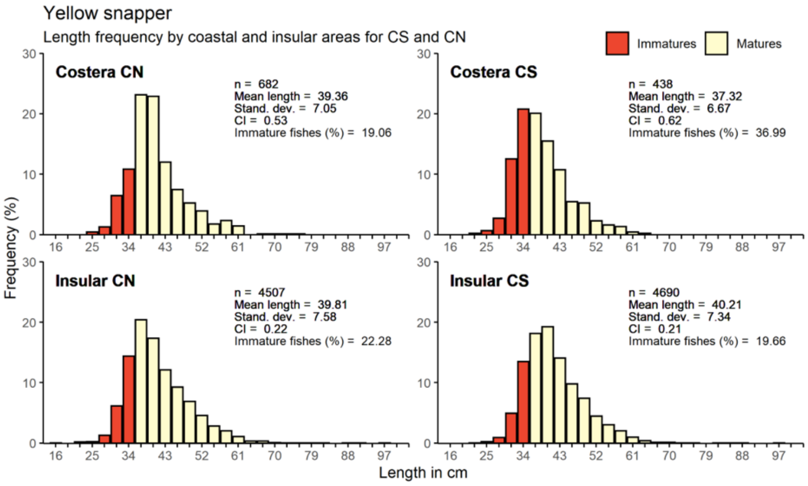


*Figure 33. Length-frequency data of pargo amarillo aggregated across all years (2009-2019); plotted by coastal (costera) and offshore (Insular) in the north and south of El Corredor. Size at maturity according to Barbosa-Ortega et al. (2014) indicated by darker colouring.*

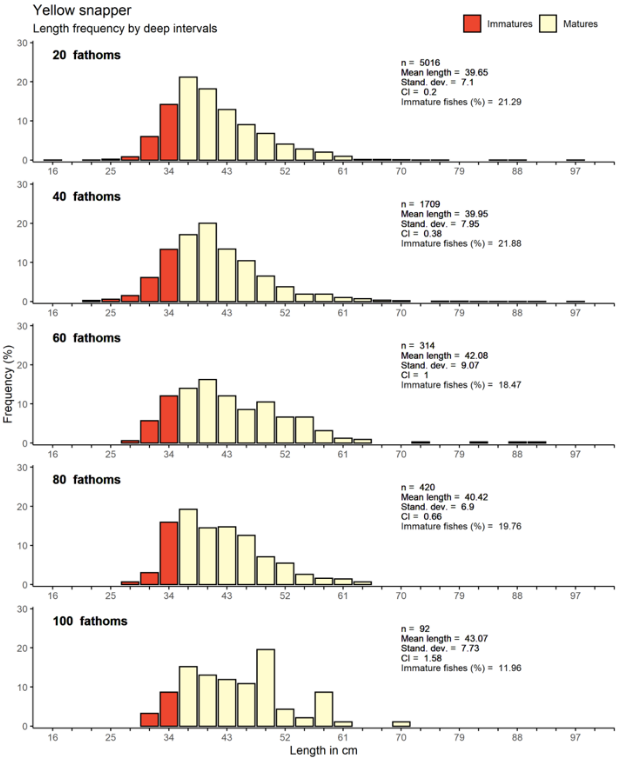


*Figure 34. Length-frequency data aggregated across all years (2009-2019) and all fishing locations plotted by depth category. Size at maturity according to Barbosa-Ortega et al. (2014) indicated by darker colouring.*

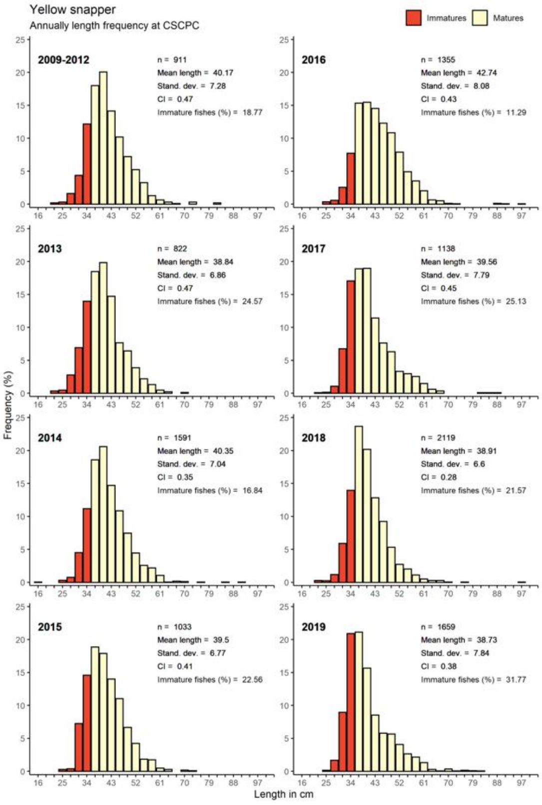


*Figure 35. Length-frequency data aggregated across all years (2009-2019) and depth categories; plotted by time period. Size at maturity according to Barbosa-Ortega et al. (2014) indicated by darker colouring.*

## Catch and Catch Per Unit Effort Data

The CPUE data for pargo amarillo is quite variable between fishing locations (Figure 36), but relative constant across the range of depths > 20 fathoms. Less than 20 m the median CPUE is higher (Figure 37) and much more variable. The variability by fishing location might indicate some finer-scale population structure, perhaps in relation to the distribution of preferred habitat.  In aggregate the CPUE appear to have remained stable over time (Figure 38), closer inspection of the medians suggests a cycle in median CPUE over time; from high CPUE (2009 – 2013) to low (2016) and back to high (2019).

Figure 39shows the proportional distribution across years, of the total reported catch (200.5t) of pargo amarillo through the period 2006-2017. This figure also suggests a cycle, but perhaps lagged 2-3 years on the cycle of median CPUE noted above. It shows that through 2009 and 2010 annual catches were almost double the catches of 2014 and 2015.

Pargo amarillo is apparently mainly caught incidentally as it is normally <50% of catch compositions and very rarely >50% (Figure 40). In this situation variation in CPUE, catches and size structure are likely to indicate population dynamics, relatively un-effected by varying targeting practices.  Thus, the relatively smooth cycling in CPUE and catches most probably indicates the pulsing or cycling of recruitment to the fishery in 2008-09 and 2016-17. (Figure 38 & Figure 39).

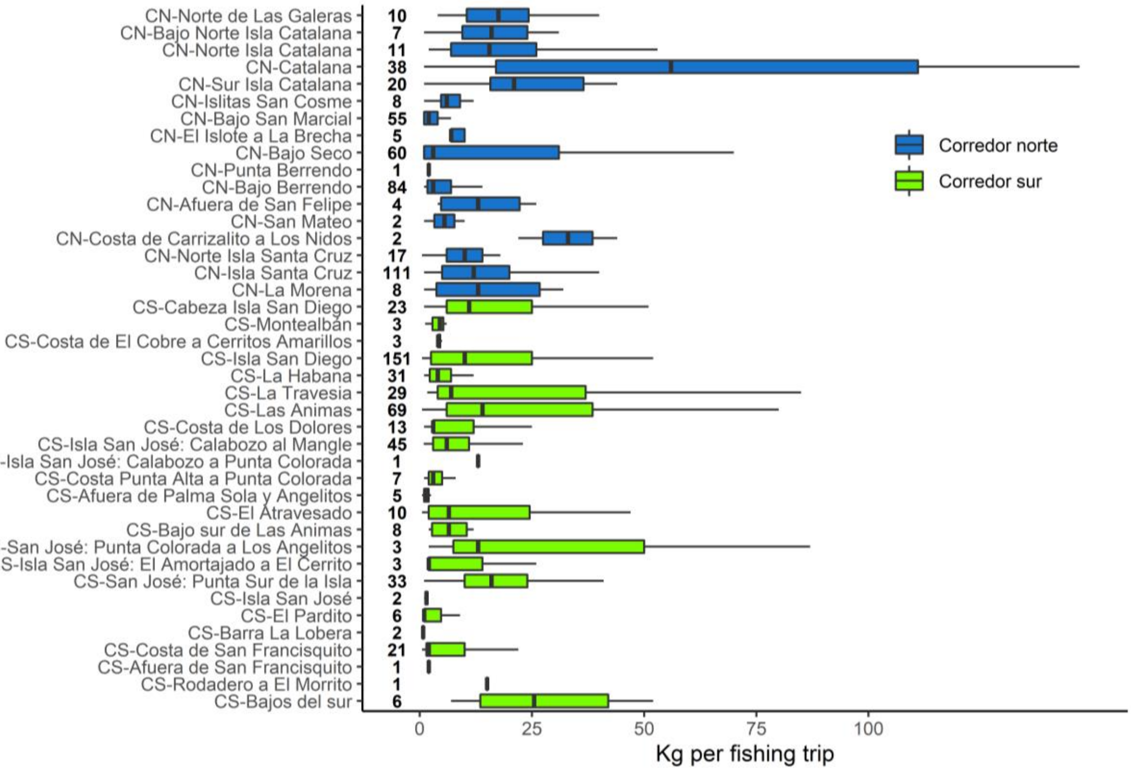


*Figure 36. Percentile catch-per-unit-effort data for pargo amarillo aggregated across all years (2009-2019) and depth categories, plotted by fishing area sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

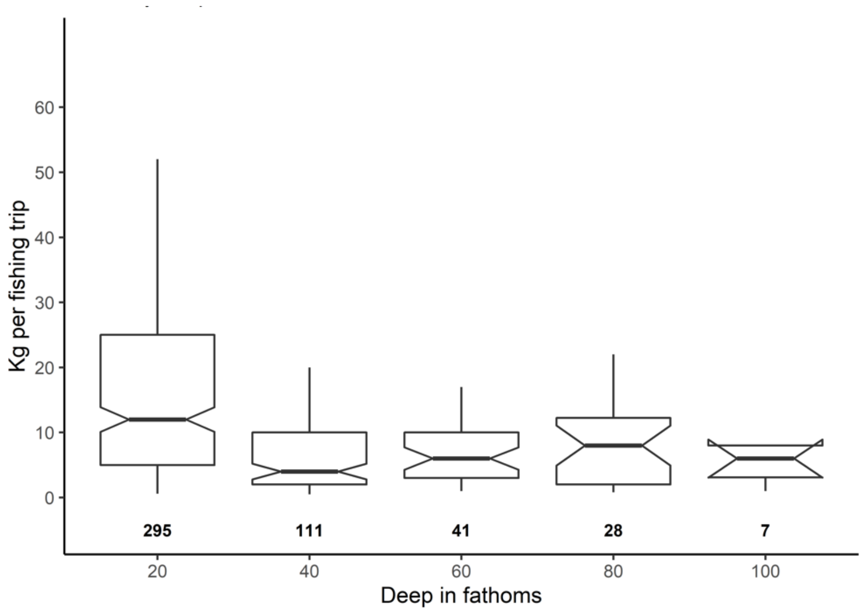


*Figure 37. Catch-Per-Unit-Effort data for pargo amarillo aggregated across all years (2009-2019) and fishing locations; plotted by depth category. Bold values mark sample size for each year, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*

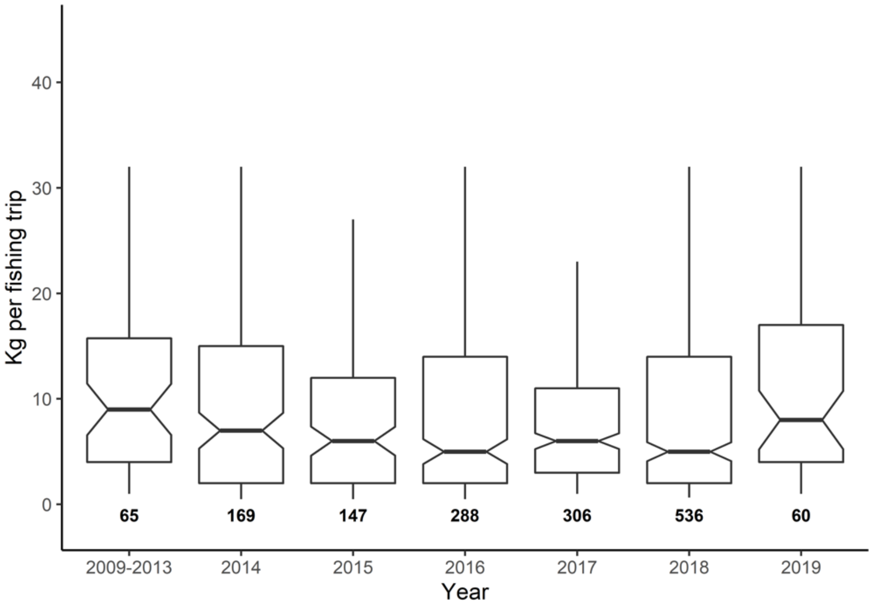
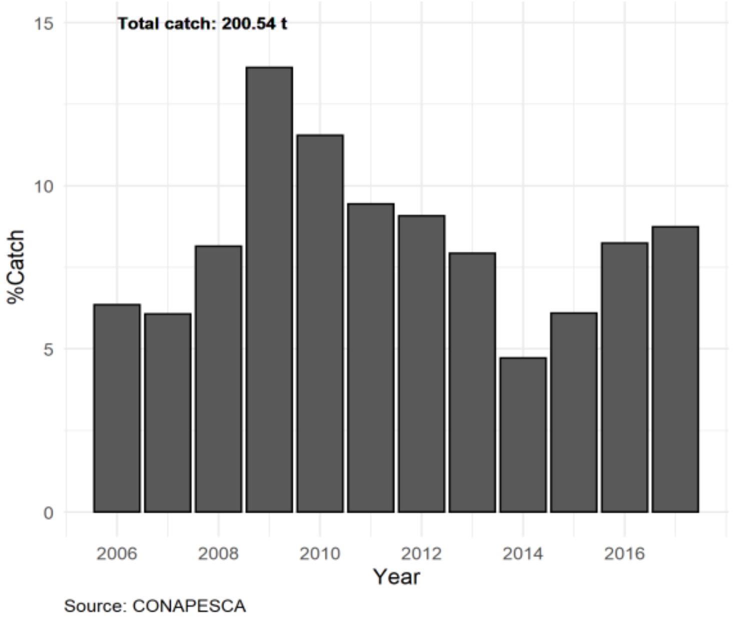


*Figure 38. Catch-Per-Unit-Effort data for pargo amarillo aggregated across all depth categories and fishing areas, plotted annually. Bold values mark sample size for each year, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*



Source: CONAPESCA

*Figure 39. The proportion of total recorded pargo amarillo catch from 2006-2017 (200.5t) that was recorded in each year of that time series. The figure shows that the 2009 and 2010 annual catches were almost double 2014 and 2015.*

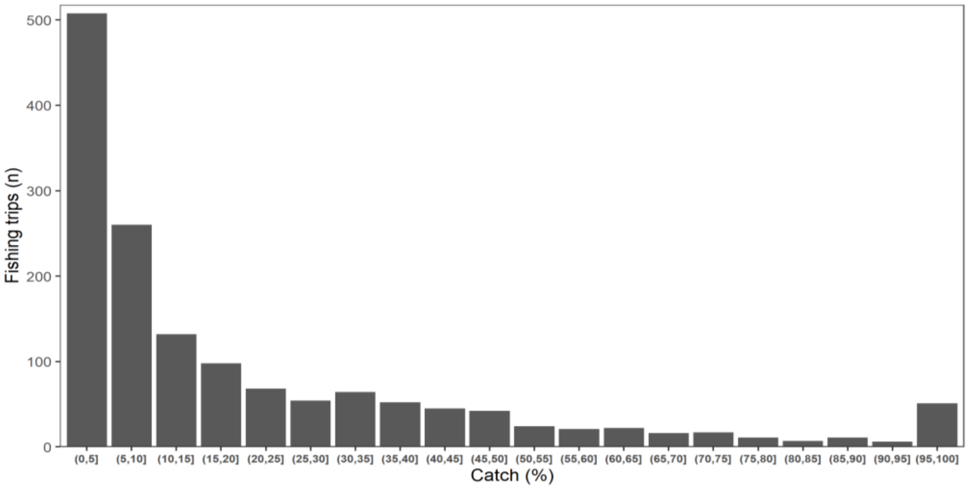


*Figure 40. Catch data aggregated across all years (2014-2019), depth categories and locations; plotted as the number of sampled trips in which pargo amarillo comprised each percentage range of the catch. This figure shows pargo amarillo is mostly <25% of a landed catch and very rarely >50%.*

## Initial LBSPR Assessment

In completing the initial LBSPR assessment of the aggregated dataset (all years, depths and fishing locations) we initially assumed the lutjanid average M/K = 0.98, and the local smaller estimate of male $L_m$ = 34 cm (Barbosa-Ortega et al.), which assuming $L_m/L_\infty$ = 0.72, implies $L_\infty$ ~ 47cm. This resulted in the implausible assessment that the stock is unfished (SPR = 1.0 and F/M = 0.0).

On the other-hand, assuming the standardized Mazatlan estimate of $L_\infty$ = 61 cm, and $L_m/L_\infty$ = 0.72 we could infer $L_{50}$ = 44 cm and with $L_{95}$ = $L_{50}$ x 1.1 = 48 cm, we produced a good-looking fit, which estimates the size selectivity of fishing being smaller than maturity (Figure 41) and relatively low initial estimate of SPR = 18% with moderately high fishing pressure

F/M = 1.5. In this scenario the SPR has apparently been low but stable across the time period (Figure 42- 44; Table 5).

Alternatively using the locally estimated larger female estimate of $L_m$ = 37 cm (Barbosa-Ortega et al. 2016) with $L_{95} = L_{50} \times 1.1$ = 41 cm, and assuming $L_m/L_\infty = 0.72$ implies $L_\infty$ = 51cm which results in higher estimates of SPR~ 40-70% (Figure 39). This result appears relatively high compared to other species in this assemblage. Under this scenario the SPR has apparently declined over the time period (Figure 45 - 47; Table 6).

| SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|
| 0.18 (0.17 - 0.19) | 32.51 (32.31 - 32.71) | 37.71 (37.34 - 38.08) | 1.49 (1.42 - 1.56) | 0.98 | 61 | 44 | 48.4 |

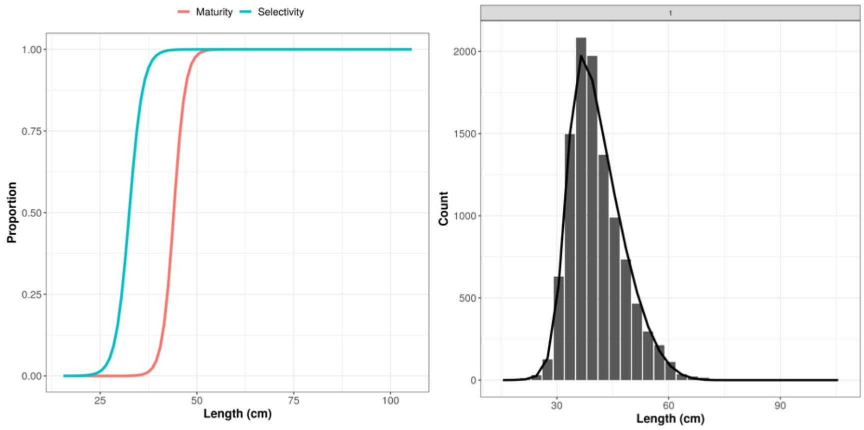


*Figure 41. Initial LBSPR assessment of pargo amarillo using size composition of the catch data aggregated across all years, fishing areas and depths; assuming $L_\infty$ =61 cm & $L_m/L_\infty$ = 0.72 to infer $L_{50}$ = 44 cm. The table shows derived estimates of spawning ratio potential (SPR) and the size of 50% and 95% selectivity (SL50 & SL95) and relative fishing pressure (F/M). The estimated 95% confidence intervals around these mean estimates are shown in brackets. The input parameters assumed are indicated to the right; life history ratio M/K, asymptotic size (Linf), size at 50% and 95% maturity (L50 & L95). The left-hand panel presents plots of assumed size of maturity ogive (red) and the estimate size of selectivity (blue). The right-hand panel plots the size composition data analysed (black bars) and the LBSPR modelled fit to those data.*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2009 | 0.12 (0.08 - 0.16) | 34.76 (33.31 - 36.21) | 41.44 (38.91 - 43.97) | 2.32 (1.67 - 2.97) | 0.98 | 61 | 44 | 48 |
| 2011 | 0.34 (0.23 - 0.45) | 32.92 (31.18 - 34.66) | 39.34 (36.08 - 42.6) | 0.85 (0.52 - 1.18) | 0.98 | 61 | 44 | 48 |
| 2012 | 0.14 (0.1 - 0.19) | 33.46 (32.39 - 34.53) | 39.54 (37.58 - 41.5) | 1.87 (1.46 - 2.28) | 0.98 | 61 | 44 | 48 |
| 2013 | 0.13 (0.1 - 0.16) | 33.11 (32.21 - 34.01) | 40.03 (38.42 - 41.64) | 1.98 (1.66 - 2.3) | 0.98 | 61 | 44 | 48 |
| 2014 | 0.17 (0.15 - 0.2) | 33.84 (33.29 - 34.39) | 39.62 (38.61 - 40.63) | 1.65 (1.46 - 1.84) | 0.98 | 61 | 44 | 48 |
| 2015 | 0.16 (0.13 - 0.19) | 32.39 (31.72 - 33.06) | 37.06 (35.77 - 38.35) | 1.61 (1.38 - 1.84) | 0.98 | 61 | 44 | 48 |
| 2016 | 0.35 (0.3 - 0.39) | 34.13 (33.46 - 34.8) | 39.96 (38.71 - 41.21) | 0.86 (0.72 - 1) | 0.98 | 61 | 44 | 48 |
| 2017 | 0.19 (0.16 - 0.22) | 31.64 (31.13 - 32.15) | 35.82 (34.83 - 36.81) | 1.38 (1.2 - 1.56) | 0.98 | 61 | 44 | 48 |
| 2018 | 0.11 (0.1 - 0.13) | 33.28 (32.86 - 33.7) | 38.82 (38.06 - 39.58) | 2.18 (1.98 - 2.38) | 0.98 | 61 | 44 | 48 |
| 2019 | 0.16 (0.14 - 0.19) | 30.8 (30.45 - 31.15) | 34.4 (33.74 - 35.06) | 1.5 (1.35 - 1.65) | 0.98 | 61 | 44 | 48 |

*Table 5. Initial LBSPR assessment of pargo amarillo using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_\infty$ = 61 cm & $L_m/L_\infty$ = 0.72 to infer $L_{50}$ = 44 cm. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

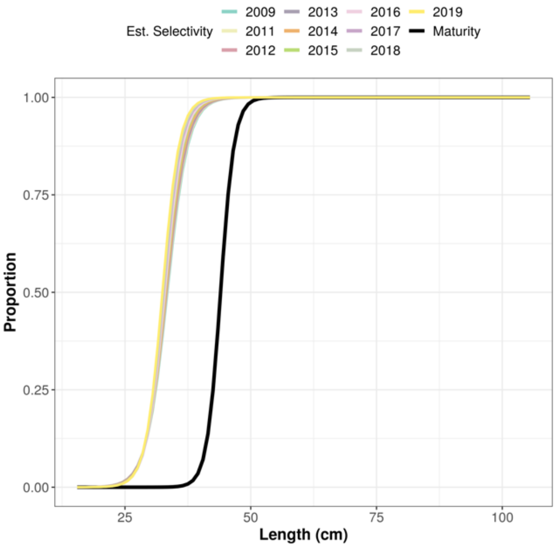


*Figure 42. Results of initial LBSPR of pargo amarillo using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_\infty = 61$ cm & $L_m/L_\infty = 0.72$ to infer $L_{50} = 44$ cm. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

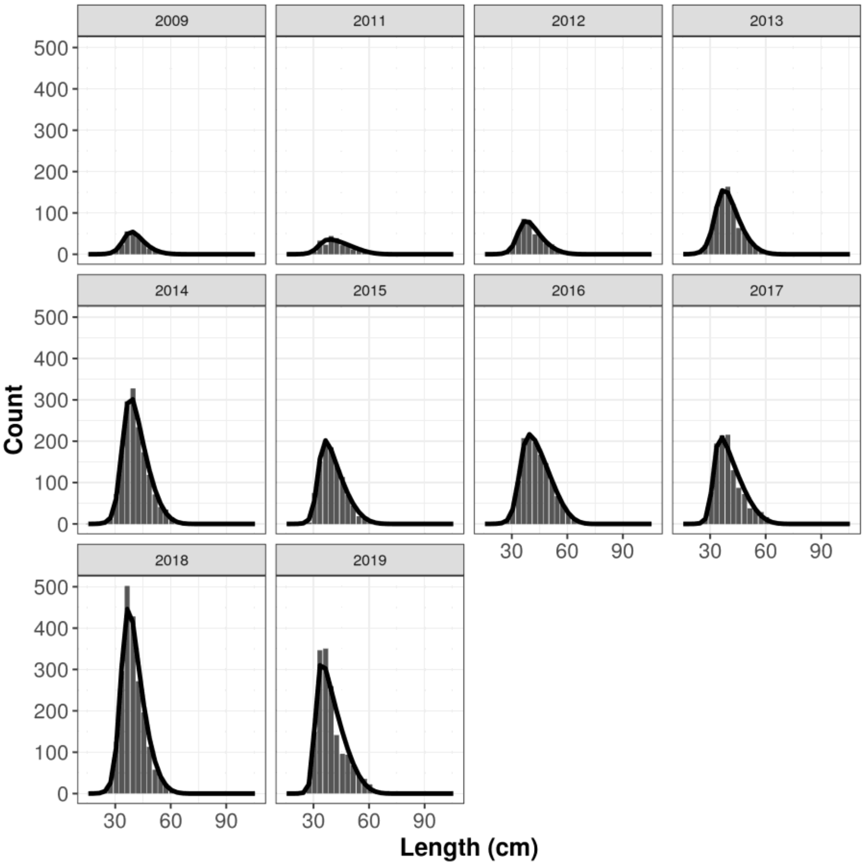


*Figure 43. Initial LBSPR assessment of pargo amarillo using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_\infty = 61$ cm & $L_m/L_\infty = 0.72$ to infer $L_{50} = 44$ cm. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

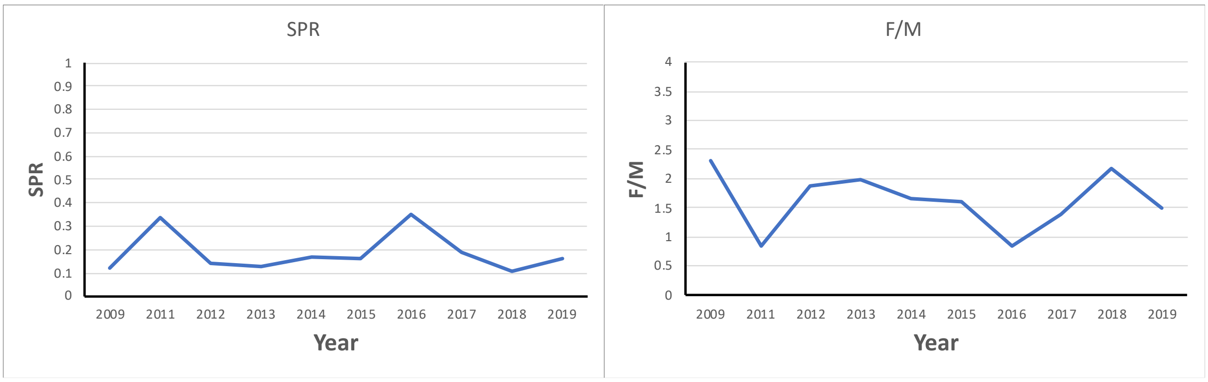


*Figure 44. Initial LBSPR assessment of pargo amarillo using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_\infty$ = 61 cm & $L_m/L_\infty$ = 0.72 to infer $L_{50}$ = 44 cm. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2013 | 0.54 (0.44 - 0.63) | 32.41 (31.24 - 33.58) | 39.02 (36.99 - 41.05) | 0.57 (0.36 - 0.78) | 0.98 | 51 | 37 | 41 |
| 2014 | 0.75 (0.67 - 0.82) | 33.03 (32.42 - 33.64) | 38.38 (37.29 - 39.47) | 0.25 (0.15 - 0.35) | 0.98 | 51 | 37 | 41 |
| 2015 | 0.64 (0.56 - 0.73) | 31.06 (30.43 - 31.69) | 34.71 (33.42 - 36) | 0.35 (0.22 - 0.48) | 0.98 | 51 | 37 | 41 |
| 2016 | 1 (1 - 1) | 33.7 (33.05 - 34.35) | 39.26 (37.97 - 40.55) | 0 (0 - 0) | 0.98 | 51 | 37 | 41 |
| 2017 | 0.72 (0.63 - 0.81) | 31 (30.49 - 31.51) | 34.37 (33.38 - 35.36) | 0.25 (0.14 - 0.36) | 0.98 | 51 | 37 | 41 |
| 2018 | 0.5 (0.45 - 0.55) | 32.3 (31.81 - 32.79) | 37.62 (36.75 - 38.49) | 0.64 (0.53 - 0.75) | 0.98 | 51 | 37 | 41 |
| 2019 | 0.55 (0.5 - 0.6) | 30.6 (30.22 - 30.98) | 34.37 (33.69 - 35.05) | 0.48 (0.39 - 0.57) | 0.98 | 51 | 37 | 41 |
| 2020 | 0.39 (0.32 - 0.45) | 32.18 (31.48 - 32.88) | 37.01 (35.75 - 38.27) | 0.97 (0.74 - 1.2) | 0.98 | 51 | 37 | 41 |

*Table 6. Initial LBSPR assessment of pargo amarillo using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_{50}$ = 37 cm & $L_m/L_\infty$ = 0.72 to infer $L_\infty$ =51 cm. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

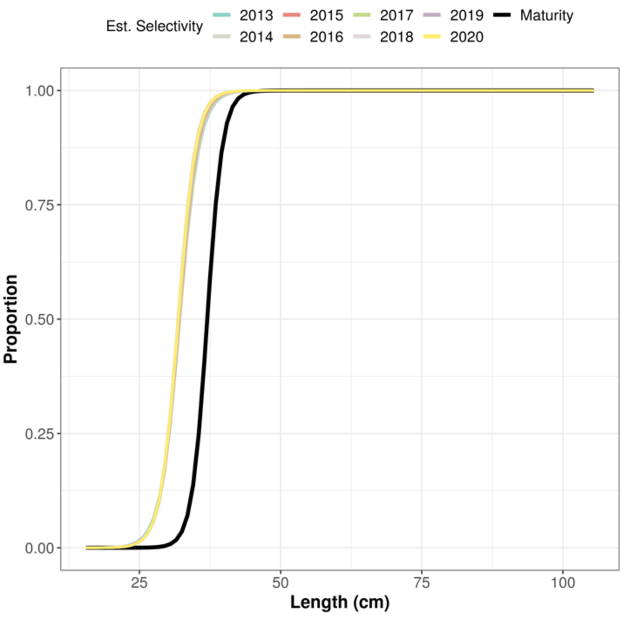


*Figure 45. Results of initial LBSPR of pargo amarillo using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_{50}$ = 37 cm & $L_m/L_\infty$ = 0.72 to infer $L_\infty$ =51 cm. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

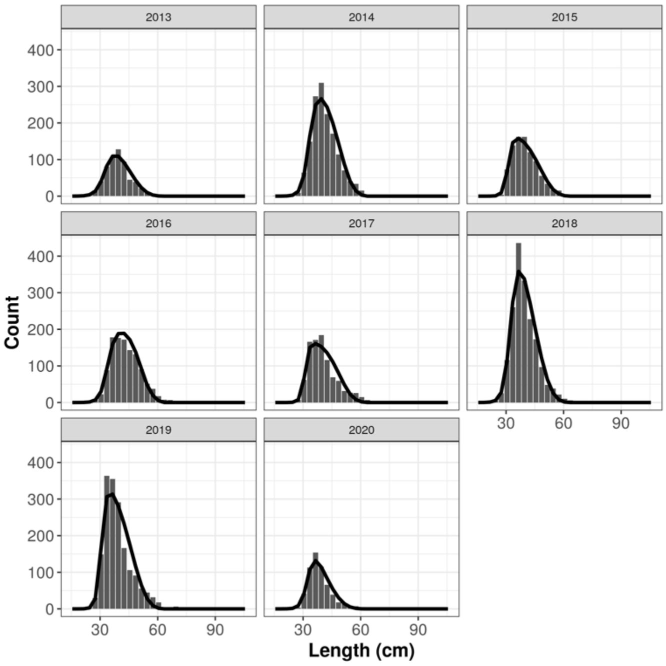


*Figure 46. Initial LBSPR assessment of pargo amarillo using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_{50}$ = 37 cm & $L_m/L_\infty$ = 0.72 to infer $L_\infty$ =51 cm. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

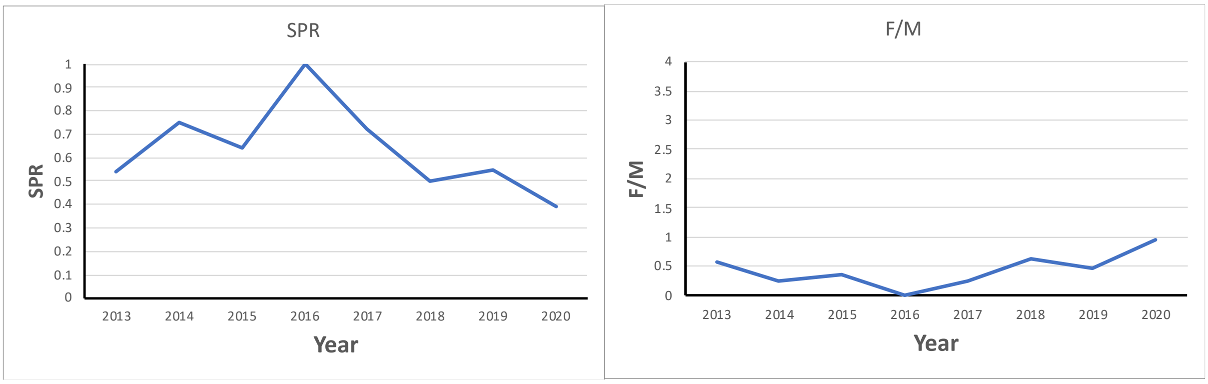


*Figure 47. Initial LBSPR assessment of pargo amarillo using size composition of the catch data aggregated fishing areas and depths and fitted by year, assuming $L_{50}$ = 37 cm & $L_m/L_\infty$ = 0.72 to infer $L_\infty$ =51 cm. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

## Pargo Amarillo Discussion

Being cleanly uni-modal, representative of the adult size composition, and relatively uniform across fishing sites and depths, pargo amarillo should be well suited for LBSPR assessment and its underlying assumptions.

At this stage of development uncertainty remains around the input parameters needed to inform our interpretation of these data, and almost any assessment is possible with the range of plausible assumptions available to us. Assuming the growth curve documented for Mazatlan by Garcia-Contreras (2009) and the average Lutjanidae $L_m/L_\infty$ implies $L_\infty$ = 61 cm and $L_m$ = 44 cm which results in a low, but apparently stable, estimates of SPR = 20 - 30%. In contrast, assuming the smaller locally estimated male $L_m$ =34 cm (Barbosa-Ortega et al. 2014) implies $L_\infty$ = 47cm produces the unbelievable estimate of the stock being unexploited. While assuming the larger local Barbosa-Ortega et al. female estimate of $L_m$ = 37 cm implies

$L_\infty$ = 51 cm which suggests a relatively lightly fished stock (SPR = 40-70%) but trending down.

Interpreted together the gender specific local $L_m$ estimates of Barbosa-Ortega et al. could well be consistent with the size composition data, and the Lutjanid characteristic that hook and line catches are primarily comprised of sub-adult and adult size classes. In this case the left hand-side of the main-mode of the catch composition is determined by the smaller male $L_m$ = 34 cm and the larger female $L_m$ = 37 would be proportional to a larger female $L_\infty$ = 51 cm which would determine the size of the largest individuals sampled, which strongly influences the SPR estimates. If this interpretation is accepted the assessment of SPR = 40-70% would be preferred, which seems very high, but might be consistent with this species normally being a small proportion of catches and apparently not heavily targeted.

However, the assumption of the Garcia-Contreras (2009) growth curve from Mazatlan from which it would be inferred that $L_m$ = 44 cm, somewhat larger than estimated by Barbosa-Ortega et al., produces the most believable assessment that is most consistent with our assessment of the other species in this assemblage.

The interpretation of these data would be strengthened with some studies of fish sampled in El Corredor focussing on comparative studies of $L_m$ and growth. In the early stage of the sampling for such studies, it would quickly become clear whether the catch contains a significant proportion of juveniles, or is mainly comprised of adult and sub-adult size classes. If the latter is found to be true, the observation would support the use of the gender-specific estimates of Barbosa-Ortega et al., and the assessment that the stock is relatively lightly fished. If on the other hand significant numbers of juveniles are observed in samples it would lend support to the more pessimistic assessment made by assuming the Garcia-Contreras (2009) growth curve from Mazatlan.

## *Cephalopholis colonus* - Cadernal - Pacific creolefish

### Life History Ratios

There is a good-sized sample of high quality LHR estimates available for the family Serranidae from the meta-analysis of Prince et al. (in prep. a) which produce the average estimates;

$M/K = 1.16$; n = 131
$L_m/L_\infty = 0.65$; n = 81

### Life History Parameters

There are no studies of cadernal growth, but there is one good size of maturity estimate from around La Paz of $L_m = 33$cm based on histological techniques (Rivera-Comacho et al. 2015). This estimate coincides with the 50th percentile of the left-hand of the length-frequency histograms which is consistent with a species that becomes vulnerable to capture upon maturation, which is commonly observed feature in hook and line fisheries for Serranids.

Assuming the average LHR values for Serranidae $L_m/L_\infty = 0.65$ and $L_m = 33$cm we can infer $L_\infty \sim 51$ cm.

### Size Composition Data

The catch size composition data for cadernal consistently produce simple bell-shaped size histograms consistent with the assumptions on which the LBSPR algorithms are based (Figure 48- 51). The size structure is remarkably uniform across the fishing locations and zones (Figure 48 & Figure 49), depth zones (Figure 50) and through the time series 2010 – 2019 (Figure 51).

Noteworthy is that the length-frequency histograms indicate a thin tail of very large animals, out to about 70+cm when implicitly $L_\infty$ ~51cm (Figure 48). This species has a long, forked tail so the anomalous measurements suggest at times total-length, rather than fork length is being recorded by observers. Some further training of observers for clarification and reinforcement might improve data-quality. At this stage the LBSPR assessment algorithms do not seem to be heavily influenced by this small proportion of anomalously large measurements.

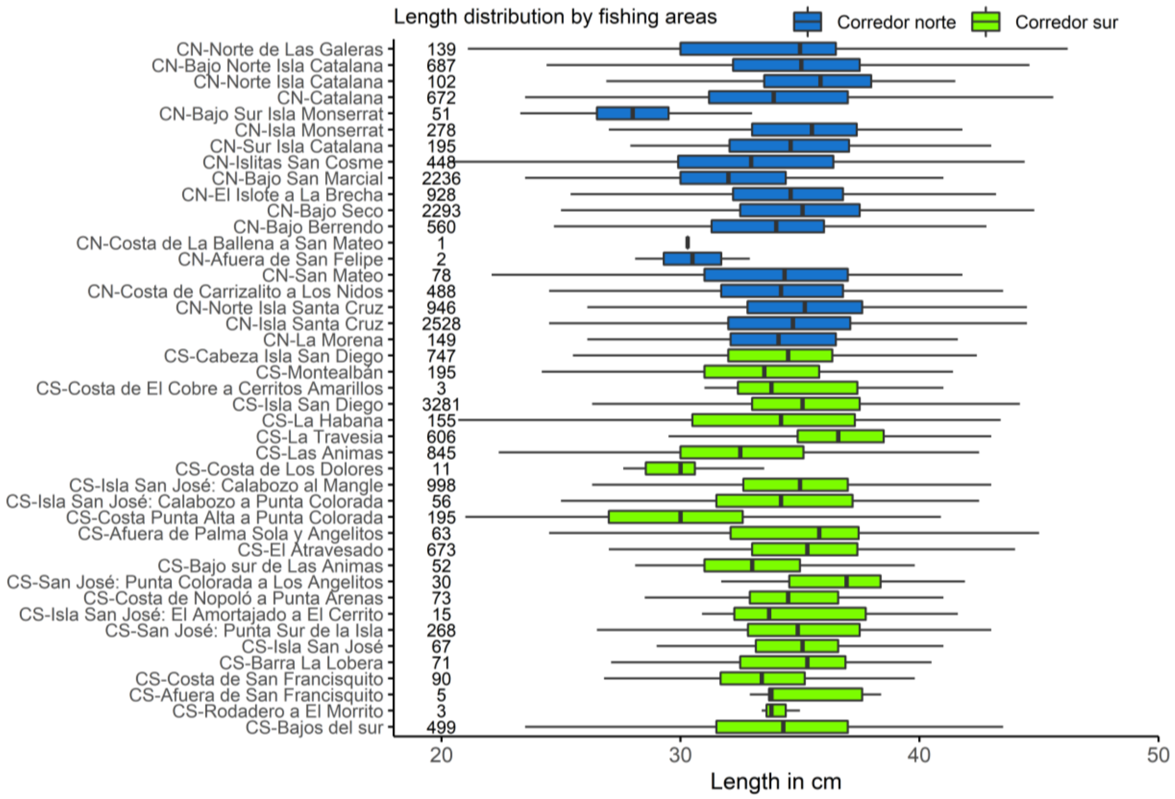


*Figure 48. Percentile length-frequency data for cadernal aggregated across all years (2009-2019) and depth categories; plotted by fishing areas sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

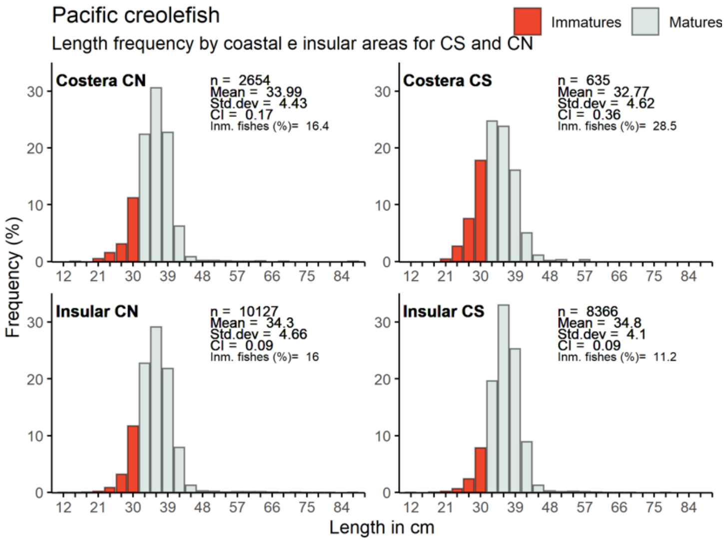


*Figure 49. Length-frequency data of cadernal aggregated across all years (2009-2019); plotted by coastal (costera) and offshore (Insular) in the north and south of El Corredor. Size at maturity according to Rivera-Comacho et al. (2015) indicated by darker colouring.*

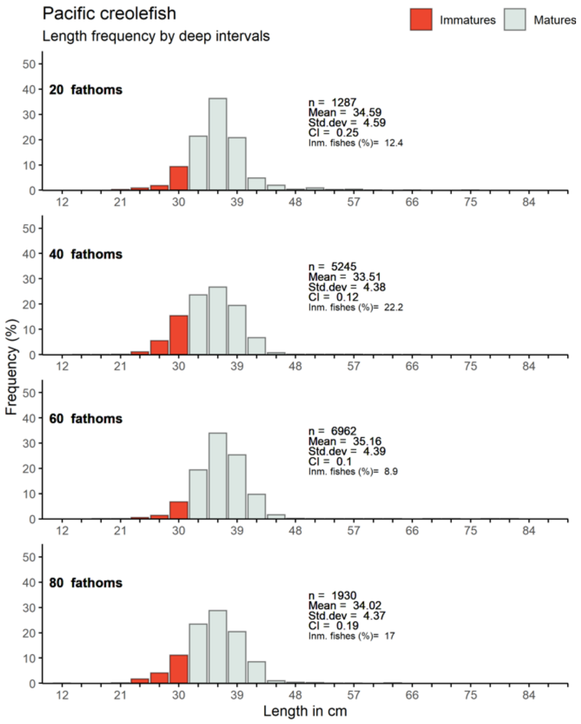


*Figure 50. Length-frequency data aggregated across all years (2009-2019) and all fishing locations plotted by depth category. Size at maturity according to Rivera-Comacho et al. (2015) indicated by darker colouring.*

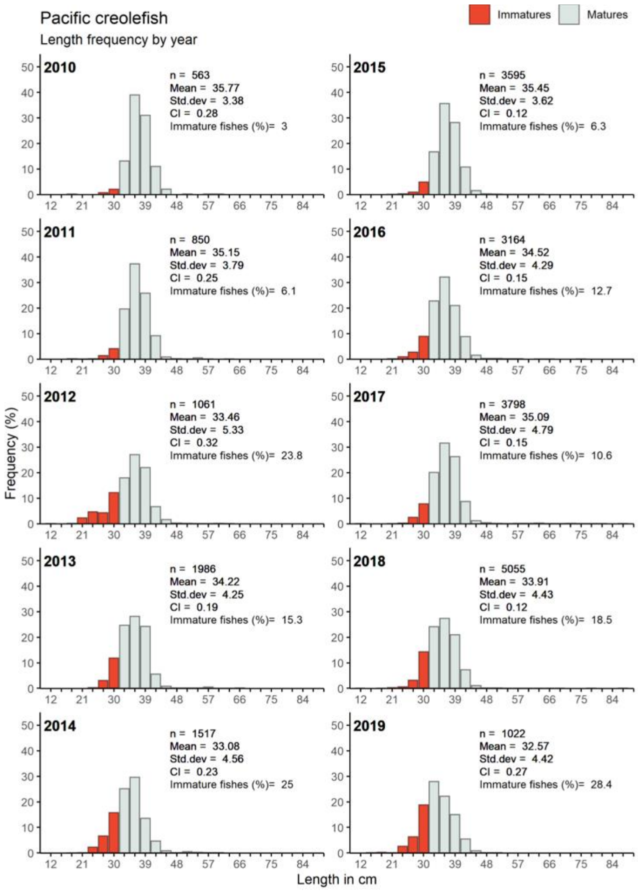


*Figure 51. Length-frequency data aggregated across all years (2009-2019) and depth categories; plotted by time period. Size at maturity according to Rivera-Comacho et al. (2015) indicated by darker colouring.*

## Catch Per Unit Effort Data

The CPUE data for cadernal suggests that higher more variable CPUE in the north compared to the south (Figure 52) The contrast is striking, possibly suggesting greater abundance and / or lower fishing pressure in the north, although if this is the case, the differential fishing pressure is not evident in the catch size composition data, which are relatively homogeneous (Figure 48). A possible alternative could be a greater degree of targeted fishing in the north, with the catch in the south being mainly caught incidentally while fishing for other species.

The CPUE of cadernal is apparently slightly higher at depth (Figure 53), but note no catches are recorded >80 fathoms. In aggregate CPUE is apparently relatively stable over time, median CPUE fell between 2011-13 and 2014 – 2015, but rose from 2015 – 2018. When these data are described spatially this trend might be explained by an increasing proportion of cadernal being caught in the north at higher catch rates (Figure 54). Figure 55 shows the annual catch of cadernal steadily increased through the time series, but with peak catches in 2008, 2011, 2015 and 2017 almost double the catch of the preceding and following years. Figure 56shows cadernal normally comprise <50% of a landed catch and rarely >50%. Which is consistent with the species being only weakly targeted, either because it is less-prized and / or its behavior makes it less targetable.

This situation might be changing as other species are fished down. The higher more variable catch rates in the north, compared with the south suggests lower fishing pressure on this species in the north, possibly due to lower value and greater distance from market. So that higher CPUE can be achieved, if and when there is incentive to target it more strongly. If this is the situation, the consistently lower CPUE in the south, closer to market, would indicate that its stocks have already been fished down to some extent. However, this interpretation is not confirmed by the similarity of the catch size composition between north and south.

An alternative interpretation that could be consistent with both the homogenous size composition and contrasting CPUE, is that while fishing pressure in the south is heavier the stock remains relatively light fished in both areas, because some biological factors limit the impact of fishing on a more broadly distributed and mixing stock. In this scenario the relatively light impact of fishing on the broader stock is indicated by the homogeneous size compositions north and south, while the lower stable CPUE in the south reflects greater fishing pressure competing for a finite level of catch from a limited area of the stock. This unusual, but not unique, dynamic would be consistent with a bentho-pelagic species that spends much of its life cycle foraging through mid-waters, out of range of a fishery that is primarily using benthic fishing techniques. So that catches are taken from a relatively small proportion of the stock foraging in any period of time within range of the bottom-set gear. This might also explain the fact that this species is not taken in >60 fathom, this being below the mid-water depth range of the species, if this interpretation is correct.

Such a dynamic might also provide the mechanism by which catches of this poorly targeted species (Figure 56) regularly doubles or halves between years (Figure 55). The amount of stock within range of the fishing gear being related to environmental factors and the behaviour of their prey, that cause the fish to spend more-or-less time foraging benthically, where they can be caught by bottom-set hooks. This sort of dynamic has been observed in the time series of shelf-based trawl surveys conducted around New Zealand, in which biomass estimates for a suite of long-lived bentho-pelagic species double or halve between years, as species move in, or out of, range of the sampling gear.

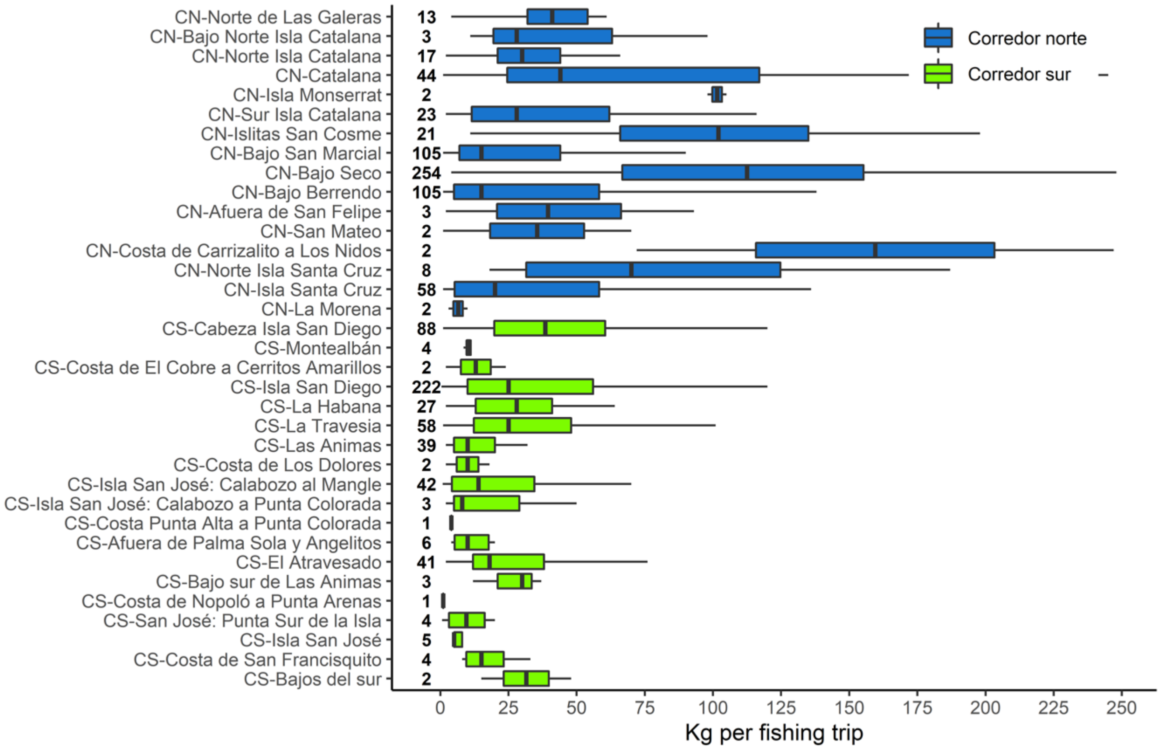


*Figure 52. Percentile catch-per-unit-effort data for cadernal aggregated across all years (2009-2019) and depth categories, plotted by fishing area sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

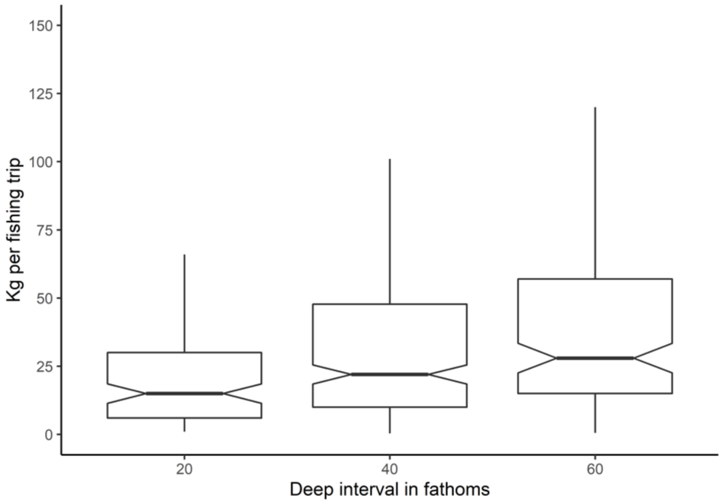


*Figure 53. Catch-Per-Unit-Effort data for cadernal aggregated across all years (2009-2019) and fishing locations; plotted by depth category. Bold values mark sample size for each year, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*

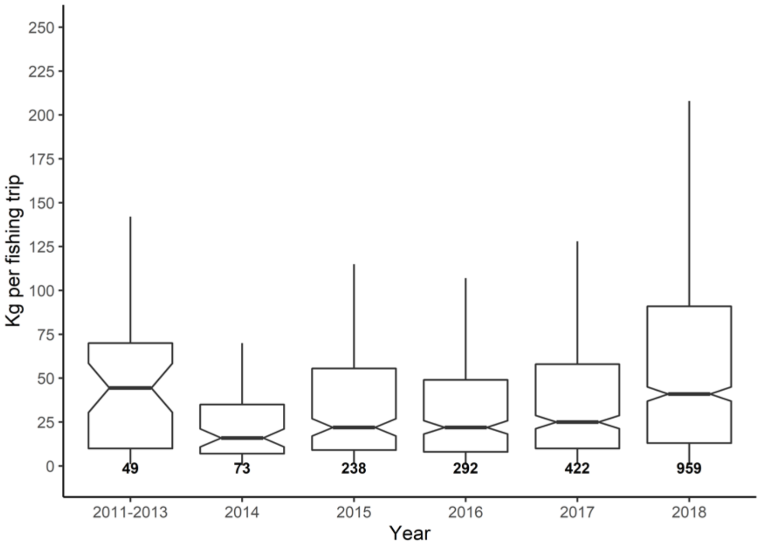
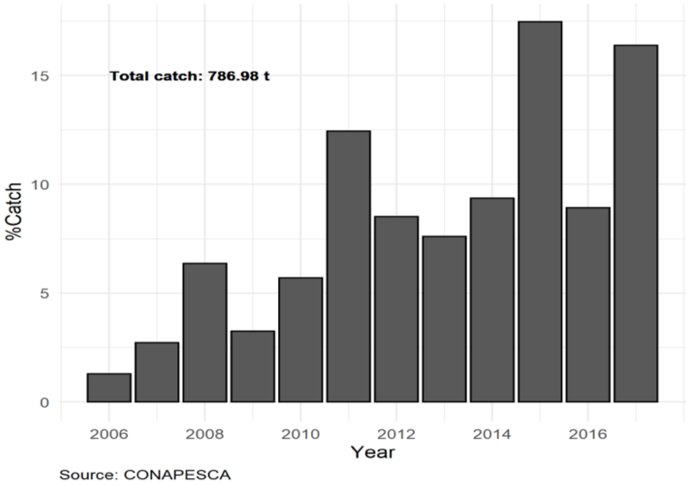


*Figure 54. Catch-Per-Unit-Effort data for cadernal aggregated across all depth categories and fishing areas, plotted annually. Bold values mark sample size for each year, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*



Source: CONAPESCA

*Figure 55. The proportion of total recorded cardinal catch from 2006-2017 (787t) that was recorded in each year of that time series. The figure shows that annual catches of cadernal are quite variable with peak years in 2008, 201, 2015 and 2017 almost double the catch of sequential years, beneath that variability annual catch have steadily increased through the time series.*

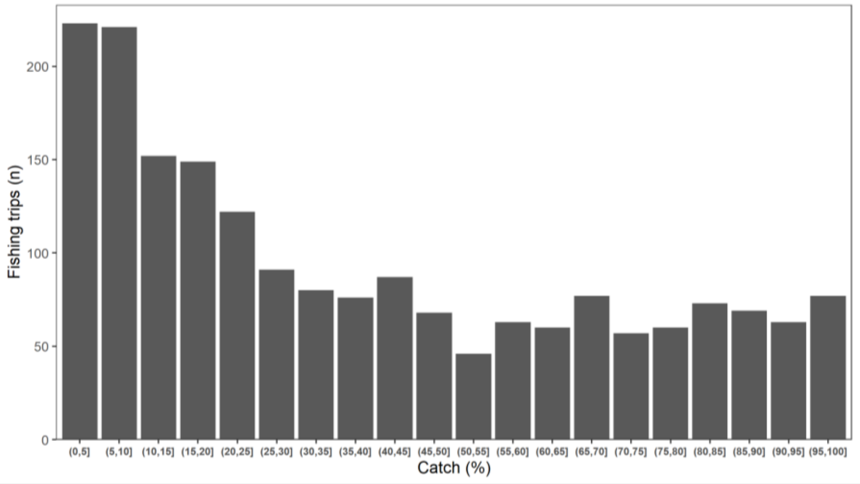


*Figure 56. Catch data aggregated across all years (2014-2019), depth categories and locations; plotted as the number of sampled trips in which cadernal comprised each percentage range of the catch. This figure shows cadernal normally comprises <50% of a landed catch and is rarely >50%.*

## Initial LBSPR Assessment

In completing the initial LBSPR assessment of the aggregated dataset (all years, depths and fishing locations) we assumed $L_m$ = 33 cm & $L_\infty$ = 51cm, and with $L_{95}$= $L_{50}$ x 1.1 for The Corridor (Figure 57).

This produced a coherent initial assessment of SPR = 0.25 with reasonably heavy relative fishing pressure (F/M = 3.86). Consistent with our observation that $L_m$ = 33 cm coincides with the 50th percentile formed by the left-hand side of the size composition we estimated that the size selectivity of fishing was similar to the maturity ogive. Meaning that juveniles are protected from being caught, conserving some low minimum level of SPR from fishing pressure and conferring some resilience on the species.

Using the same assumptions to analyse annual trends we estimated slightly downward trend in SPR from around 25% to 18% by the end of the time series (Figure 58-60; Table 7). There is a suggestion in these results that fishing pressure is relatively stable at high levels, but that the size of selectivity is slowly declining, causing the SPR to decline slowly.

Given the difference in CPUE between north and south it would be interesting to compare LBSPR assessments between north and south, potentially they might indicate different levels of SPR and relative fishing pressure between north and south, with lower F/M and higher SPR in the north, but trending similarly.

| SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|
| 0.25 (0.24 - 0.25) | 34.83 (34.63 - 35.03) | 41.78 (41.49 - 42.07) | 3.86 (3.67 - 4.05) | 1.2 | 50.77 | 33 | 38 |

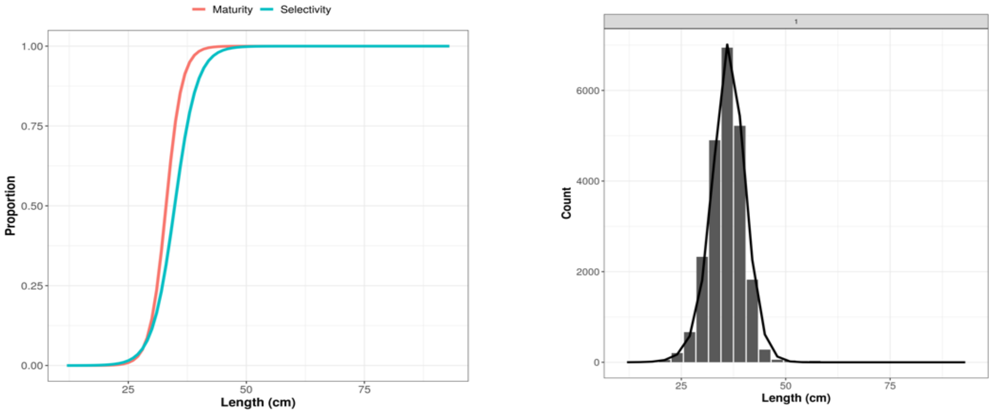


*Figure 57. Initial LBSPR assessment using size composition of the catch data aggregated across all years, fishing areas and depths. The table shows derived estimates of spawning ratio potential (SPR) and the size of 50% and 95% selectivity (SL50 & SL95) and relative fishing pressure (F/M). The estimated 95% confidence intervals around these mean estimates are shown in brackets. The input parameters assumed are indicated to the right; life history ratio M/K, asymptotic size (Linf), size at 50% and 95% maturity (L50 & L95). The left-hand panel presents plots of assumed size of maturity ogive (red) and the estimate size of selectivity (blue). The right-hand panel plots the size composition data analysed (black bars) and the LBSPR modelled fit to those data.*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.27 (0.23 - 0.31) | 36.22 (35.3 - 37.14) | 41.37 (40 - 42.74) | 5.05 (3.51 - 6.59) | 1.16 | 51 | 33 | 38 |
| 2011 | 0.25 (0.22 - 0.28) | 35.02 (34.35 - 35.69) | 40.46 (39.42 - 41.5) | 4.12 (3.3 - 4.94) | 1.16 | 51 | 33 | 38 |
| 2012 | 0.21 (0.15 - 0.28) | 37.04 (35.25 - 38.83) | 47.51 (45.22 - 49.8) | 5.58 (3.67 - 7.49) | 1.16 | 51 | 33 | 38 |
| 2013 | 0.23 (0.21 - 0.25) | 33.49 (32.92 - 34.06) | 39.46 (38.57 - 40.35) | 3.38 (2.88 - 3.88) | 1.16 | 51 | 33 | 38 |
| 2014 | 0.2 (0.17 - 0.22) | 32.17 (31.51 - 32.83) | 38.86 (37.84 - 39.88) | 3.18 (2.68 - 3.68) | 1.16 | 51 | 33 | 38 |
| 2015 | 0.26 (0.24 - 0.28) | 35.69 (35.3 - 36.08) | 41.38 (40.79 - 41.97) | 4.47 (3.96 - 4.98) | 1.16 | 51 | 33 | 38 |
| 2016 | 0.24 (0.22 - 0.26) | 34.22 (33.78 - 34.66) | 40.58 (39.89 - 41.27) | 3.56 (3.17 - 3.95) | 1.16 | 51 | 33 | 38 |
| 2017 | 0.25 (0.23 - 0.27) | 35.04 (34.61 - 35.47) | 41.39 (40.74 - 42.04) | 4.01 (3.55 - 4.47) | 1.16 | 51 | 33 | 38 |
| 2018 | 0.22 (0.2 - 0.23) | 33.88 (33.42 - 34.34) | 40.68 (39.99 - 41.37) | 3.81 (3.4 - 4.22) | 1.16 | 51 | 33 | 38 |
| 2019 | 0.18 (0.14 - 0.21) | 32.44 (31.39 - 33.49) | 39.7 (38.1 - 41.3) | 3.77 (2.95 - 4.59) | 1.16 | 51 | 33 | 38 |

*Table 7. Initial LBSPR assessment of cadernal by year using size composition of the catch data aggregated fishing areas and depths and fitted by year. This table shows input assumptions (M/K, $L_{\infty}$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets*

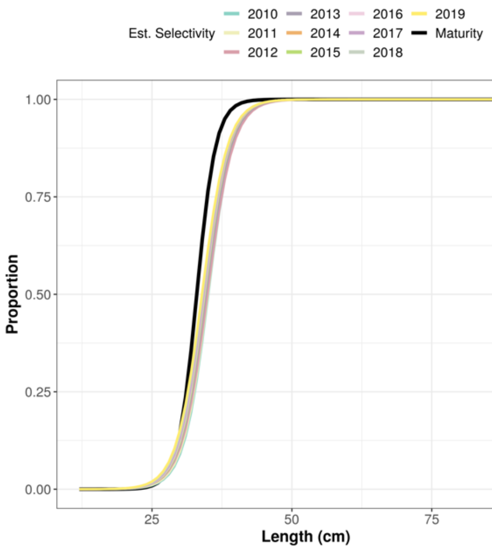


*Figure 58. Results of initial LBSPR assessment of cadernal using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

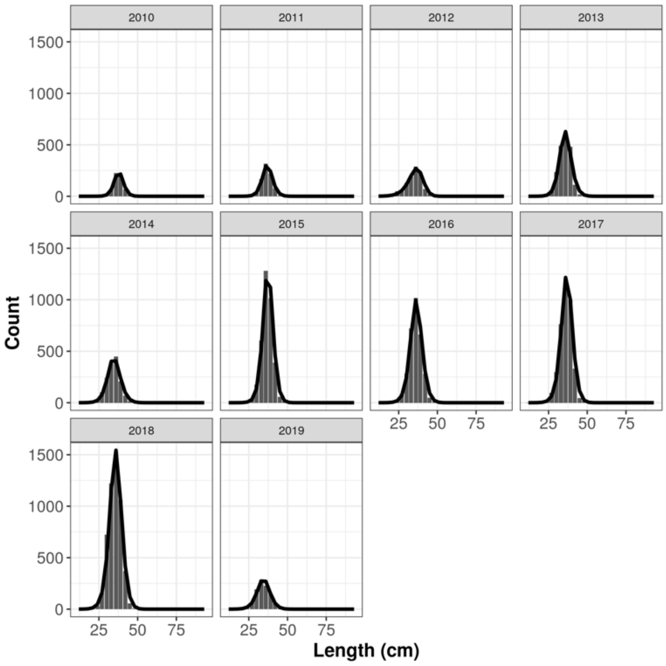


*Figure 59. Initial LBSPR assessment of cadernal using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

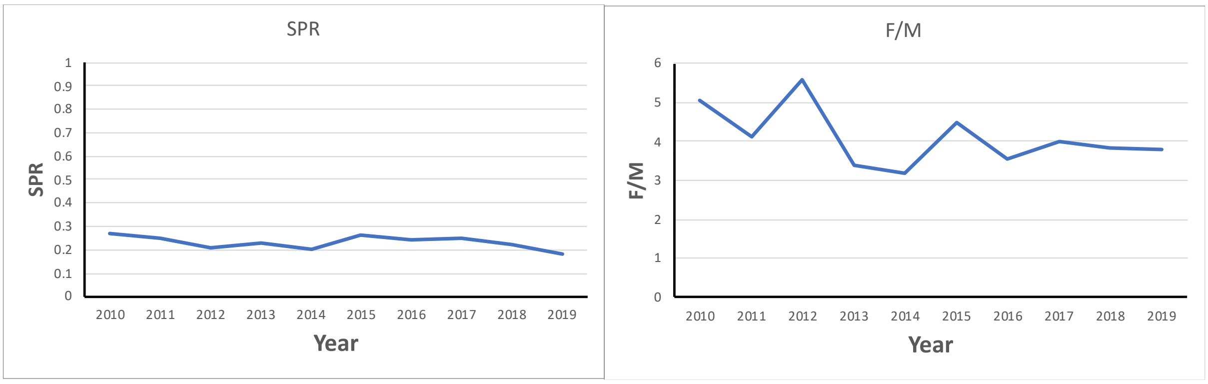


*Figure 60. Initial LBSPR assessment of cardenal using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

## Cadernal Discussion

With little if any evidence of data structuring (no differences by depth, location or region) and the catch length composition data having a simple uni-modal, bell-like shape, consistent with the assumptions of the LBSR algorithms, this species should be very conducive to LBSPR assessment.

The initial LBSPR assessment for this species suggests the stock is being fished relatively heavily (F/M = >4), but due to the size of first capture being similar to the size of maturity SPR has remained relatively stable >20%SPR, but slowly trending down. This is consistent with the indication in these data that targeting may be increasing and the size of first capture declining.

Given the difference in CPUE it would be interesting to compare LBSPR assessments between north and south, potentially they might indicate different levels of SPR and relative fishing pressure between north and south, with lower F/M and higher SPR in the north, but trending similarly.

This assessment is currently based almost entirely on a single estimate of $L_{50}$ so it would be very informative to have some further estimates of size of maturity and growth to help inform the assessment. As with the other species we would recommend applying a range of comparative techniques for estimating size of maturity, and collaboration with the Niparaja size monitoring programs to bolster samples of the largest size classes.

# *Seriola lalandi* – Yellowtail kingfish – Jurel

## Life History Ratios

High quality LHR estimates are available for the family Carangidae from the Prince et al. (in prep. a) meta-analysis.

$M/K = 1.3$; n=42
$L_m/L_\infty = 0.62$; n=29

## Life History Parameters

No biological studies of jurel have been conducted around La Paz, but *Seriola lalandi* have been studied internationally.

The characteristic bi-modality of the catch size composition (Figure 61- 64), suggests there is a smaller mode comprised of juveniles (45 – 85 cm) and a larger mode of adults (>85 cm). Assuming that the larger main mode is comprised of maturing and adult individuals, we can use the principal that the 50% percentile of the adult mode approximates size of maturity to infer $L_m \sim 95$cm, and then assuming the Carangid average $L_m/L_\infty = 0.62$ we can infer $L_\infty \sim 153$ cm.

These inferred LHP estimates are within the range, if towards the upper end, of the estimates found in the international literature for this species of $L_\infty = 106 – 184$ cm and $L_m = 57 – 97$ cm (Gillanders et al. 1999; Dunn 2014; Shiraishi et al. 2010; McKenzie et al. 2014). That our LHP estimates for this stock are towards the upper end of the range of published values is consistent with our understanding of the marine resources at southern end of Baja being enriched by their proximity to sources of cool deep upwelling oceanic water, and so likely to produce a large body size in this sub-tropical species.

## Size Composition Data

To a large extent the size compositions exhibits the single relatively clean uni-modal bell-shaped curve, consistent with the assumptions underlying LBSPR assessment. In these cases the median size in the catch generally remains ~100cm (Figure 61-– 65). However, bi-modality is observed, with some samples have a lesser mode of smaller fish (median length ~ 60 cm), which we infer is comprised principally of juvenile age classes of fish.

This ‘juvenile’ mode is more evident in shallower (0 - 40 fathoms; Figure 63), coastal areas (Figure 62), outside the season for targeting jurel (March & April), and in some years with 2013 - 2014 and 2018 – 2019 being years when it was particularly evident (Figure 65). This looks to be evidence for episodic pulses of better than average recruitment in those years affecting this fishery, but could potentially also be caused by different targeting patterns in some years. With more fishing occurring in some years in the depth ranges where, and months when, juveniles are more likely to be caught. That alternative interpretation seems less likely, however, as the 2013 ‘pulse’ of probably 1+ and 2+ year-old ‘recruits’ can be tracked growing through the size composition until it merges with the adult mode in 2015 - 2016. Such a coherent pattern of modal progressions is unlikely to be caused by a sequence of gradually changing targeting practices, especially as it would apparently imply the fishers were maximising catches of smaller, rather than larger, fish.

To attain the best description of the size composition of the adult part of the population the LBSPR assessment should focus on the ≥ 40 fathom data and truncate the size compositions at 75cm to reduce the importance of the juvenile mode for the LBSPR fitting routines.

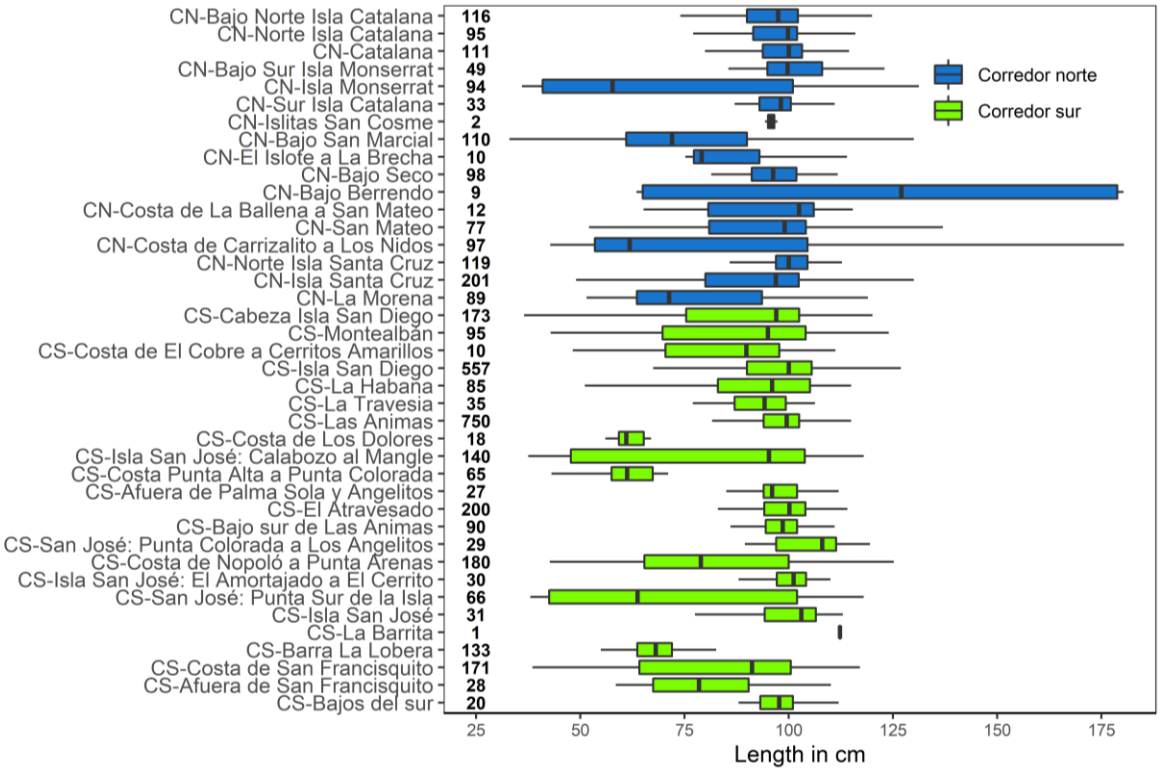


*Figure 61. Percentile length-frequency data for jurel aggregated across all years (2009-2019) and depth categories; plotted by fishing areas sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

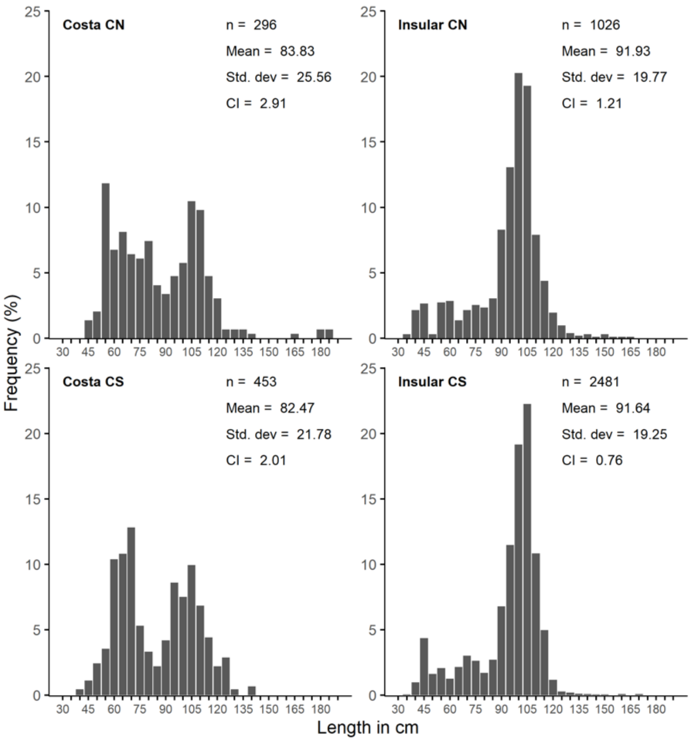


*Figure 62. Length-frequency data of jurel aggregated across all years (2009-2019); plotted by coastal (costera) and offshore (Insular) in the north and south of El Corredor.*

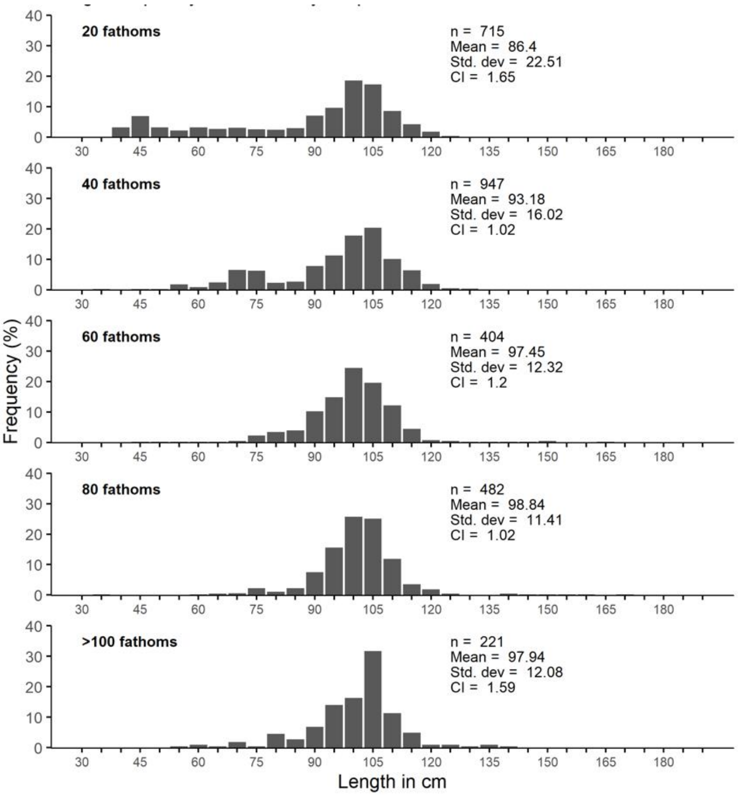


*Figure 63. Length-frequency data aggregated across all years (2009-2019) and all fishing locations plotted by depth category.*

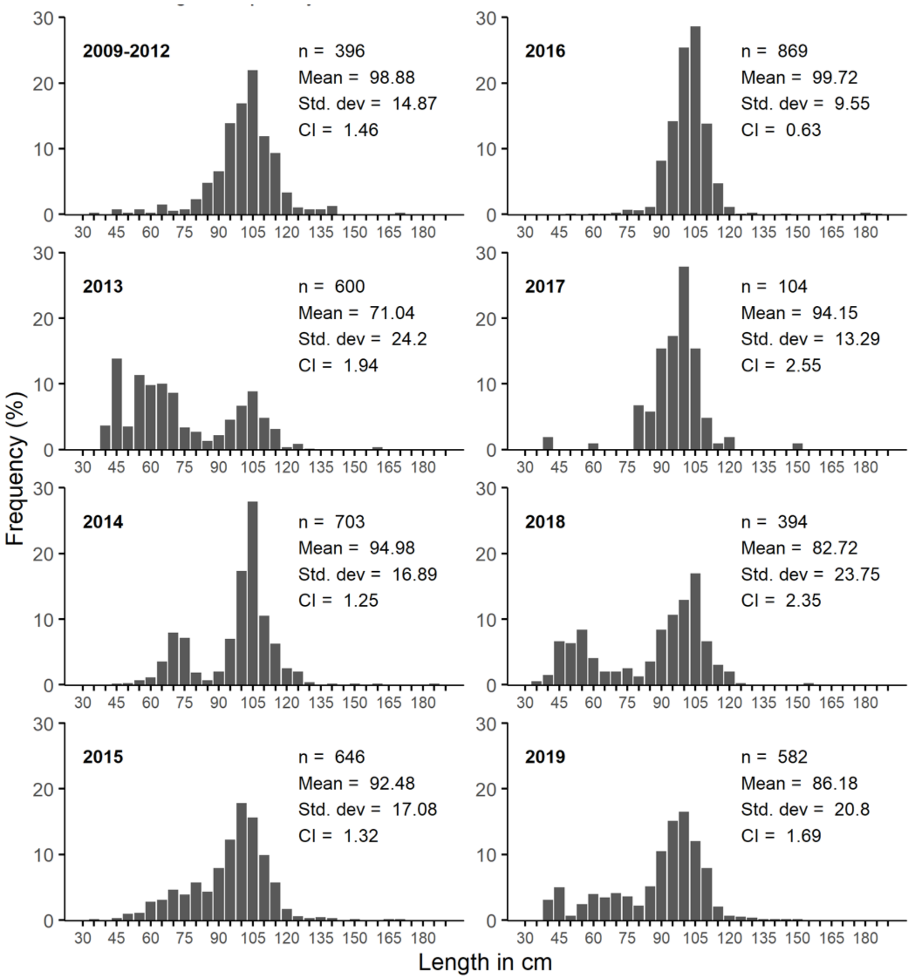


*Figure 64. Length-frequency data of jurel aggregated across all years (2009-2019) and depth categories; plotted by time period.*

## Catch Per Unit Effort Data

Higher more variable CPUE is observed amongst the southern sites (Figure 65), which is opposite to the pattern observed for cadernal. It is not clear whether this indicates better stocks in the south, which seems unlikely for such a mobile species, or more targeted fishing in the south. If there is a differential in the price of fuel between north and south in El Corredor, with cheaper fuel in the south, there could simply be more targeting of this species in the south by trolling.

The highest CPUE for this species is over 40-80 fathoms of depth (Figure 66)

There is little apparent trend over time in the aggregate CPUE but the aggregation of these data and also the scale against which they are plotted probably obscures component trends (Figure 67). Catch rates in shallow water must cycle with the pulses of recruitment evident in (Figure 64) and a closer inspection of Figure 67 reveals a hint of higher CPUE through 2014 & 2015 co-incident with the pulse of recruitment indicated by the size composition of catch.

The time series showing the annual proportion of the total 2006 to 2017 jurel catch shows a peak in annual catches in 2010 followed by a larger peak 2013 & 2014 (Figure 68). Note the coincidence of the second peak in catches with the appearance of the 2013 recruitment pulse evident in the size composition data (Figure 64).

From the composition of catches that contain jurel (Figure 69) it is evident that jurel is commonly 100% of the catch, and very commonly >50% which illustrates the extent to which jurel can be targeted by trolling during March / April. Jurel is also commonly a small proportion of catches containing it, illustrating that it is also widely caught incidentally at low catch rates throughout the seasons, fishing grounds and depth range.

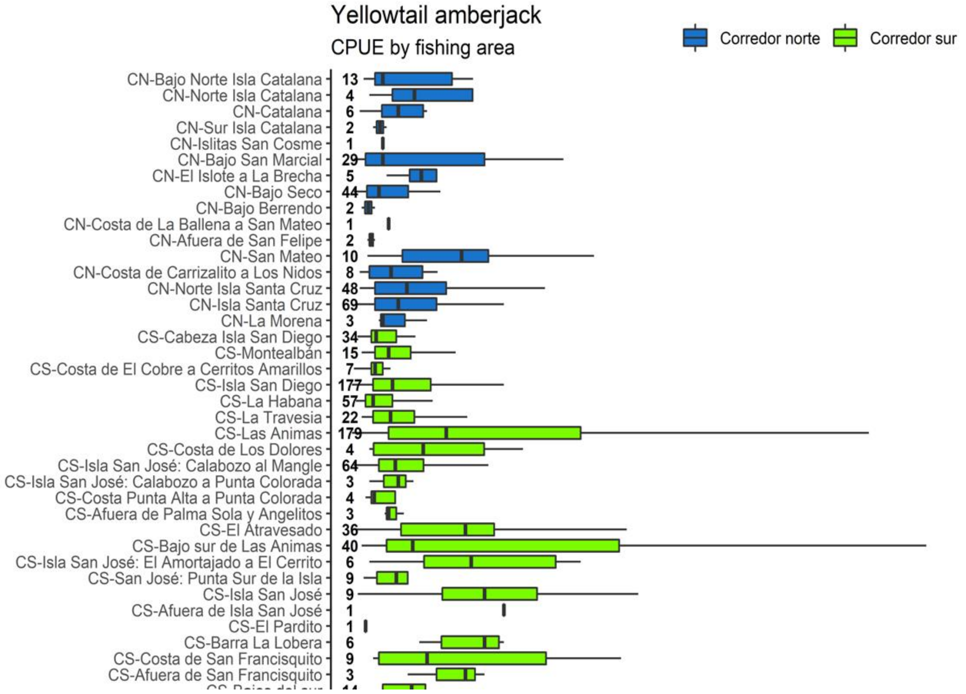


*Figure 65. Percentile catch-per-unit-effort data for jurel aggregated across all years (2009-2019) and depth categories, plotted by fishing area sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

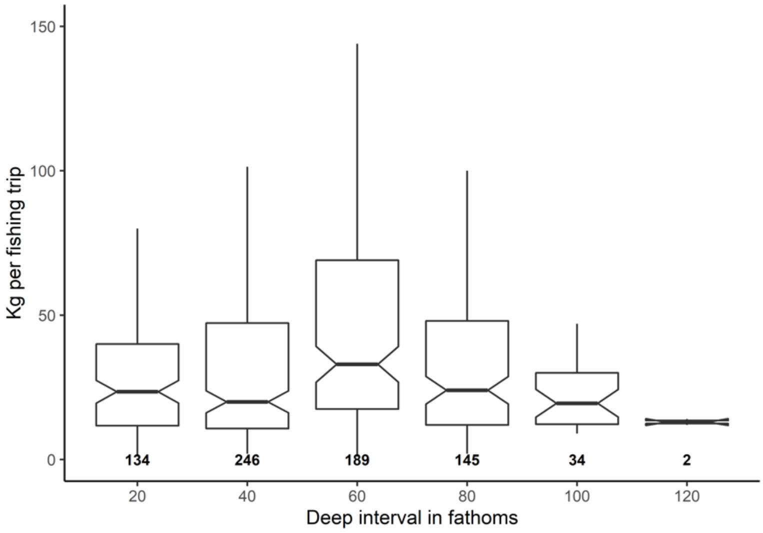


*Figure 66. Catch-Per-Unit-Effort data for jurel aggregated across all years (2009-2019) and fishing locations; plotted by depth category. Bold values mark sample size for each year, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*

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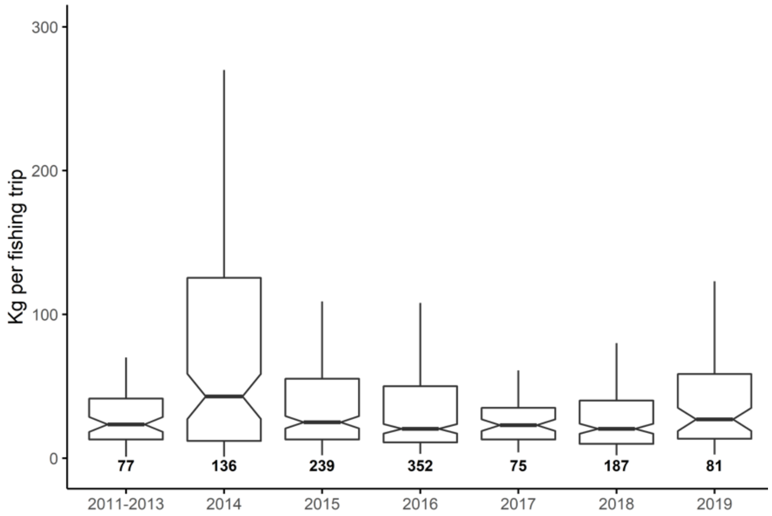

*Figure 67. Catch-Per-Unit-Effort data for jurel aggregated across all depth categories and fishing areas, plotted annually. Bold values mark sample size for each year, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*

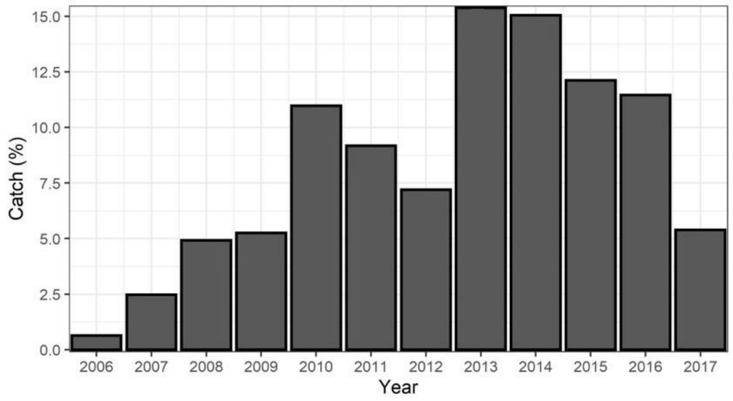

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*Figure 68. The proportion of total recorded jurel catch from 2006-2017 that was recorded in each year of that time series. This figure shows annual jurel catches peaked 2010 with a second larger peak in catches 2013 & 2014.*

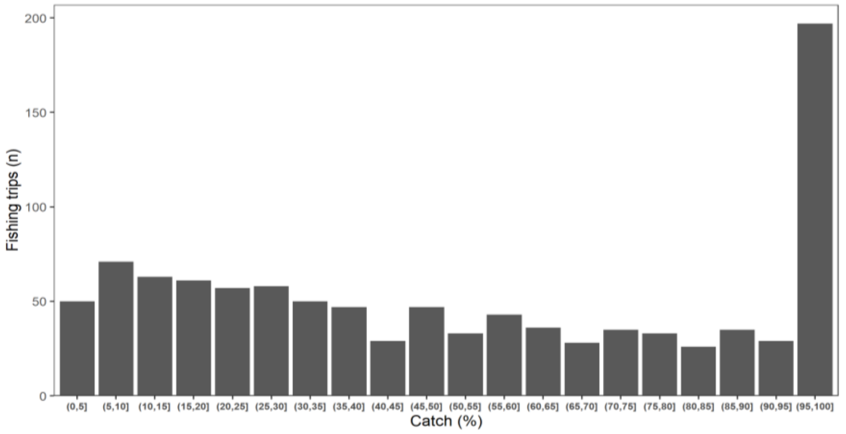


*Figure 69. Catch data aggregated across all years (2014-2019), depth categories and locations; plotted as the number of sampled trips in which jurel comprised each percentage range of the catch. This figure shows jurel is commonly >90% of landed catches because it can be targeted seasonally by trolling, but that it can be almost any proportion of catches due to the fact that it is also taken as by-catch throughout the fishery.*

## Initial LBSPR Assessment

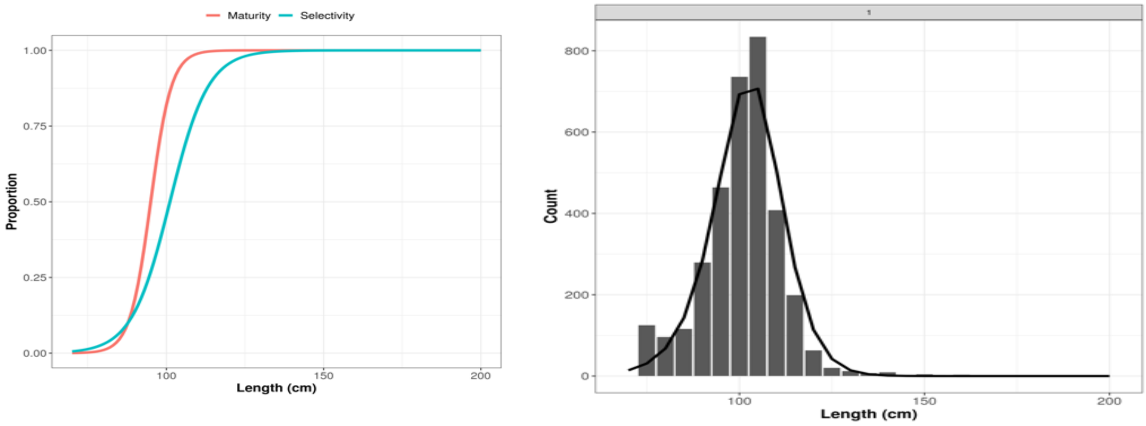
In completing this initial LBSPR assessment for jurel we started with the aggregated dataset (all years, depths and fishing locations) which gives a sample of n = 4041. To constrain the LBSPR model to fit to the single adult mode in the size composition data we truncated the data at 75 cm resulting in an all years, depths and fishing locations sample with n = 3387. We assumed $L_{50}$ = 95cm for El Corredor, which we derived from the 50th percentile of the left-hand side of the adult mode, with $L_{95} = L_{50} \times 1.1 = 104.5$ cm. Assuming the Carangidae average $L_m/L_\infty = 0.62$ we inferred $L_\infty = 153$ cm.

With these data and assumptions, we produced the apparently coherent initial assessment and estimated low SPR = 0.15 and heavy fishing pressure F/M > 5 (Figure 70). The size selectivity is estimated as being similar to maturity ogive but we determined this with our assumptions. The multi-year assessment also seems to work well with these input assumptions (Figure 71 - 73), estimating SPR = 0.13 - 0.19 trending down, and F/M trending up from 3.17 – 5.0 (Table 8).

The estimate of $L_{50}$ = 95cm which this assessment hinges off, is only approximated from the left-hand side of the adult mode in the size composition, based on the assumption that $L_{50}$ coincides with the 50th percentile (midway point) of the left-hand side of the adult size composition. So we also trialled the assessment assuming $L_{50}$ = 90cm which is closer to the base of the left-hand side of the adult size composition, and implies $L_\infty$ = 145 cm rather than 153 cm (Figure 74- 76). With this scenario the SPR estimate is still comparatively low SPR = 0.20 – 0.18 and declining under relatively heavy fishing pressure F/M = 2.5 to >5 (Table 9).

We also explored a range of other plausible input assumptions for this species based on the average Carangidae M/K = 1.277 with a standard deviation of 0.491, and $L_m/L_\infty = 0.621$ with a standard deviation of 0.085, exploring scenarios assuming LHR up to 1 S.D. different to the mean values (M/K = 1.0 – 1.73, $L_m/L_\infty$ = 0.5 – 0.621). We also used the maximum length recorded in our data base ($L_{max}$ = 181 cm) assuming $L_\infty = 0.8L_{max}$ ($L_\infty$ = 145 cm). The most pessimistic result of SPR ~ 0.11 assumed $L_m/L_\infty = 0.621$ and M/K = 1.0 and the most optimistic SPR ~ 0.35 assumed $L_m/L_\infty = 0.500$ and M/K = 1.753. Regardless of the input parameters SPR declines from 2011 to 2019, with the decline occurring in two steps, one in 2012 and the other in 2016. SPR has been stable since 2016.

| SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|
| 0.15 (0.13 - 0.16) | 101.11 (99.94 - 102.28) | 119.01 (117.35 - 120.67) | 6.43 (5.7 - 7.16) | 1.3 | 153 | 95 | 104.7 |



≥ 40 fathom data and truncated at 75cm.

*Figure 70. Initial LBSPR assessment of jurel using size composition of the catch aggregated across all years and fishing areas from ≥ 40 fathoms and truncated at 75 cm; assuming $L_\infty$ = 153 cm & $L_m/L_\infty$ = 0.72 to infer $L_{50}$ = 95 cm. The table shows derived estimates of spawning ratio potential (SPR) and the size of 50% and 95% selectivity (SL50 & SL95) and relative fishing pressure (F/M). The estimated 95% confidence intervals around these mean estimates are shown in brackets. The input parameters assumed are indicated to the right; life history ratio M/K, asymptotic size ($L_\infty$), size at 50% and 95% maturity ($L_{50}$ & $L_{95}$). The left-hand panel presents plots of assumed size of maturity ogive (red) and the estimate size of selectivity (blue). The right-hand panel plots the size composition data analysed (black bars) and the LBSPR modelled fit to those data.*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2011 | 0.19 (0.16 - 0.23) | 95.24 (92.81 - 97.67) | 107.6 (103.6 - 111.6) | 3.17 (2.35 - 3.99) | 1.3 | 153 | 95 | 105 |
| 2013 | 0.17 (0.13 - 0.21) | 96.77 (93.76 - 99.78) | 108.98 (104.17 - 113.79) | 4.11 (2.66 - 5.56) | 1.3 | 153 | 95 | 105 |
| 2014 | 0.17 (0.15 - 0.19) | 99.75 (98.24 - 101.26) | 109.36 (106.92 - 111.8) | 5.97 (4.58 - 7.36) | 1.3 | 153 | 95 | 105 |
| 2015 | 0.17 (0.14 - 0.21) | 92.88 (90.59 - 95.17) | 104.2 (100.35 - 108.05) | 3.14 (2.36 - 3.92) | 1.3 | 153 | 95 | 105 |
| 2016 | 0.13 (0.11 - 0.15) | 99.77 (98.13 - 101.41) | 111.47 (109.02 - 113.92) | 8.62 (6.76 - 10.48) | 1.3 | 153 | 95 | 105 |
| 2018 | 0.13 (0.09 - 0.16) | 93.28 (90.65 - 95.91) | 103.52 (99.19 - 107.85) | 4.86 (3.28 - 6.44) | 1.3 | 153 | 95 | 105 |
| 2019 | 0.13 (0.1 - 0.16) | 91.21 (88.65 - 93.77) | 101.12 (96.69 - 105.55) | 4.06 (2.89 - 5.23) | 1.3 | 153 | 95 | 105 |

*Table 8. Initial annual LBSPR assessment of jurel using size composition of the catch aggregated across fishing areas from ≥ 40 fathoms and truncated at 75 cm; assuming $L_\infty$ = 153 cm & $L_m/L_\infty$ = 0.72 to infer $L_{50}$ = 95 cm. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

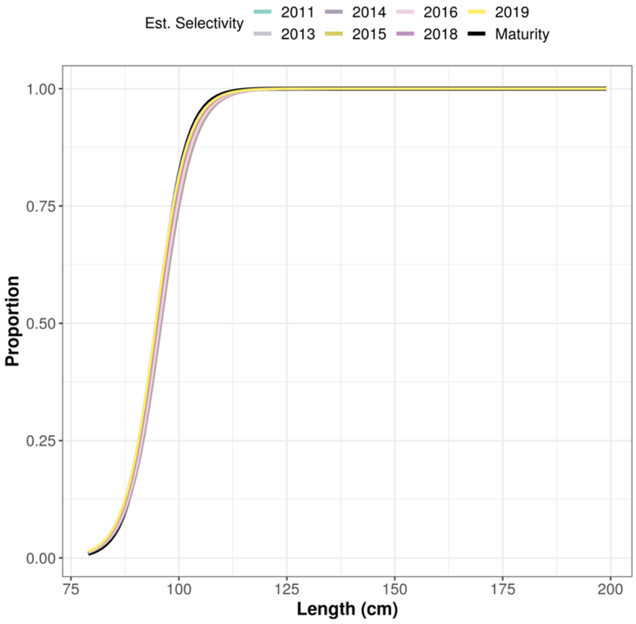


*Figure 71. Initial annual LBSPR assessment of jurel using size composition of the catch aggregated across fishing areas from > 40 fathoms and truncated at 75 cm; assuming $L_\infty$ = 153 cm & $L_m/L_\infty$ = 0.72 to infer $L_{50}$ = 95 cm. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

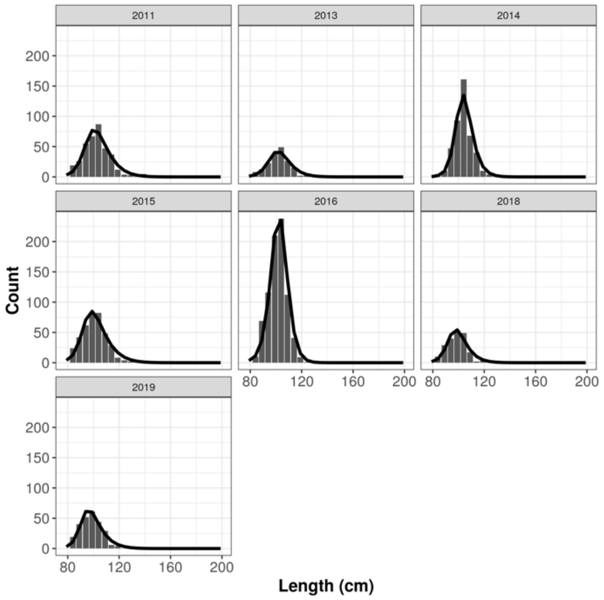


*Figure 72. Initial annual LBSPR assessment of jurel using size composition of the catch aggregated across fishing areas from > 40 fathoms and truncated at 75 cm; assuming $L_\infty$ = 153 cm & $L_m/L_\infty$ = 0.72 to infer $L_{50}$ = 95 cm. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

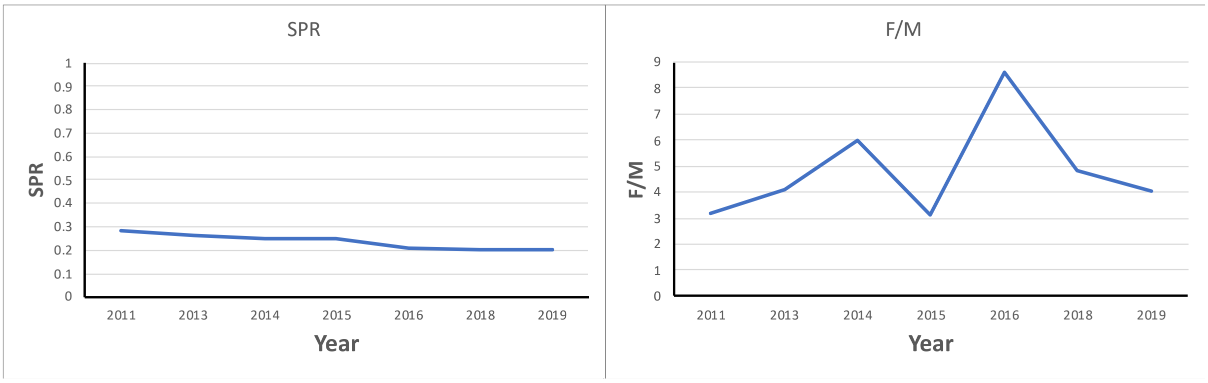


*Figure 73. Initial annual LBSPR assessment of jurel using size composition of the catch aggregated across fishing areas from ≥ 40 fathoms and truncated at 75 cm; assuming $L_\infty$ = 153 cm & $L_m/L_\infty$ = 0.72 to infer $L_{50}$ = 95 cm. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2011 | 0.28 (0.23 - 0.32) | 95.3 (92.66 - 97.94) | 107.72 (103.45 - 111.99) | 2.58 (1.8 - 3.36) | 1.3 | 145 | 90 | 100 |
| 2013 | 0.26 (0.2 - 0.31) | 96.6 (93.46 - 99.74) | 108.74 (103.8 - 113.68) | 3.26 (1.99 - 4.53) | 1.3 | 145 | 90 | 100 |
| 2014 | 0.25 (0.22 - 0.28) | 99.83 (98.26 - 101.4) | 109.48 (106.98 - 111.98) | 4.99 (3.75 - 6.23) | 1.3 | 145 | 90 | 100 |
| 2015 | 0.25 (0.21 - 0.3) | 92.91 (90.39 - 95.43) | 104.28 (100.13 - 108.43) | 2.58 (1.82 - 3.34) | 1.3 | 145 | 90 | 100 |
| 2016 | 0.21 (0.18 - 0.23) | 99.75 (98.09 - 101.41) | 111.42 (108.95 - 113.89) | 7.15 (5.56 - 8.74) | 1.3 | 145 | 90 | 100 |
| 2018 | 0.2 (0.15 - 0.24) | 93.13 (90.44 - 95.82) | 103.29 (98.88 - 107.7) | 3.95 (2.59 - 5.31) | 1.3 | 145 | 90 | 100 |
| 2019 | 0.2 (0.16 - 0.24) | 90.99 (88.41 - 93.57) | 100.72 (96.25 - 105.19) | 3.27 (2.28 - 4.26) | 1.3 | 145 | 90 | 100 |

*Table 9. Annual LBSPR assessment of jurel using size composition of the catch aggregated across fishing areas from ≥ 40 fathoms and truncated at 75 cm; assuming $L_{50}$ = 90 cm & $L_m/L_\infty$ = 0.72 to infer $L_\infty$ = 145 cm. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

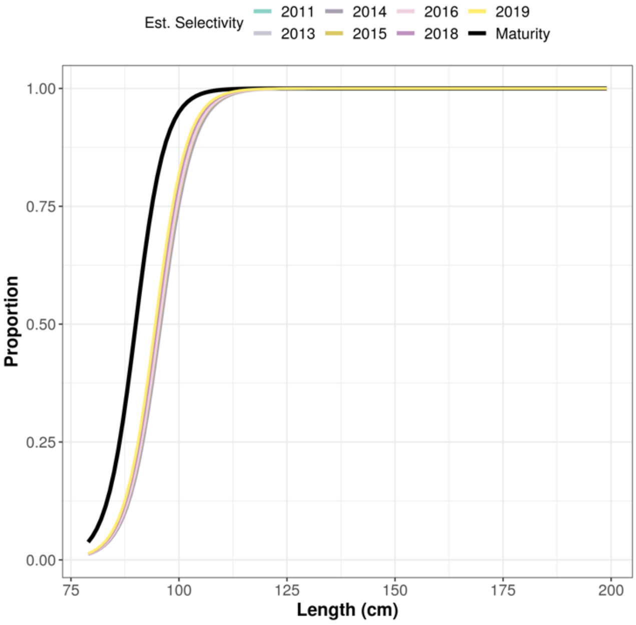


*Figure 74. Annual LBSPR assessment of jurel using size composition of the catch aggregated across fishing areas from ≥ 40 fathoms and truncated at 75 cm; assuming $L_{50}$ = 90 cm & $L_m/L_\infty$ = 0.72 to infer $L_\infty$ = 145 cm. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

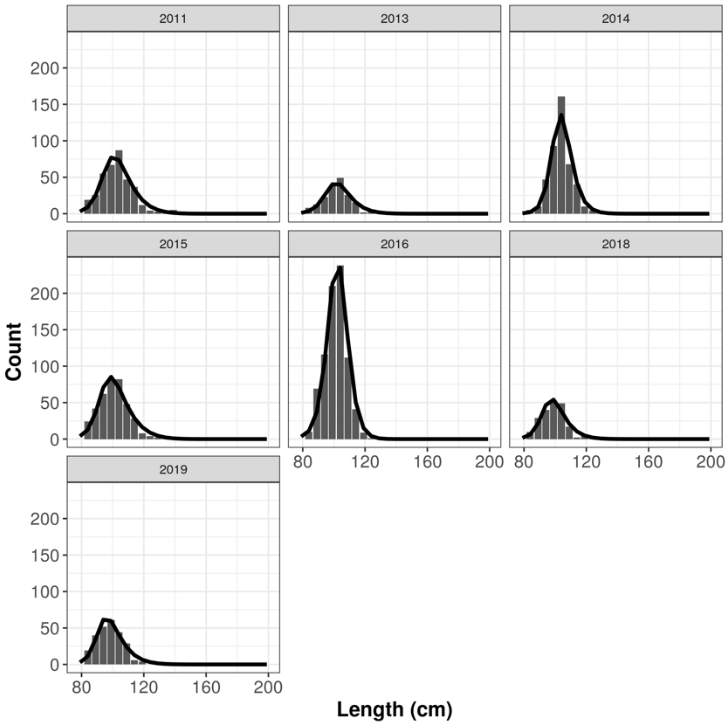


*Figure 75. Annual LBSPR assessment of jurel using size composition of the catch aggregated across fishing areas from ≥ 40 fathoms and truncated at 75 cm; assuming $L_{50}$ = 90 cm & $L_m/L_\infty$ = 0.72 to infer $L_\infty$ = 145 cm. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

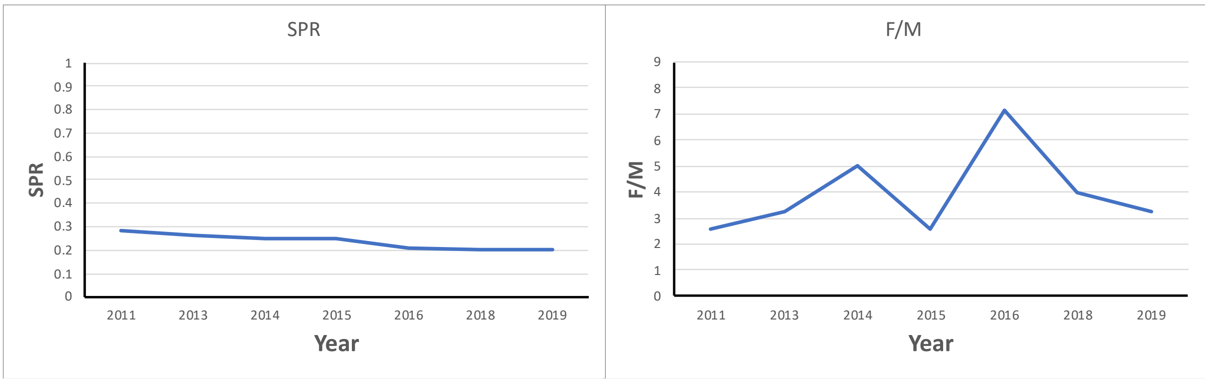


*Figure 76. Annual LBSPR assessment of jurel using size composition of the catch aggregated across fishing areas from ≥ 40 fathoms and truncated at 75 cm; assuming $L_{50}$ = 90 cm & $L_m/L_\infty$ = 0.72 to infer $L_\infty$ = 145 cm. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

## Jurel Discussion

Jurel caught in the area of El Corredor are assumed to be part of a highly mobile, geographically more extensive stock, which is fished from the Midriff Islands region in the Gulf of California, all the way south to Cabo San Lucas and around up, along the west coast of the Peninsula. In this context the fishery in El Corredor is asserting only part of the fishing pressure on this stock, that is being assessed from the stock's size composition in El Corredor.

Within the range of $L_\infty$ = 145 – 153 cm used this appears to be a reasonably robust assessment estimating that SPR is in the range 0.11 – 0.35 and trending down, with heavy fishing pressure increasing. The SPR estimates produced are low, perhaps surprising so, but never-the-less apparently coherent. Although the lack of biological information in this assessment should be noted. Our estimate of $L_m$ is approximated from the size composition data, rather than by direct biological study, and the inference of $L_\infty$ = 145 - 153cm, is based on that assumption and the internationally estimated average LHR for the family of Carangidae and $L_{max}$ in the catch. In defence of our input assumptions; they are consistent with estimates published in the international literature for this species and the $L_{max}$ in the catch.

As with some of the other species jurel provides evidence that fisheries of El Corredor exhibit episodic pulses of recruitment in 2013 and again in 2017 / 2018.

Size of maturity studies for El Corredor would greatly inform this assessment, as would a local study of growth to confirm or challenge our input assumptions. With regard to these studies, the comments made about studying the other species, apply also to jurel. A range of comparative methodologies for estimating size of maturity (histological, fecundity at length, gonadosomic) should be conducted in parallel, and in the estimation of growth particular emphasis should be placed on sampling the rarest largest individuals in the catch.

## *Caulolatilus princeps* – Pierna / Ocean Whitefish

### Life History Ratios

There are high quality LHR estimates available for the Malacanthidae family from the meta-analysis of Prince et al. (in prep. a), although the sample sizes is relatively small;

$M/K = 1.02$; n=14
$L_m/L_\infty = 0.66$; n=10

### Life History Parameters

There is a study of pierna growth from La Paz (Elorduy-Garay 2005) which estimated $L_\infty = 46.1$ cm. Redigitizing those data and standardizing the growth estimates resulted in a similar $L_\infty = 45.5$ cm. This is another study limited by its failing to sample many fish around the asymptotic size, so that the estimate of $L_\infty$ is poorly informed by data, and largely an extrapolation of the growth rates of sub-adults.

Older published studies of Malacanthidae in other regions can be found, which it can be inferred studied populations less heavily impacted by fishing. From those studies it appears that the Malacanthidae are generally long-lived, deep-water species, and that lightly fished populations would normally contain many fish around asymptotic size. Which is typical of a species with $M/K \leq 1.0$. These studies add to the impression that, the La Paz population sampled Elorduy-Garay (2005) had already been truncated by fishing affecting the Elorduy-Garay (2005) growth estimates. An impression that strengthens when the LHP estimates produced by Elorduy-Garay (2005) are combined to estimate $M/K = 1.63$, which seems unrealistically high in comparison to the Malacanthidae family estimate of $M/K = 1.02$ (SD = 0.407). The estimate of $M/K = 1.63$ produced with the LHP from the Elorduy-Garay (2005) is more typical of shallower highly productive coastal taxa like mullet (Mugilidae) and goatfish (Mullidae). This high estimate for M/K is almost certainly due to Elorduy-Garay's unrealistic estimation of t0 which implies growth begins at >10cm, and inaccurate estimate of $L_\infty$, making it appear as if growth to asymptotic size (K) is lower than actual. All of this strengthens the expectation that the estimate of $L_\infty \sim 45.5$ cm is not particularly robust, and probably only indicative of the size range of this population's true $L_\infty$.

Size of maturity is difficult to estimate directly for this family, and species, with standard techniques, because catches are comprised almost entirely of mature fish, which prevents the transition from 100% immature to 100% mature being defined. However, knowing that only maturing and mature fish are caught, justifies approximating $L_m$ from the 50th percentile of left hand-side of the catch size composition. With this technique we infer $L_m \sim 37$cm, and assuming the Malacanthidae average $L_m/L_\infty = 0.66$ infer that $L_\infty = 54$ cm. This is within the range of, but higher than, the local published estimate which never-the-less appears plausible in the situation.

## Size Composition Data

The pierna size catch compositions consistently presents as a standard simple unimodal bell-shape curve which is consistent with the assumptions underlying LBSPR algorithms (Figure 77-80). There is perhaps some gradual shifting to the right, towards larger fish, with increasing depth (Figure 79), which is most pronounced in the small catch at 100 fathoms. In the off-shore waters the size composition might be slightly truncated in the south relative to the north of the Corridor (Figure 78). There may also be some truncation later in the time series of aggregated size composition data (Figure 80).

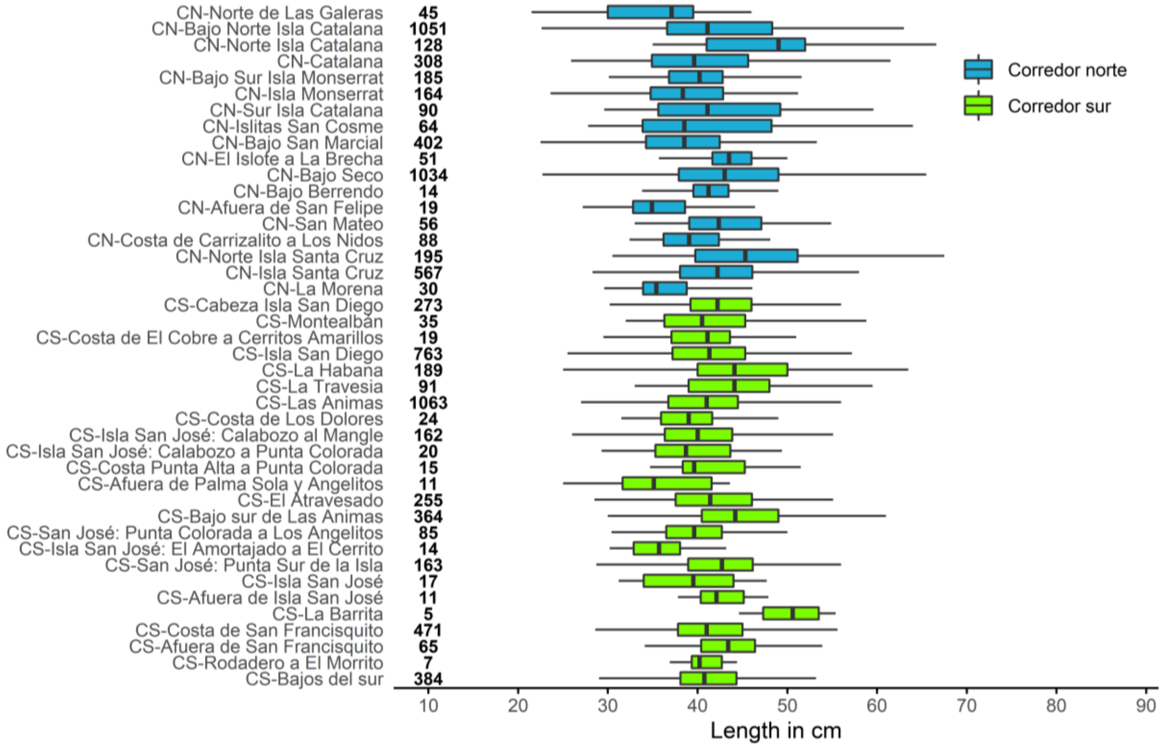


*Figure 77. Percentile length-frequency data for pierna aggregated across all years (2009-2019) and depth categories; plotted by fishing areas sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

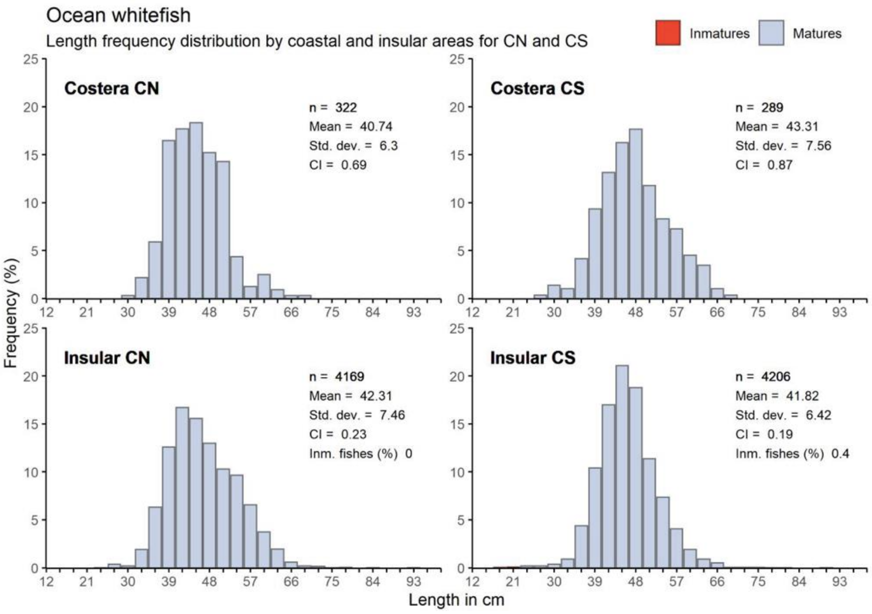


*Figure 78. Length-frequency data for pierna aggregated across all years (2009-2019); plotted by coastal (costera) and offshore (Insular) in the north and south of El Corredor. Size at maturity according to Ramirez-Luna (2010).*

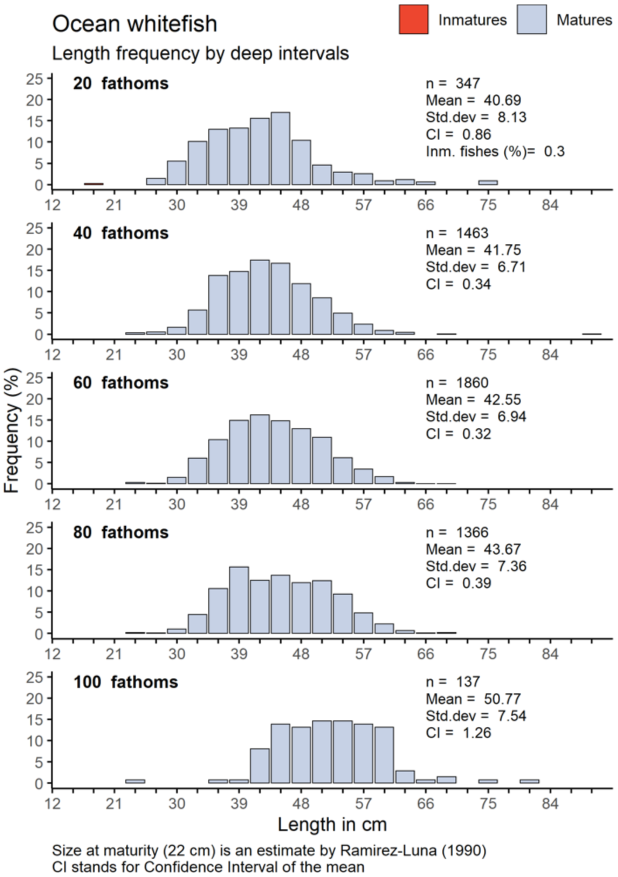


*Figure 79. Length-frequency data for pierna aggregated across all years (2009-2019) and all fishing locations plotted by depth category. Size at maturity according to Ramirez-Luna (2010).*

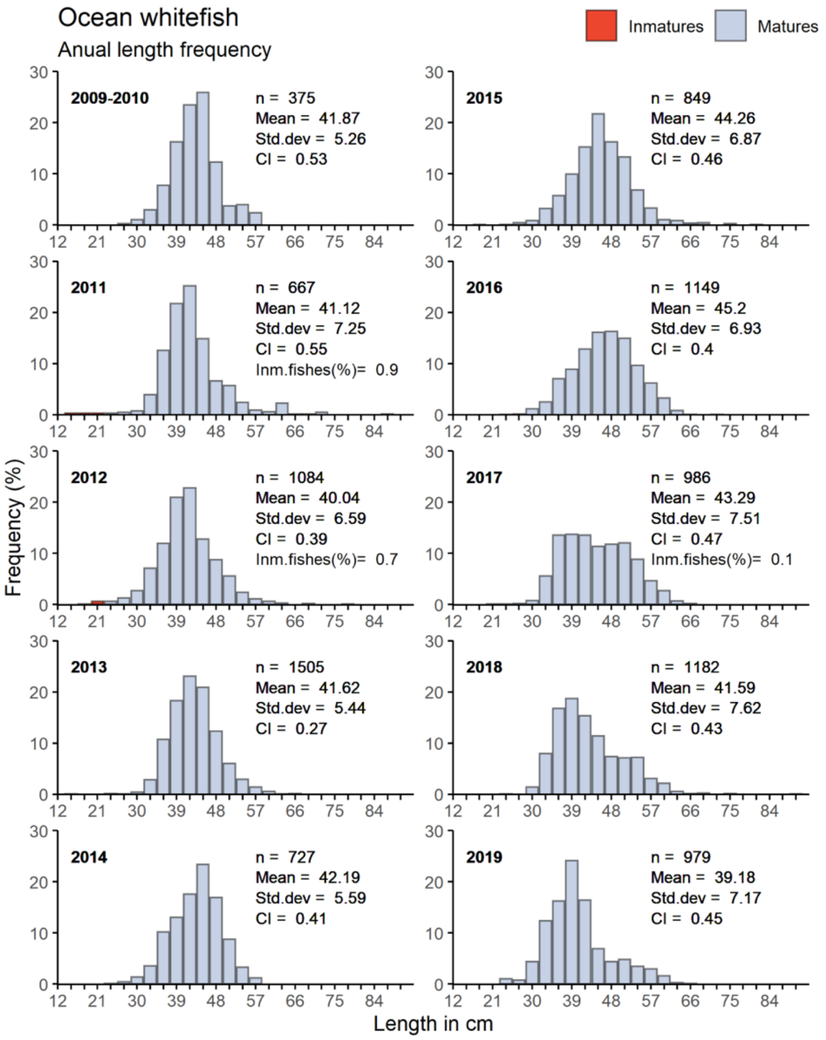


*Figure 80. Length-frequency data for pierna aggregated across all years (2009-2019) and depth categories; plotted by time period. Size at maturity according to Ramirez-Luna (2010).*

## Catch Per Unit Effort Data

The CPUE data for pierna suggests that the highest most variable CPUE are in the north (Figure 81), at depths of 60-80 fathoms (Figure 82). The difference between south and north is quite striking and suggests the stocks in the south closer to market are more depleted which is consistent with expectations of exploitation pressure being highest closer to markets.

There is little apparent trend over time in the aggregated CPUE data, but the degree of aggregation probably masks changes that have occurred over time within specific sites (Figure 83). The median CPUE may cycle, similar to pargo amarillo, between highs in 2012 and 2018 but the large scale of the x-axis makes this difficult to gauge. Disaggregating the CPUE and size-composition data, to examine the extent which trends differ, or are shared by area, at least to the level of north and south, is suggested by the trends and contrasts that are evident.

The time series of the proportion of the total pierna caught, from 2006 to 2017 (845.2t), shows that from 2006 – 2011 the catch of pierna increased steadily, doubling over the period (Figure 84). This is consisted with an initially lightly exploited species being subject to a rapid increase in fishing pressure. Catches peaked in 2011 and subsequently declined to about half of the 2011 peak, suggesting the initially, relatively lightly fished stock, has now been fished down to some extent. The difference between north and south, with higher more variable CPUE in the north (Figure 81), might indicate that this initial fish-down of the resource has been greatest in the south closer to markets. These observations are all consistent with accounts that historically pierna was a lower value, less preferred deeper species, that was not so heavily targeted, but that as other species have been fished down, targeting practices have been developed for pierna, and its importance to the fishery has increased subjecting the species to higher levels of fishing pressure.

Figure 85 illustrates that the proportion of catch comprised of pierna is highly variable. This very uniform profile of catches being from 0 – 100% comprised of pierna, illustrates that the species is widely distributed and often caught incidentally, but that it can also be targeted relatively selectively at depth.

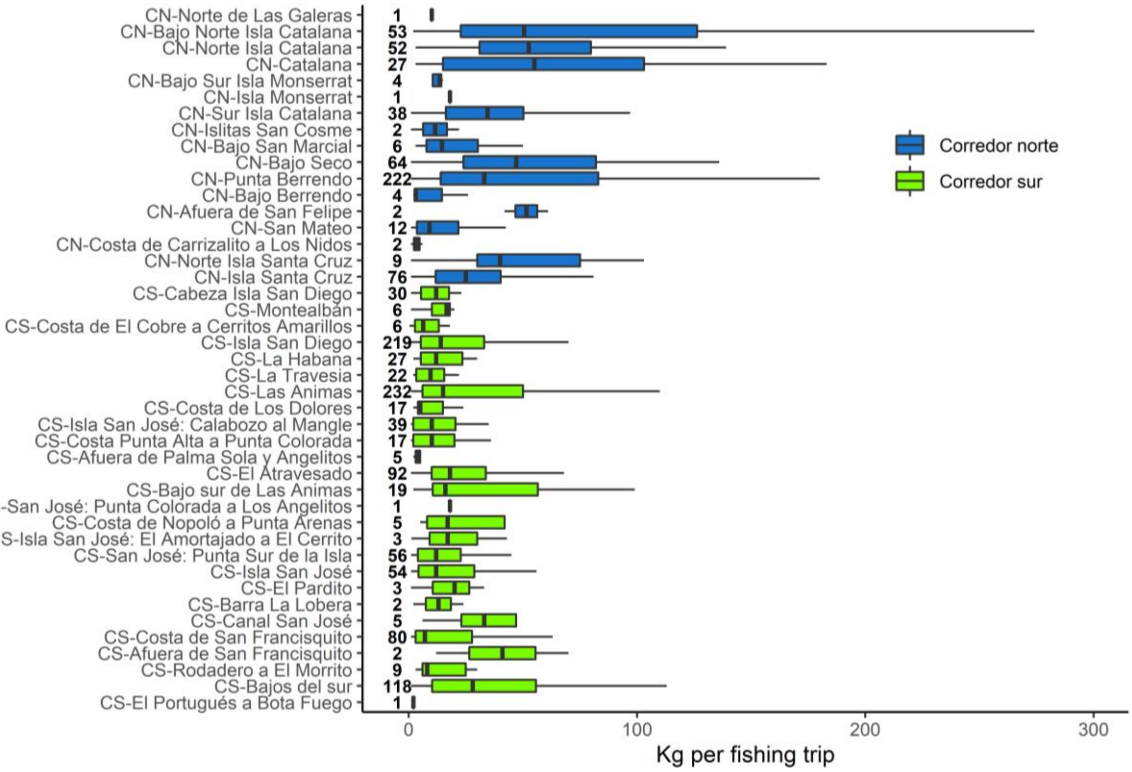


*Figure 81. Percentile catch-per-unit-effort data for pierna aggregated across all years (2009-2019) and depth categories, plotted by fishing area sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

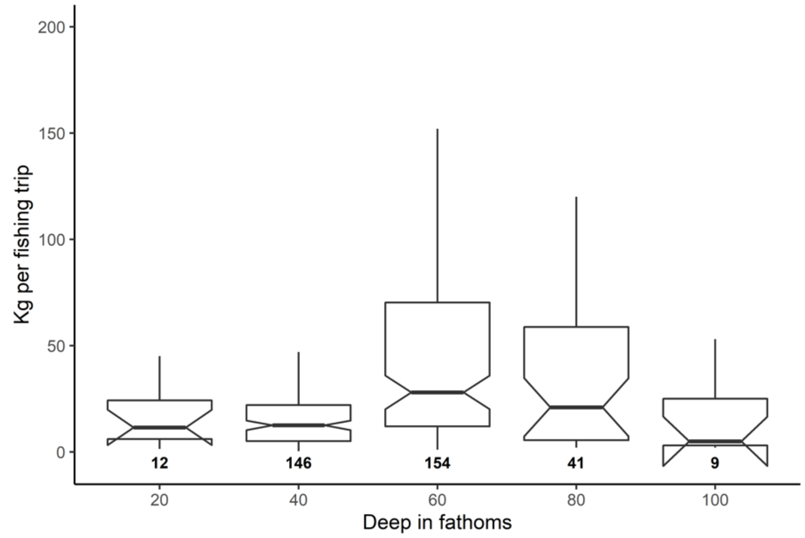


*Figure 82. Catch-Per-Unit-Effort data for pierna aggregated across all years (2009-2019) and fishing locations; plotted by depth category. Bold values mark sample size for depth category, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range. The unusual shape of the last boxplot indicates the low sample size.*

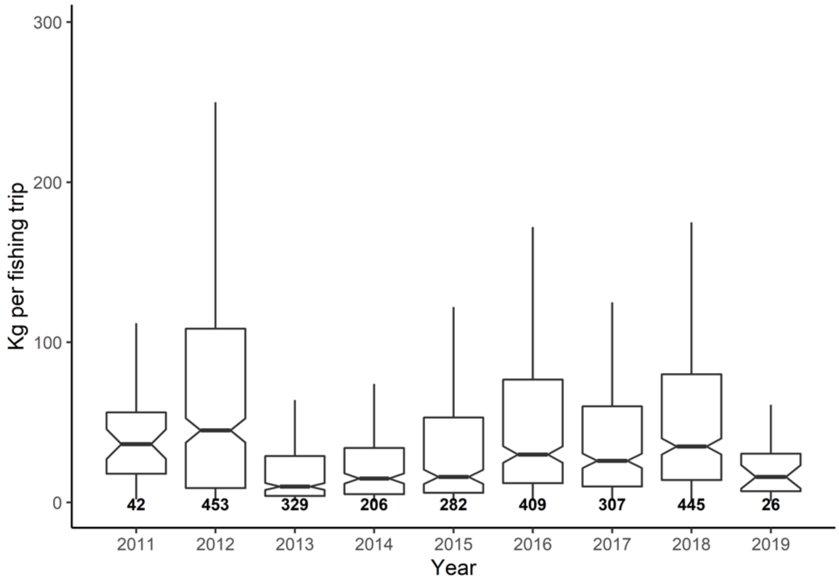
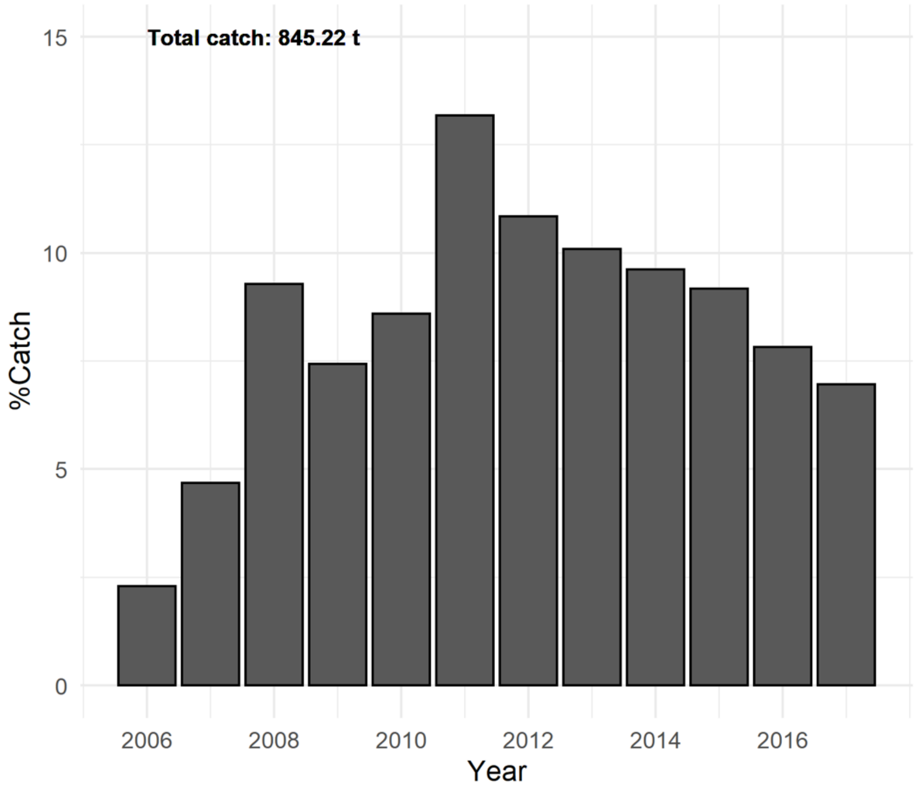


*Figure 83. Catch-Per-Unit-Effort data for pierna aggregated across all fishing grounds and depth categories; plotted by year. Bold values mark sample size for depth category, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*



Source: CONAPESCA

*Figure 84. The proportion of total recorded pierna catch from 2006-2017 (845.2t) that was recorded in each year of that time series. The figure shows that annual catches of pierna peaked in 2011 and declined to about half by 2017.*

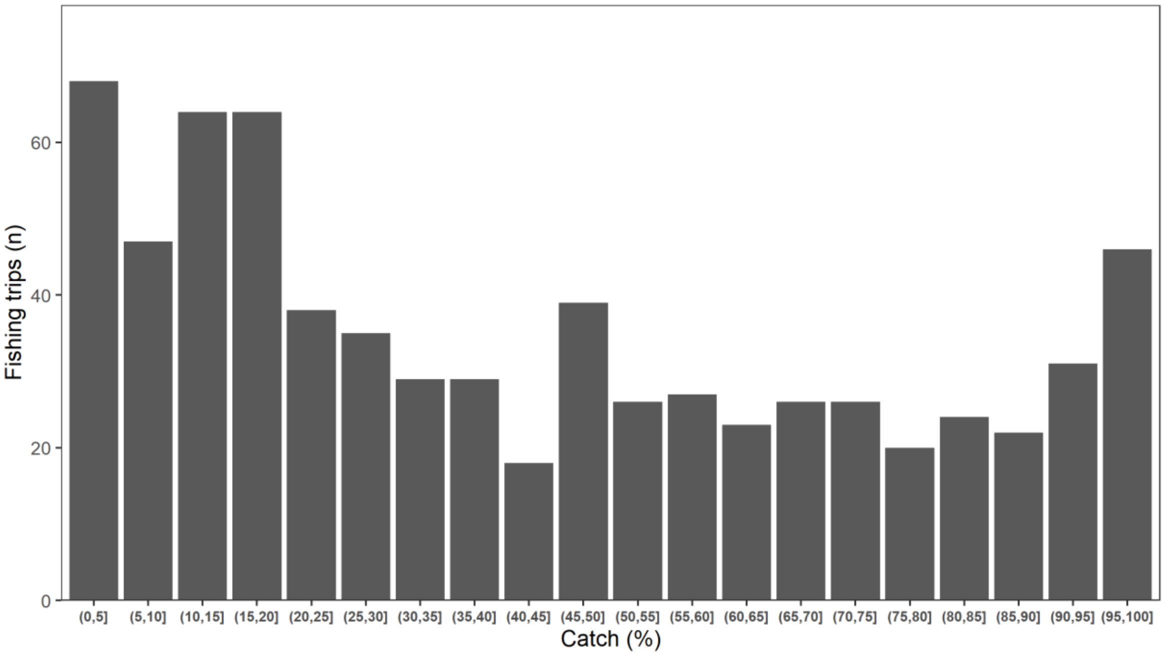


*Figure 85. Catch data aggregated across all years (2014-2019), depth categories and locations; plotted as the number of sampled trips in which pierna comprised each percentage range of the catch. This figure shows pierna is similarly likely to comprise 0 - 100% of catches.*

## Initial LBSPR Assessment

In completing the initial LBSPR assessment of the aggregated dataset (all years, depths and fishing locations) we assumed $L_m$ = 37 cm which we inferred from the left-hand side of the size composition, and $L_m/L_\infty$ = 0.66 derived for Malacanthidae through meta-analysis to infer $L_\infty$ = 56cm. Assuming M/K = 1.02, also derived through meta-analysis, we initially produced a seemingly coherent initial assessment SPR = 0.58 and F/M = 0.55, which seems to suggest a relatively light level of fishing (Figure 86).

These high estimates of SPR might possibly be explained by being a legacy effect on size structure? The Malacanthidae are typically long-lived and the initial fish-down has happened in the relatively recent past, so that the effect of fishing down the size structure may not have had sufficient time to 'grow through' the size structure. Meaning that to some extent the size composition of catches might still reflect the previous lightly fished status of the stock and the persistence of some of the larger individuals in the population. Alternatively, we should bear in mind our initial uncertainty about input parameters; and the potential for lighter exploited populations in the north to influence the analysis of the aggregated data.

Analysis by year produces a lot of estimates (2009 – 2014 & 2019) of SPR ~40% & F/M ~ 1-2 and a few higher estimates SPR ~60-90% & F/M <0.5 (Table 10 Figure 87-89). This adds support to the possibility that some aspects of our results might reflect the extent to which our aggregated annual samples are comprised of fish from the more lightly exploited north, or the more heavily exploited south.

| SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|
| 0.58 (0.56 - 0.61) | 35.85 (35.54 - 36.16) | 42.86 (42.31 - 43.41) | 0.55 (0.5 - 0.6) | 1.02 | 56.06 | 37 | 42 |

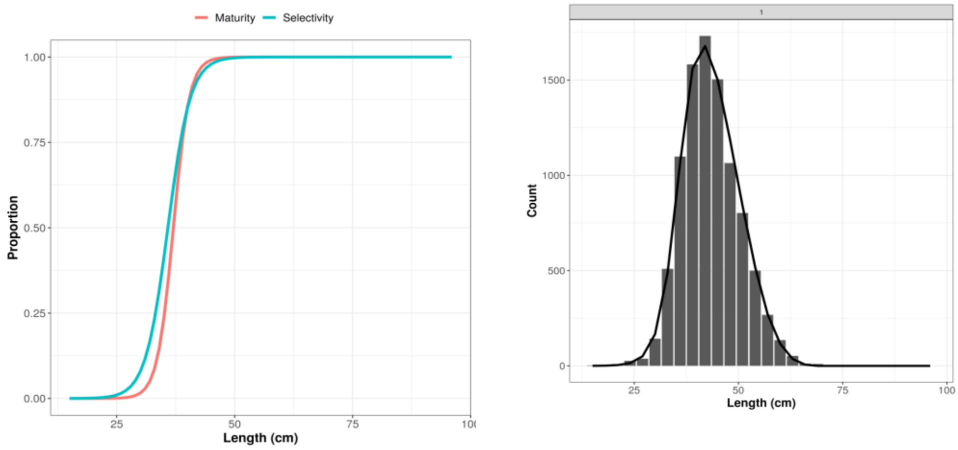


*Figure 86. Initial LBSPR assessment using size composition of the catch data aggregated across all years, fishing areas and depths. The table shows derived estimates of spawning ratio potential (SPR) and the size of 50% and 95% selectivity (SL50 & SL95) and reltive fishing pressure (F/M). The estimated 95% confidence intervals around these mean estimates are shown in brackets. The input parameters assumed are indicated to the right; life history ratio M/K, asymptotic size (Linf), size at 50% and 95% maturity (L50 & L95). The left-hand panel presents plots of assumed size of maturity ogive (red) and the estimate size of selectivity (blue). The right-hand panel plots the size composition data analysed (black bars) and the LBSPR modelled fit to those data.*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2009 | 0.4 (0.32 - 0.47) | 40.73 (39.04 - 42.42) | 48.46 (45.81 - 51.11) | 1.96 (1.23 - 2.69) | 1.02 | 56 | 37 | 42 |
| 2011 | 0.42 (0.37 - 0.47) | 36.84 (36.03 - 37.65) | 43.82 (42.42 - 45.22) | 1.14 (0.9 - 1.38) | 1.02 | 56 | 37 | 42 |
| 2012 | 0.36 (0.32 - 0.4) | 37.1 (36.08 - 38.12) | 46.15 (44.49 - 47.81) | 1.48 (1.19 - 1.77) | 1.02 | 56 | 37 | 42 |
| 2013 | 0.41 (0.38 - 0.45) | 38.25 (37.55 - 38.95) | 44.56 (43.36 - 45.76) | 1.35 (1.12 - 1.58) | 1.02 | 56 | 37 | 42 |
| 2014 | 0.41 (0.32 - 0.49) | 42.91 (40.66 - 45.16) | 53.35 (50.19 - 56.51) | 2.32 (1.43 - 3.21) | 1.02 | 56 | 37 | 42 |
| 2015 | 0.63 (0.55 - 0.71) | 41.01 (39.42 - 42.6) | 50.67 (48.21 - 53.13) | 0.67 (0.41 - 0.93) | 1.02 | 56 | 37 | 42 |
| 2016 | 0.91 (0.78 - 1) | 38.9 (37.04 - 40.76) | 47.87 (44.86 - 50.88) | 0.09 (0 - 0.25) | 1.02 | 56 | 37 | 42 |
| 2017 | 0.97 (0.85 - 1) | 33.58 (32.9 - 34.26) | 38.01 (36.7 - 39.32) | 0.02 (0 - 0.11) | 1.02 | 56 | 37 | 42 |
| 2018 | 0.66 (0.59 - 0.73) | 33.15 (32.66 - 33.64) | 36.76 (35.82 - 37.7) | 0.35 (0.25 - 0.45) | 1.02 | 56 | 37 | 42 |
| 2019 | 0.42 (0.37 - 0.47) | 32.67 (31.96 - 33.38) | 38.58 (37.32 - 39.84) | 0.84 (0.67 - 1.01) | 1.02 | 56 | 37 | 42 |

*Table 10. Initial LBSPR assessment of pierna by year using size composition of the catch data aggregated fishing areas and depths and fitted by year. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

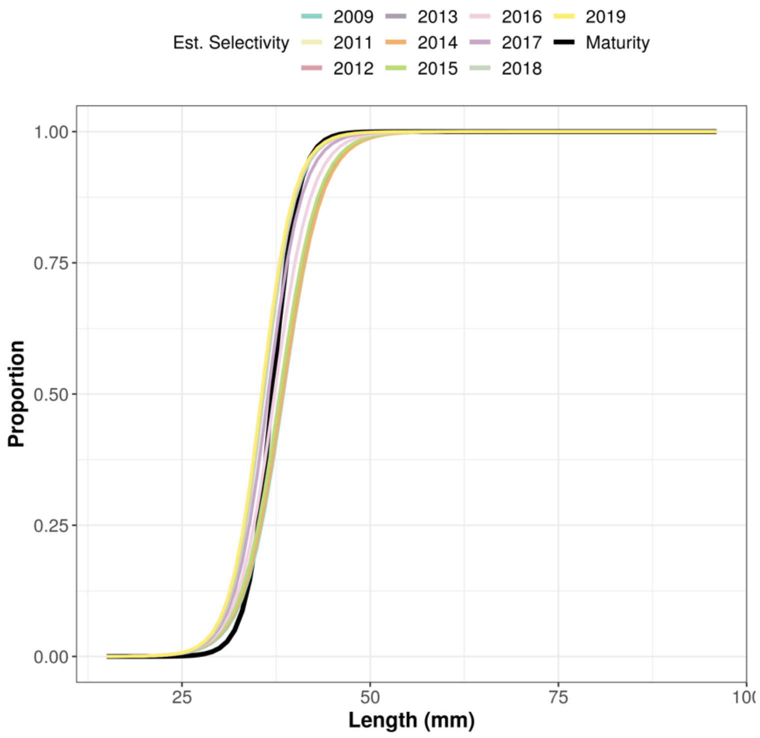


*Figure 87. Results of initial LBSPR assessment of pierna using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

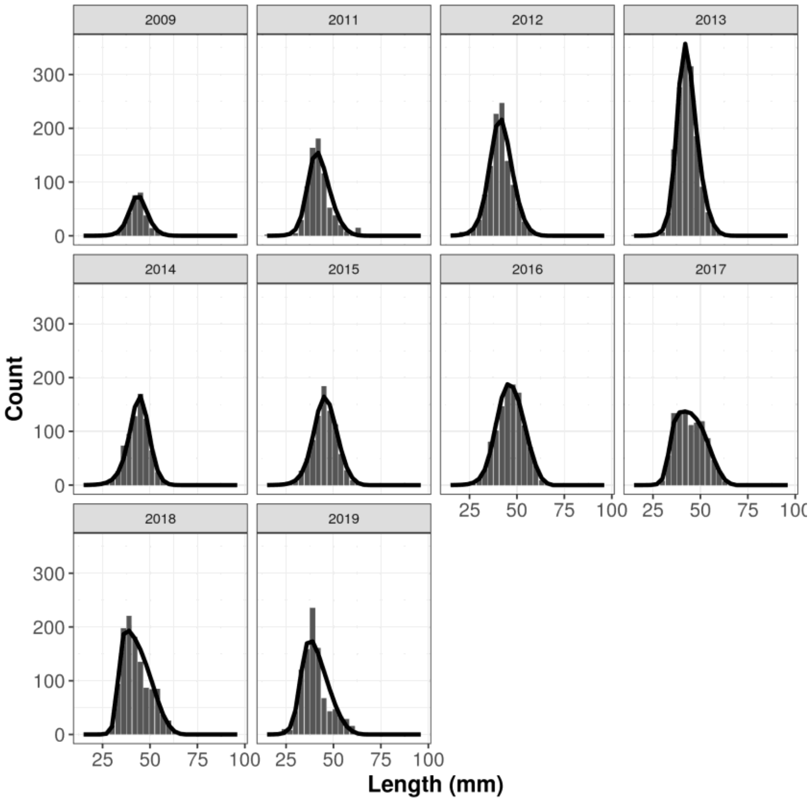


*Figure 88. Initial LBSPR assessment of pierna using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

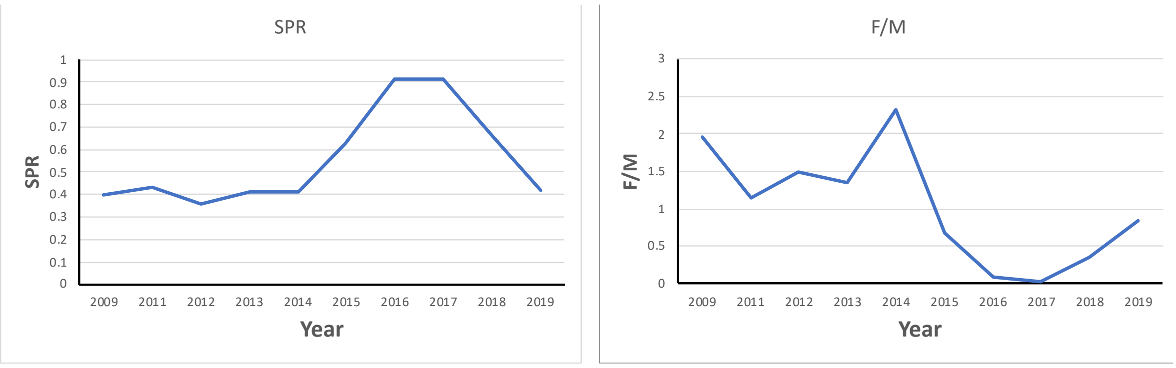


*Figure 89. Initial LBSPR assessment of pierna using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of the estimate trend in SPR (left) and relative fishing pressure (F/M) by year (right).*

## Pierna Discussion

Pierna should be conducive to relatively simple assessment with the LBSPR technique with little if any evidence of problematic structuring in the data. The issues for assessing this species, revolve around uncertainty about input assumptions, and the potential for the size structure to differ between north and south, as the available data suggest there maybe differing levels of depletion from north to south. Overall, our initial assessment suggests this species still has a relatively high level of SPR. Given the anecdotal accounts of how this fishery has been developing and the differences in size composition and CPUE between north and south, these data should be dis-aggregated into north and south. Potentially that may indicate quite different levels of SPR and relative fishing pressure between north and south, with lower F/M and higher SPR in the north, but trending similarly.

It would be very informative to have some more estimates of size of maturity and growth to help inform this assessment, particularly from the northern region of the fishery which may still have a greater proportion of larger older individuals for sampling, and also to extend the meta-analysis of Malacanthidae Life History Ratios to bolster the robustness of the estimates of input parameters.

## *Lutjanus peru* – Huachinango – Pacific Red snapper

Huachinango is the most important species in the El Corredor assemblage, compromising ~60% of the catch from 2014 – 2020. As a result more studies of this species have been conducted. Unfortunately, the biology and fishery for this species is much more complicated than the others, some of the information is contradictory, and during the time period we have data for, the stock has evidently not been in the steady or equilibrium state assumed by most data-poor assessment methodologies, and by standard LBSPR assessment.

### Life History Ratios

There is a good-sized sample of high quality LHR estimates available for the family Lutjanidae from the meta-analysis of Prince et al. (in prep. a) which can be used to derive average LHR estimates;

$M/K = 0.98$; $n = 88$
$L_m/L_\infty = 0.72$; $n = 30$

### Life History Parameters

Around La Paz the growth of huachinango has been studied by Rocha-Olivares et al. (1998) who estimated $L_\infty = 97.3$ cm. When those data were re-digitized and a standardized re-analysis conducted the result was $L_\infty = 94.2$ cm. However, the length at age sample used for that study contains very few fish around the estimated asymptotic size, so that both the published and standardized estimates of $L_\infty$ are poorly informed by data, basically $L_\infty$ is extrapolated from the faster growth of the sub-adults.

The maximum length recorded in the Niparaja-Pronatura files is 101 cm which provides another way for approximating $L_\infty$. Froese & Binohlan (2000) recommend using the approximation of $L_\infty \sim Lmax \times 0.9$, however the analysis of Hordyk et al. (2015) suggests $L_\infty \sim Lmax \times 0.8$ is more accurate for taxa like Lutjanids with $M/K < 1.5$. On the basis of the maximum length in the data base (101 cm) these rules of thumb suggest $L_\infty \sim 80 – 90$ cm supporting the supposition that the Rocha-Olivares et al. (1998) estimates are biased high.

Using histological techniques on samples of fish collected from around the La Paz area Barbosa-Ortega et al. estimated that female $L_m = 32$ cm with some sexually mature females from 26.6 cm, and estimated male $L_m = 29.5$ cm. These estimates are strangely similar to the estimates Barbosa-Ortega et al. derived for pargo amarillo (37 & 26 cm) which is accepted as being the smaller species. The estimates for pargo amarillo are $L_\infty = 60 – 75$ cm and fish > 60 cm are extremely rare in the catch samples, in comparison huachinango > 75cm are relatively commonly observed. These comparisons raise some questions around the Barbosa-Ortega et al. estimate of $L_m$ for huachinango.

Never-the-less, these published estimates from around La Paz, $L_\infty$ ~95cm, and $L_m$ ~ 32 cm were favoured by most workshop participants. Although there was also agreement that the lack of larger individuals in the size at age data means the $L_\infty$ estimate is an approximation, rather than a precise estimate. On the other-hand the workshop participants with local expertise were confident in the quality of the samples and methodologies used to derive the estimate of $L_m$ ~ 32 cm.

An alternative evaluation of these LHP estimates is possible using estimates of average Lutjanidae $L_m/L_\infty$ derived through meta-analysis. The meta-analysis of Prince (in prep. a) contains 30 high quality, standardized Lutjanid estimates which produce an average $L_m/L_\infty = 0.72$ and SD = 0.11. With this ratio, the mis-match between our various life history parameter estimates is illustrated by using $L_m/L_\infty = 0.72$ and the local estimate of $L_m = 32.2$ cm to infer $L_\infty = 44$ cm for huachinango, which is much smaller than the $L_\infty = 60 – 75$ cm estimated for pargo amarillo.

Alternatively, if we accept the local estimates of growth ($L_\infty$ ~ 95 cm; Rocha-Olivares et al. 1998) and $L_m = 33$ cm (Barbosa-Ortega et al.) we estimate $L_m/L_\infty = 0.33$ which is >3 SD below the lutjanid average; which is statistically improbable. We can put our local estimate of $L_m/L_\infty = 0.33$ into the context of our broader meta-analysis, by noting it is considerably smaller than even the smallest average $L_m/L_\infty = 0.41$ derived for any other of the 77 families in that meta-analysis. And also, by noting that families with M/K <1.5, such as Lutjanidae, have larger than the average $L_m/L_\infty$ ~ 0.65 estimated across all species and families in the meta-analysis. In this context it becomes evident that with these local LHP estimates we are either being confronted with some highly anomalous biology for this species in this location, or that, these local LHP estimates are biased in some way. Not-with-standing, the opinion of the workshop participants, it seems most likely that both our local LHP estimates are biased; $L_\infty$ high and $L_m$ low.

If we were to accept $L_m$ ~ 33 cm is without significant bias, as favoured by the workshop participants, then any $L_\infty$ >70 cm implies $L_m/L_\infty$ > 2 SD larger than the Lutjanidae average; which is highly unlikely. On the other-hand the workshop participants considered $L_\infty \leq 70$ cm to be improbably low for huachinango, and it would also be inconsistent with the size of the largest fish measured in samples. If we assume the lutjanid family average $L_m/L_\infty$ applies to huachinango, then it must be concluded that our size composition data imply $L_m$ > 33 cm.

An alternative estimate of $L_m = 54$ cm derived with a different methodology, was published by Spanopoulos-Zarco et al. (2016) who bred and reared huachinango at La Paz. This estimate did not find support amongst the workshop participants, who methodologically, preferred the estimate of Barbosa-Ortega et al. Never-the-less using the estimate of $L_m = 54$ cm with the Rocha-Olivares et al. (1998) estimate of $L_\infty = 97.3$ cm, infers $L_m/L_\infty = 0.574$, which is closer to the lutjanid family average and not implausible (< 2 x SD). Alternatively, assuming our lutjanid family average $L_m/L_\infty = 0.72$ and $L_m = 54$ cm infers $L_\infty = 74$ cm, which is also not implausible.

## Size Composition Data

The size composition data for huachinango are also more complicated than the other species in this assemblage, by being structured by depth and time.

As discussed initially in the introduction, the combined processes of growth, mortality and logistic size selectivity, normally ensure that length frequency histograms of catch size composition data are comprised of one or two relatively normally shaped (bell-shaped) modal size classes. Under conditions approaching equilibrium this structure will remain relatively constant over time, but is eroded away from the right by increasing fishing pressure. In cases where there are two modes, the one on the left is normally minor (numerically smaller) and primarily comprised of juveniles, while the larger right-hand mode will be comprised of sub-adult and adult individuals. Aggregation of these data over extended time periods, will normally reveal this underlying size composition more clearly, as it tends to remain relatively stable over time, despite other sources of variability which may make individual samples noisier.

In the case of huachinango in El Corredor, aggregating the size composition data across the time series reveals that the length-frequency data do not conform to the ‘normal’ pattern described above (Figure 90 & 91). Instead, the aggregated size composition data reveal a single mode that is strongly skewed to the right. The size composition data vary considerably between fishing locations (Figure 90). Few fish >45 cm captured on coastal fishing grounds, while a long tail of fish, out to 85+ cm, is observed being caught in offshore fishing areas (Figure 91). The size classes > 45cm are particularly prevalent in catches from >60 fathoms (Figure 92). Catches from off-shore sea-mount fishing grounds such as Bajo Seco, Las Animas, Sur de Las Animas, have the largest median sizes, although sample sizes are low (Figure 90). This segregation of the size classes by depth is commonly observed amongst larger bodied Lutjanids, and is indicative of ontogenetic (age and size related) movement to deeper water through life, and often the adoption of more pelagic feeding behaviour by adults.

Examining Figure 93reveals pulses of recruitment entering the size composition at 25-30 cm in 2011/12 and 2016 / 2017. The resulting modes can be tracked growing through the stock over the subsequent years. The 2011/12 cohort is apparently considerably larger than the subsequent pulse in 2016/17, but the effect of the second pulse is proportionally much smaller, because the first pulse increases the population’s size to such an extent that the proportional impact of the second pulse is less. By the end of the time series the modal size of the first pulse is 65-70 cm, and its rate of growth is slowing as it approaches asymptotic size and merges with other similarly sized adult cohorts, which it dwarfs numerically. The less obvious 2016/17 pulse is attaining ~40cm by the end of the times series.

The growth of the numerically large 2011/12 cohort, through the size spectrum and depth range, dominates this time series. Dwarfing the other cohorts, its progression through the size spectrum obscures the ‘normal’ distinction between the sub-adult mode on the left, and adult mode on the right. Normally we would expect to observe a distinct and permanent minimum between the sub-adult and adult modes.

Figure 94, plots size-frequency histograms aggregated for all years and fishing locations (top panel), all fishing locations in 2019 and 2020 (middle panel) and deep fishing locations (≥ 60 fathoms) in 2019 and 2020 (bottom panel). In the bottom panel of Figure 94 the length-frequency histogram conforms with the ‘normal’ size composition pattern, with a main mode (albeit with a split peak) of ~70cm and a secondary smaller mode of ~40 cm. This provides the clearest view available of distinct sub-adult and adult modes. In the previous years the super-abundance of the 2011/12 cohort, compared with the adjacent cohorts, obscures the distinctiveness of the sub-adult mode on the left, and the adult mode on the right, even at depth (Figure 95). By 2019/20 the 2011/12 cohort has grown through the minimum between the modes and has merged into the adult size range.

In the bottom panel of Figure 94 and the bottom right-hand panel of Figure 95(i.e. 2020), that we can see that the 50th percentile of the left-hand side of the main mode coincides with Spanopoulos-Zarco et al. (2016) estimate of $L_m$ = 54 cm. While the Barbosa-Ortega et al. estimate of $L_m$ = 32 cm coincides with the 50th percentile of the left-hand side of the main mode from shallow water, and all samples aggregated (Figure 94- top panel).

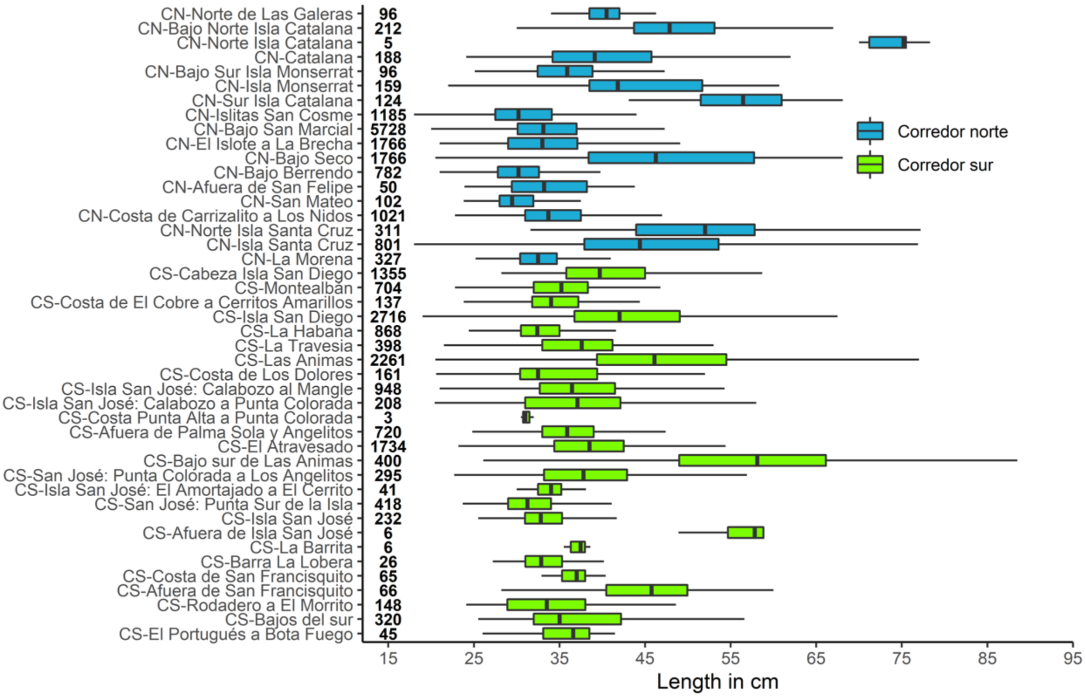


*Figure 90. Percentile length-frequency data for huachinango aggregated across all years (2009-2019) and depth categories; plotted by fishing areas sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

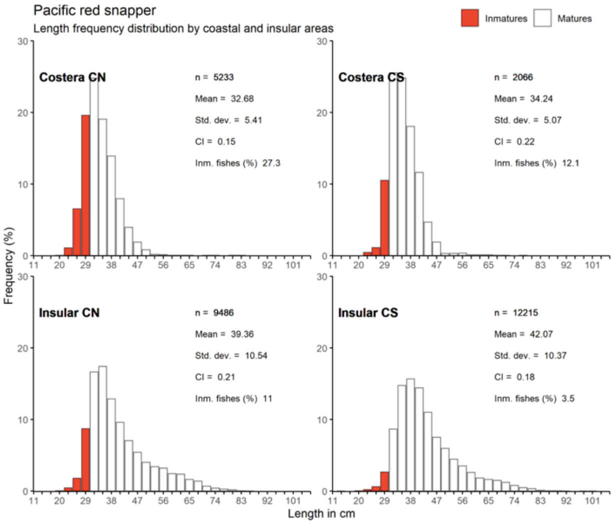


*Figure 91. Length-frequency data for huachinango aggregated across all years (2009-2019); plotted by coastal (costera) and offshore (Insular) in the north and south of El Corredor. Size at maturity according to Barbosa-Ortega et al. (2014) indicated by darker colouring. Size at maturity according to Barbosa-Ortega et al. (2014) indicated by darker colouring in the left-hand panel.*

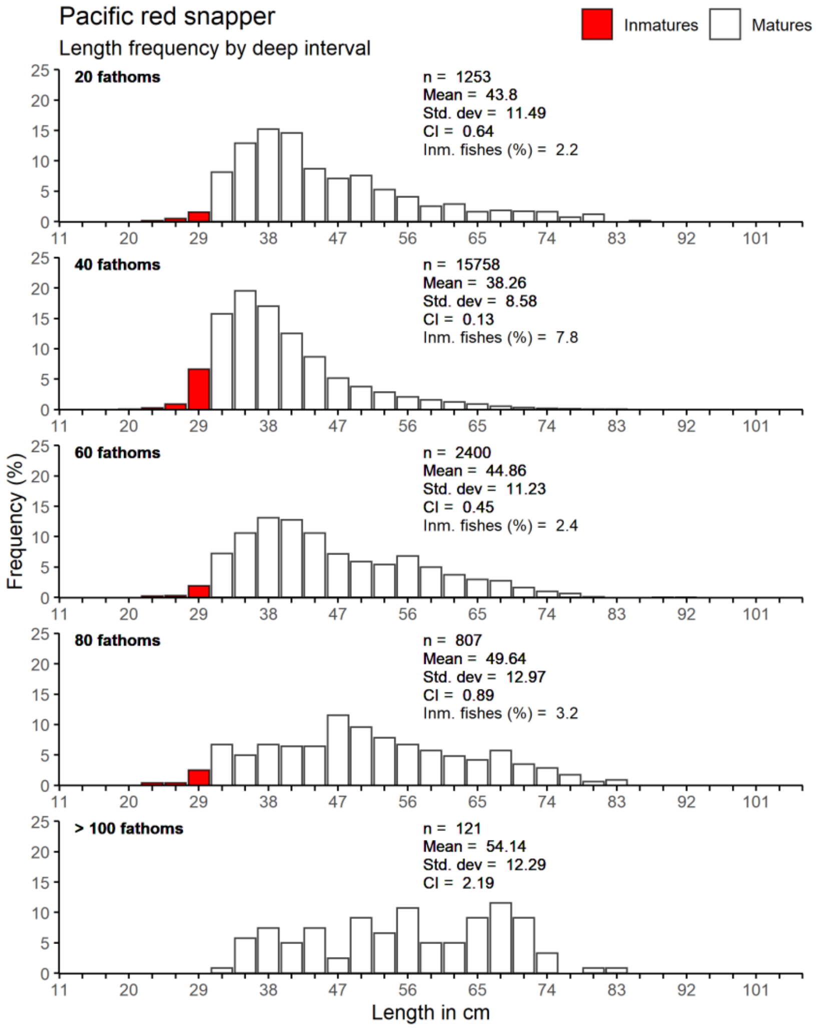


*Figure 92. Length-frequency data for huachinango aggregated across all years (2009-2019) and all fishing locations plotted by depth category. Size at maturity according to Barbosa-Ortega et al. (2014) indicated by darker colouring.*

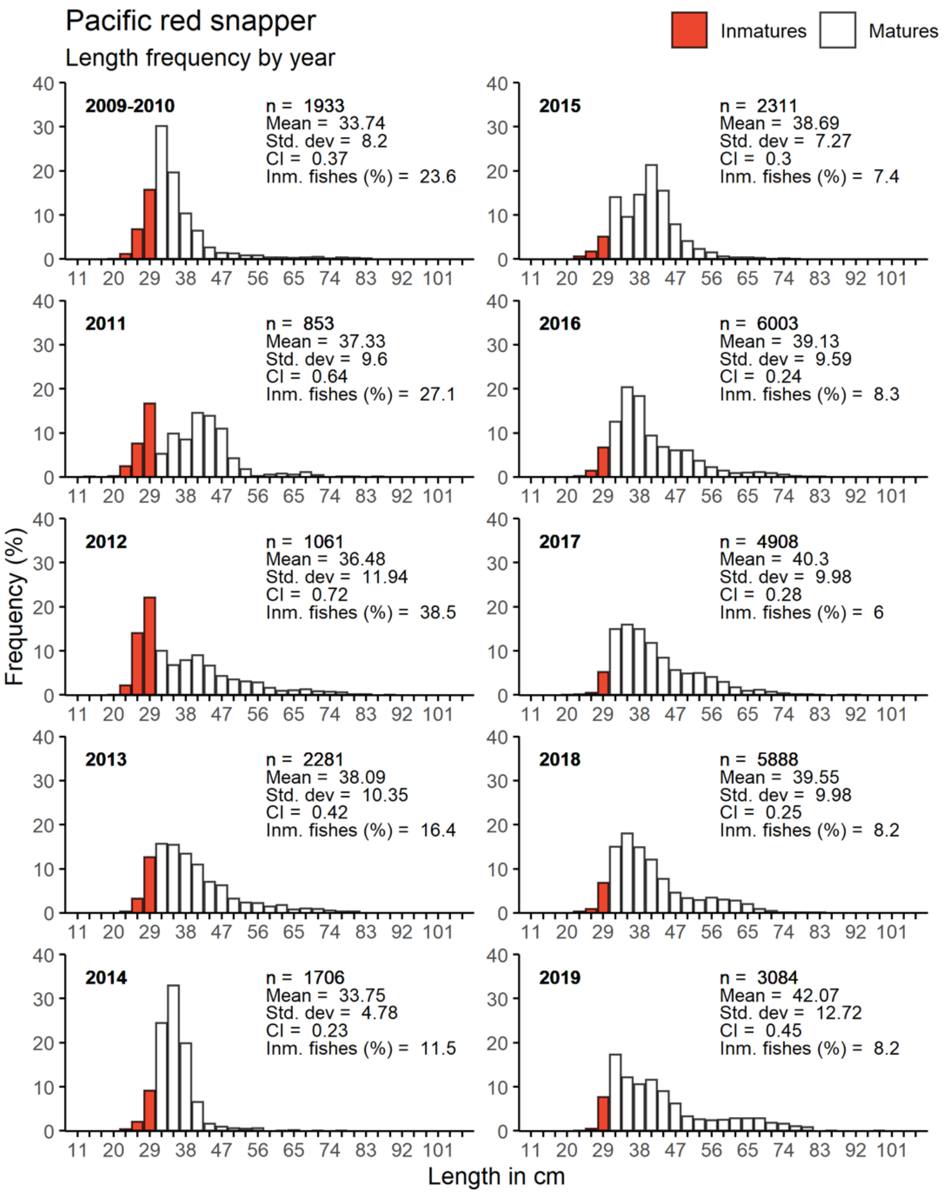


*Figure 93. Length-frequency data for huachinango aggregated across all fishing areas and depth categories; plotted by time period. Size at maturity according to Barbosa-Ortega et al. (2014) indicated by darker colouring.*

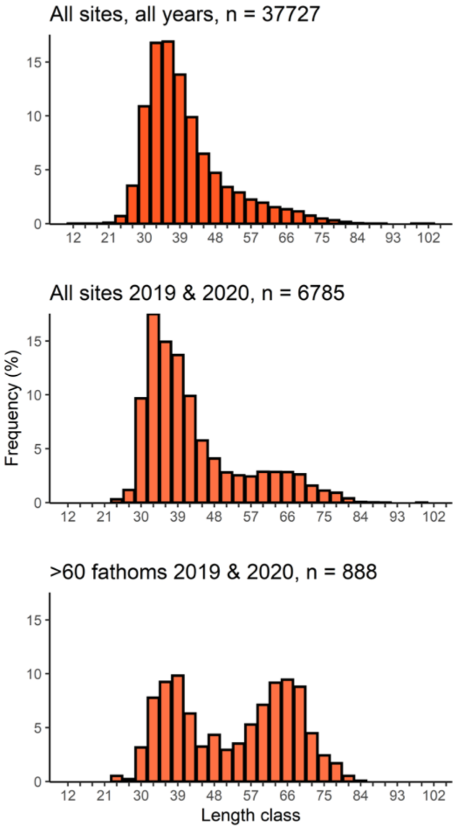


*Figure 94Length-frequency data for huachinango; top panel - aggregated across all years (2009-2019) and all fishing sites; middle panel - all fishing sites in 2019 & 2020; bottom panel – 60 and 80 fathom fishing sites in 2019 & 2020.*

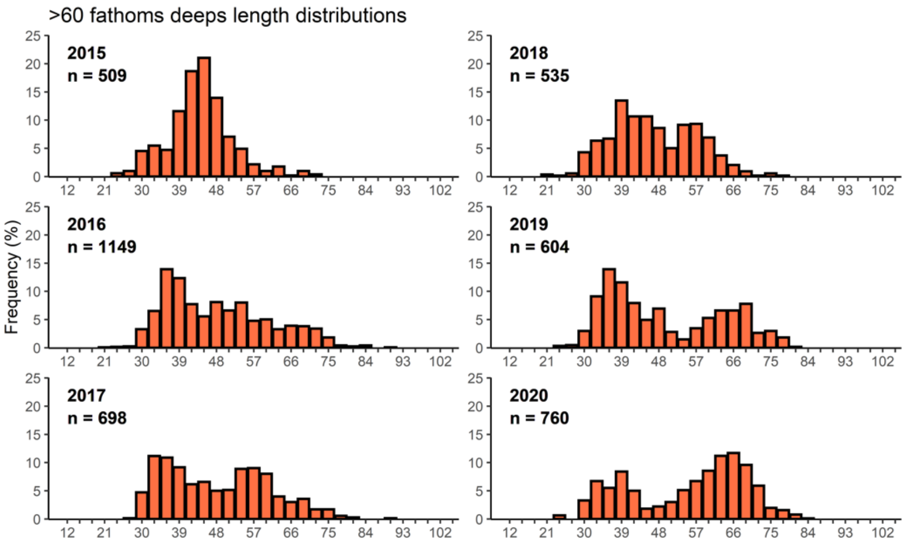


*Figure 95. Length-frequency data for huachinango caught in ≥ 60 fathoms for the years 2015 – 2020 illustrating how the strong 2011/12 pulse of recruitment has grown into the adult size range. The adult mode was initially obscured by the greater abundance of this recruitment pulse (2015 – 2018) but it has re-emerged in recent years as the 2011/12 cohorts have attained their adult size (2019 & 2020).*

## Re-evaluating Size of Maturity Estimates

In the introduction, we discussed how the shape of size composition data might be used to infer $L_m$; where a mode in size frequency histogram is known to be comprised entirely of mature individuals, the 50th percentile of the left-hand side of that mode (i.e. half-way up the left hand side of the mode) can be used to approximates $L_{50}$. Also discussed in the introduction, was the issue that for the purpose of stock assessment maturity has been defined as the size at which individuals begin contributing to the spawning potential of populations in proportion to their adult body weight (Beverton & Holt 1957) i.e. the size at the origin of the relation between length and fecundity. Which contrasts with the definition use for histological studies, that was developed to be precise and reproduceable, and which is the first appearance of a viable gamete in the gonad (Brown-Peterson et al. 2011). Thus, the histological definition of maturity is the size at which the maturation process begins, while for stock assessment the definition should be the size at which adult quantities of gametes begin being produced, which is generally ~20% larger than the $L_{50}$ we estimated histologically.

In this context we note that, the Barbosa-Ortega et al.estimate of $L_m = 33$ cm coincides with the 50th percentile of the left-hand side of the mode on the left-hand side of the aggregated length frequency histograms (Figure 90). Which on one hand gives us some coincidence that this histological estimate is indexing a stage of maturation. On the other hand, we also note that the alternative estimate of $L_m = 54$ cm from the captive rearing program of Spanopoulos-Zarco et al. (2016) intriguingly coincides with the 50th percentile of the left-hand side of the larger mode observed in the 2019 - 2020 size composition data from $\geq$ 60 fathoms which, as discussed below, we surmise most accurately reflects the size composition of the functionally adult stock (Figure 94; bottom panel).

Based on my interpretation of the size composition data, my opinion is that these two alternative estimates of $L_m$ confront us with the issue of mis-matching definitions of maturity. That the estimate of Barbosa-Ortega et al. ($L_m \sim 33$ cm) accurately quantifies the size at which 50% of individuals begin the maturation process and produce their first viable gametes, and that this is the size at which recruitment to the shallow water fishery for sub-adults occurs. While the Spanopoulos-Zarco et al. (2016) estimate $L_m = 54$ cm more accurately reflects the size at which individuals become functionally adult, and useful for maintaining captive breeding programs. The size I would expect to be indicated by the 50th percentile on the left-hand side of an adult size mode (Figure 94; bottom panel).

At this point, there is no way of resolving our uncertainty about the huachinango input parameters, we can only proceed by defining plausible bounds; $L_m = 33 – 54$ cm, $L_\infty = 75 –$ 95 cm which we use for alternative LBSPR analyses to illustrate the implications of our uncertainty for our assessment of this stock.

## Catch Per Unit Effort Data

The huachinango CPUE data vary considerably across fishing grounds (Figure 96), CPUE is generally higher and more variable in the south. Higher CPUE in the south than in the north, is to some extent contrary to expectation. Generally, fishing grounds closest to major markets are most heavily exploited, and consequently have lower CPUE and smaller fish, and so to be expected for the southern grounds closer to La Paz. That the reverse is true suggests a biological cause which could be illuminating if understood.

Higher and more variable catch rates are observed in shallower depths ≤ 60 fathoms (Figure 97). This is also of interest, as catches and CPUE are normally determined by the distribution of the older and heavier adults, which generally comprise most of a population’s biomass, and which for huachinango are found at depth. That the highest CPUE is in the shallows suggests that the through this time series, at least, the juvenile biomass in the shallows has been larger than the adult biomass at depth. This undoubtedly reflects the magnitude of the two pulses of recruitment that grow through the shallower sub-adult size range during this time series. It might also be consistent with the adult stocks of this species having been depleted before this time series began.

Over the time series the CPUE appear to have remained relatively stable, although to some extent this may be due to the scale of the x-axis visually compressing the actual variation. There is apparently some evidence of two cycles of higher CPUE coinciding with the recruitment pulses in 2011/12 and 2015/2016 (Figure 98).

Figure 99shows the proportional distribution of the total reported catch of huachinango (1832t) over the time period 2006-2017. In effect this plotted trend can be viewed as a time series of catches, normalized for comparison across species. The figure shows that over the time period catches have increased relatively steadily, but with notable sharply lower catches in 2012 and 2015, apparently coincidental with pulses (increases) of CPUE (Figure 97) and recruitment (Figure 93). The coincidence of sharply lower annual catches, but higher catch rates (CPUE) is also worth noting and investigating further, because it is counter-intuitive. More normally CPUE and annual catches are directly related, with higher CPUE resulting in higher landings. If real, the underlying biological cause is likely to be insightful.

The rapid escalation of annual catches since 2010 suggests that fishing pressure on this species is continuing to intensify (Figure 99), but with evidence of two pulses of recruitment bolstering the biomass through our time series, this steady increase in catch to some extent probably also reflects growth in this population’s biomass over the time period as the two large cohorts grow into the stock. This, interpretation, however, adds to the impression that the stock had been severely depleted prior to the recent pulses of recruitment.

Consistent with huachinango being the main species targeted by this multi-species fishery it is normally the dominant component of the catches, and commonly >95% of the catch composition (Figure 100).

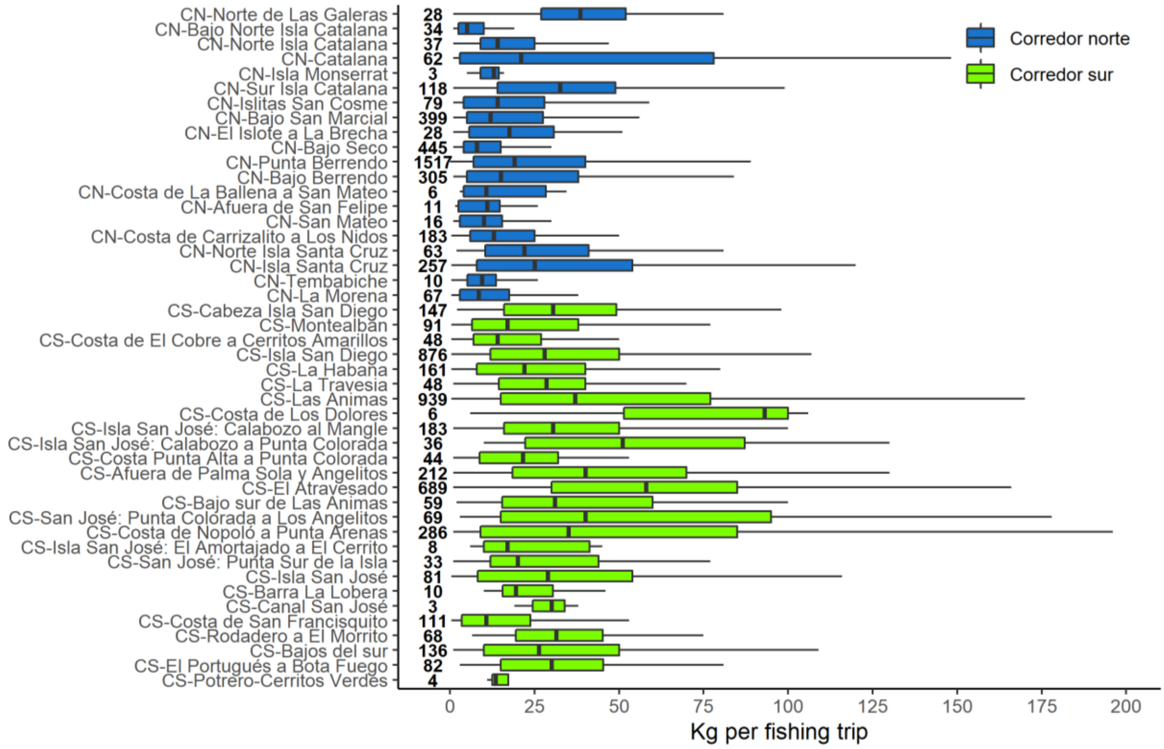


*Figure 96. Percentile catch-per-unit-effort data for huachinango aggregated across all years (2009-2019) and depth categories, plotted by fishing area sorted north to south. Bold values mark sample size for each area, black bars indicate median, coloured bars indicate interquartile range (0.25 – 0.75), horizontal lines the range. Confidence intervals cannot be estimated due to low record numbers for most fishing areas.*

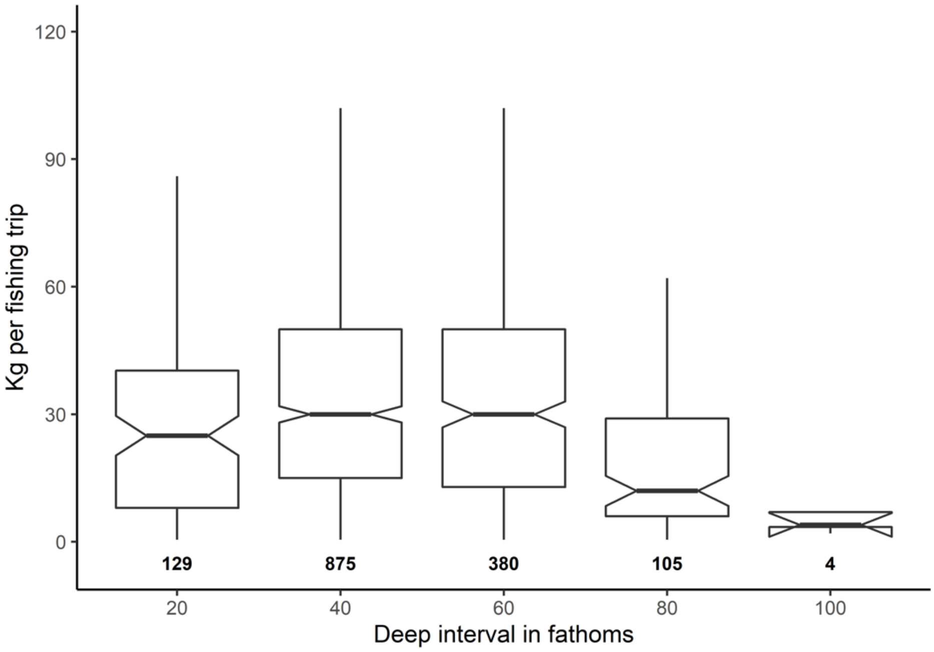


*Figure 97. Catch-Per-Unit-Effort data for huachinango aggregated across all years (2009-2019) and fishing locations; plotted by depth category. Bold values mark sample size for each area, black bars indicate medians, boxes indicate the interquartile range (0.25 – 0.75), and dots indicate outlier values. The notch in the boxplot marks a confidence interval for the median at 95% probability. The unusual shape of the last boxplot indicates the low sample size.*

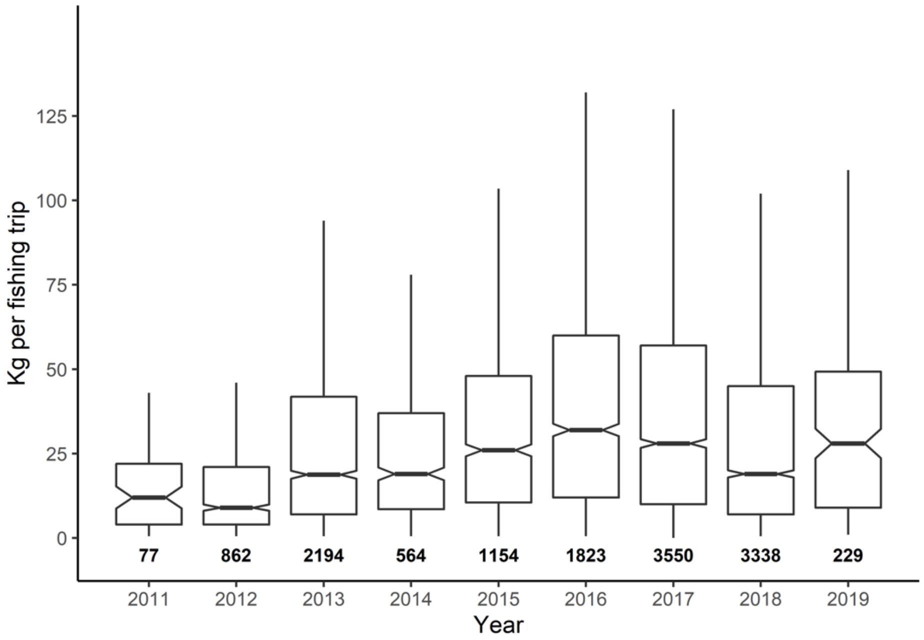
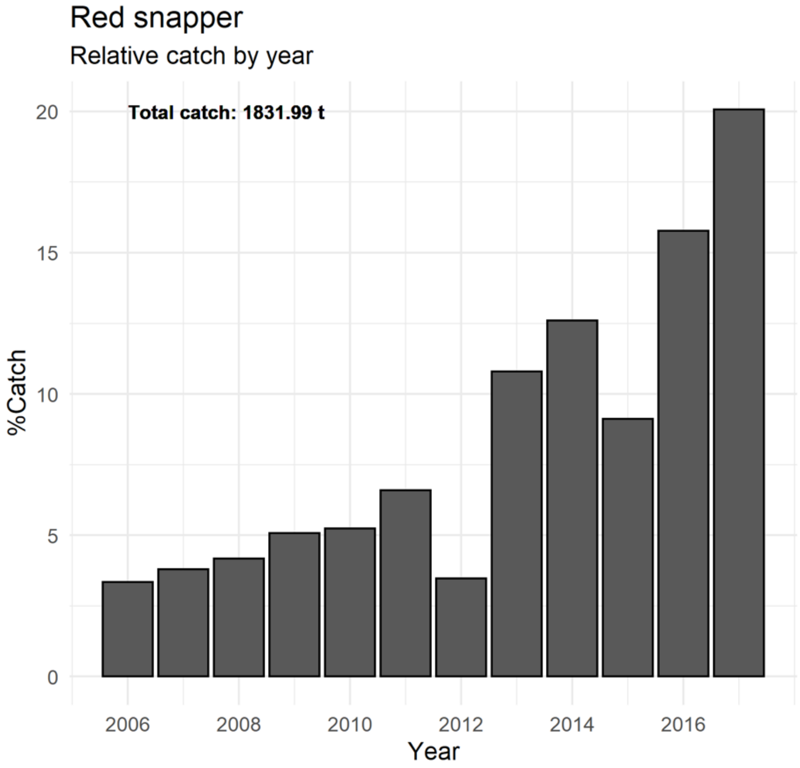


*Figure 98. Catch-Per-Unit-Effort data for huachinango aggregated across fishing grounds and depth categories; plotted by year. Bold values mark sample size for depth category, black horizontal bars indicate medians with 95% confidence intervals indicated by notches, boxes indicate interquartile range (0.25 – 0.75) and vertical lines the range.*



Source: CONAPESCA

*Figure 99. The proportional annual distribution through the period 2006-2017, of the total catch of huachinango during that time period (1832t). The figure shows catches of huachinango have increased relatively steadily through that time period, but with notable sharply lower catches in 2012 and 2015.*

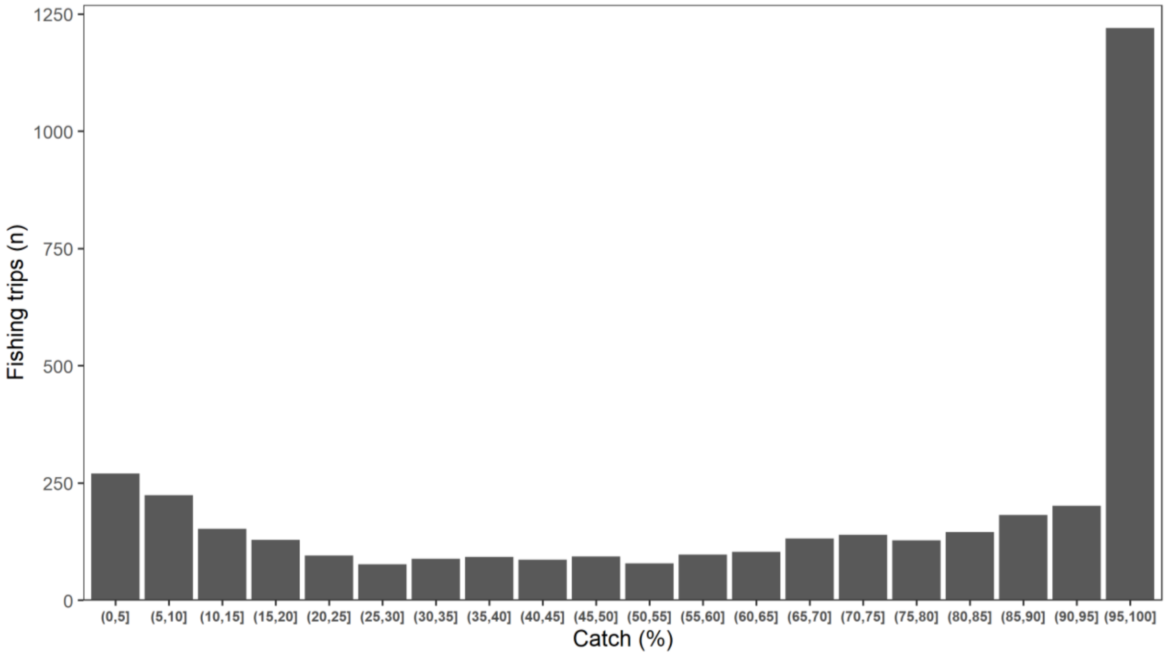


*Figure 100Catch data aggregated across all years (2014-2019), depth categories and locations; plotted as the number of sampled trips in which huachinango comprised each percentage range of the catch. This figure shows huachinango is commonly >50% of landed catches, and often >95% of the catch composition which is consistent with it being a main target species for this fishery.*

## Initial LBSPR Assessment

Our uncertainty with huachinango assessment pertains both to body size ($L_m$ & $L_\infty$) which has been discussed above, but also, how best to use the size data to most accurately reflect the actual size composition of the adult size classes (i.e. right hand side of the size composition).

### *Size Composition Data*

The complexity of the size composition data for huachinango means we must decide how best to aggregate or subset the data to most accurately portray the size composition of the adult stock, as we can derive very different size frequency histograms depending on the depth range and/or time period we select. Differences that are unrelated to the status of the stock.

As discussed in the introduction, the LBSPR methodology is fundamentally an analysis of the shape of the length-frequency histogram of adults. Only adults have reproductive potential, and it is how large the adults get to be, in relation to their asymptotic size, which primarily determines SPR. The size composition of the juvenile part of the stock is not as informative for SPR estimation. The LBSPR method primarily uses the relative shape of the right hand-side of a uni-modal size compositions data to approximate SPR. The slope of this part of the curve, which would normally be comprised of entirely adult cohorts, informs the estimation of relative fishing pressure (F/M) while the size of the largest adults, relative to the assumed $L_\infty$, strongly influences the final estimate of SPR. This is not to say that the left-hand side of the length composition curve has no influence on the assessment. From the left hand-side of the uni-modal size composition the LBSPR methodology estimates the size at which fish in the sample are first caught, or size-selectivity ($SL_{50}$ & $SL_{95}$), which is used to determine the relative fishing pressure (F/M).

Of relevance to developing our assessment of huachinango; if the relative proportion of the smallest sizes classes in the catch are ‘over-represented’, or inversely the largest size classes are under-represented, SPR will be under-estimated, and relative fishing mortality (F/M) over-estimated. In the case of huachinango, we must ask ourselves whether the smallest size classes are ‘over-represented’? Paradoxically this can occur even when sampling has correctly recorded the relative proportions of the various size classes in the catch, because the issue relates to the assumption of constant M that is widely used in stock assessment, and how effectively a fishery catches the juvenile size classes. As discussed more fully in the introduction the simplifying assumption that M remains constant across size and age classes is widely relied upon for stock assessment, and thought to be relatively true for the similar sized adult cohorts, although almost universally, M is higher for smaller size classes. The implication of this is that in many marine stocks the juvenile cohorts are more numerous than stock assessment methodologies based on constant M can predict, and fisheries that target juvenile size classes create issues for LBSPR modelling of the shape of the right-hand adult side of the size frequency histograms. The issue arises when the modelled shape of the size composition is fitted accurately to the numerically dominant juvenile portion of the size composition, determined mainly by the size related M, at the expense of accurately describing the adult right-hand size of size composition data which contains the information about SPR and F/M that is of interest to us.

In this context, and with regard to assessing huachinango, we must ask how best to use these size composition data to fit the LBSPR model most accurately to the shape of the adult portion of the population?

The simplest way to view these data is in total aggregation, and normally we would expect such an aggregation to reveal a smooth shape that can serve as predictor of the general shape observed more noisily in the annual samples which are subject to the impact of smaller annual sample sizes and changing fishing pressure. Across all fishing grounds, depths and years some 33, 727 huachinango have been measured and the LBSPR algorithms can provide an approximation of the shape (Figure 101 – black line). It is not, however, a very satisfactory description for such a large sample. The fitted line systematically over-estimates the numerical abundance of size classes in the middle of the right side mode (40 – 60 cm), and then systematically under-estimates the proportions of the largest size classes (> 60 cm). This nicely illustrates the problems that arise when the LBSPR model’s description of the shape of the adult size composition, is over-whelmed by the super-abundance of juvenile size classes on the left. It can be seen that the shape of the fitted curve on the right-hand side, is being determined by the most abundant 30-40cm size classes on the left, together with the largest size classes commonly measured (~ 80 cm). These main features of the dataset determine the simple uni-modal curve which must be fitted by the model, causing it to be a poor predictor of the shape of the largest adult size classes which contain the best information about SPR. In consequence this does not seem to be a good description of the adult part of the stock.

Never-the-less, if we were to take the curve fitted to these aggregated size composition data as being indicative of the adult stock, our uncertainty about biology becomes almost irrelevant. Within our envelope of input assumptions ($L_m$ = 33 – 54 cm, $L_\infty$ = 75 – 95 cm) all our possible alternate assessments suggest a heavily fished stock with F/M = 1.83 – 3.71, with low SPR = 0.03 – 0.18 (Table 11).

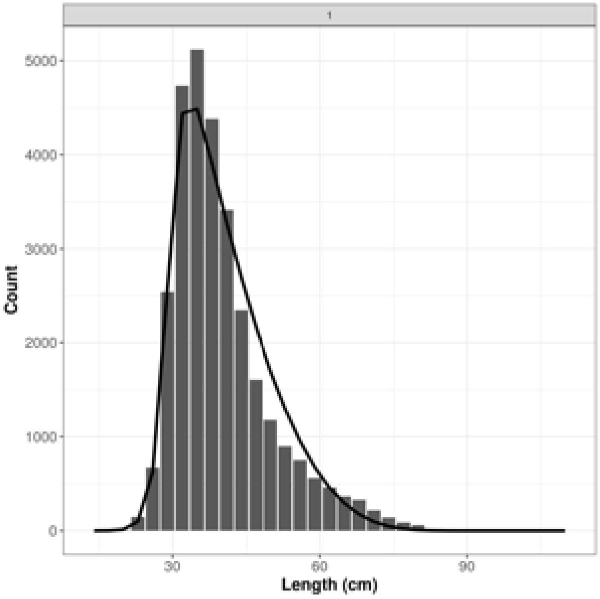


*Figure 101. LBSPR fitting to the huachinango catch size composition data aggregated across all years, fishing locations and depths categories.*

| MK | Linf | L50 | L95 | Lm/Linf | SPR | SL50 | F/M |
|---|---|---|---|---|---|---|---|
| 0.97 | 75 | 33 | 40 | 0.44 | 0.18 | 27.23 | 1.83 |
| 0.98 | 75 | 45 | 54 | 0.60 | 0.13 | 27.23 | 1.83 |
| 0.98 | 75 | 54 | 65 | 0.72 | 0.09 | 27.23 | 1.83 |
| 0.98 | 85 | 33 | 40 | 0.39 | 0.1 | 27.7 | 2.76 |
| 0.98 | 85 | 45 | 54 | 0.53 | 0.07 | 27.7 | 2.76 |
| 0.98 | 85 | 54 | 65 | 0.64 | 0.04 | 27.7 | 2.76 |
| 0.98 | 95 | 33 | 40 | 0.35 | 0.06 | 27.98 | 3.71 |
| 0.98 | 95 | 45 | 54 | 0.47 | 0.04 | 27.98 | 3.71 |
| 0.98 | 95 | 54 | 65 | 0.57 | 0.03 | 27.98 | 3.71 |

*Table 11. Comparative results of LBSPR assessments of huachinango using all size composition data aggregated across fishing locations, depth ranges and years, and applying a plausible range of assumptions about $L_m$ (33 – 54 cm) and $L_\infty$ (75 – 95 cm).*

As noted above, in most fisheries the catch size composition data aggregated over long time periods creates a length-frequency histogram that will be similar to the histogram observed in annual aggregations of data, but smoother and more complete due to its greater sample size. This is not the case for huachinango. The distribution of fishing by depth in any year has a strong influence on the aggregate size composition (Figure 92), as does the two recruitment pulses which grow through the size range during our time series (Figure 93). With these two pulses of recruitment occurring a dynamic transition occurs throughout our time series preventing it from settling into the equilibrium size composition we might expect in the long term.

Dis-aggregating the data by depth and year, and sub-setting for ≥ 60 fathoms where the adult size classes are mainly caught, and for the last two years (2019 & 2020) when the dominant 2012/13 cohorts are attaining adult size so that the adult size composition starts become discernible in something approaching an equilibrium shape, produces what appears to be our best representation of the adult population for the time being. Applying our plausible range of assumptions about $L_m$ (33 – 54 cm) and $L_\infty$ (75 – 95 cm) to this length composition produces a better fit of the model to our data with no systematic mis-fitting, although the model still cannot predict spikes in the data around 40, 45 & 65 cm and to some extent over-estimates the right-hand side of the curve. In this case our possible alternate assessments describe a broad range of possibilities; F/M = 1.16 – 6.28 and SPR = 0.65 – 0.17 (Figure 102; Table 12).

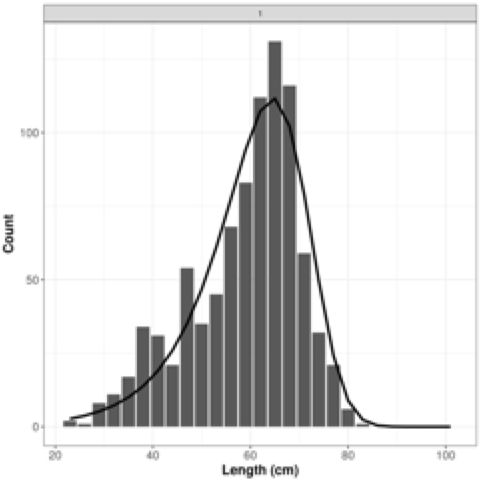


*Figure 102. LBSPR fitting to the huachinango catch size composition data from 2019 and 2020 from ≥60 fathoms.*

| MK | Linf | L50 | L95 | SPR | SL50 | F/M |
|---|---|---|---|---|---|---|
| 0.97 | 75 | 33 | 40 | 0.65 | 59.84 | 1.17 |
| 0.97 | 75 | 45 | 54 | 0.62 | 59.84 | 1.17 |
| 0.97 | 75 | 54 | 65 | 0.55 | 59.84 | 1.17 |
| 0.97 | 85 | 33 | 40 | 0.39 | 61.29 | 3.61 |
| 0.97 | 85 | 45 | 54 | 0.35 | 61.29 | 3.61 |
| 0.97 | 85 | 54 | 65 | 0.28 | 61.29 | 3.61 |
| 0.97 | 95 | 33 | 40 | 0.25 | 61.86 | 6.28 |
| 0.97 | 95 | 45 | 54 | 0.21 | 61.86 | 6.28 |
| 0.97 | 95 | 54 | 65 | 0.17 | 61.86 | 6.28 |

*Table 12. Comparative results of LBSPR assessments of huachinango using data from catches in 2019 and 2019 from ≥ 60 fathoms and applying a plausible range of assumptions about $L_m$ (33 – 54 cm) and $L_\infty$ (75 – 95 cm).*

With this sub-set of the adult data our fit is improved if we truncate the data at 54 cm removing the noisy sub-adult size classes (Figure 103), although our plausible range of assumptions about $L_m$ (33 – 54 cm) and $L_\infty$ (75 – 95 cm) still produce a similarly broad range of estimates; F/M = 2.13 – 27.8, with low SPR = 0.59 – 0.13 (Table 13).

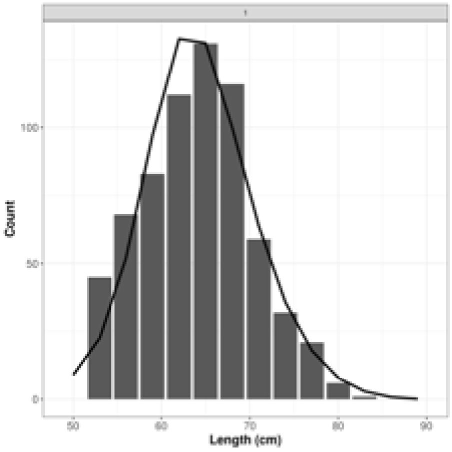


*Figure 103. LBSPR fitting to the huachinango catch size composition data from 2019 and 2020 from 60 and 80 fathoms and truncated to exclude TL < 54cm.*

| MK | Linf | L50 | L95 | SPR | SL50 | F/M |
|---|---|---|---|---|---|---|
| 0.97 | 75 | 33 | 40 | 0.59 | 68.1 | 2.13 |
| 0.97 | 75 | 45 | 54 | 0.55 | 68.1 | 2.13 |
| 0.97 | 75 | 54 | 65 | 0.48 | 68.1 | 2.13 |
| 0.97 | 85 | 33 | 40 | 0.33 | 75.82 | 10.48 |
| 0.97 | 85 | 45 | 54 | 0.29 | 75.82 | 10.48 |
| 0.97 | 85 | 54 | 65 | 0.23 | 75.82 | 10.48 |
| 0.97 | 95 | 33 | 40 | 0.20 | 81.34 | 27.81 |
| 0.97 | 95 | 45 | 54 | 0.17 | 81.34 | 27.81 |
| 0.97 | 95 | 54 | 65 | 0.13 | 81.34 | 27.81 |

*Table 13. Comparative results of LBSPR assessments of huachinango using data from catches in 2019 and 2019, from 60 and 80 fathoms and truncated to exclude TL < 54cm and applying a plausible range of assumptions about $L_m$ (33 – 54 cm) and $L_\infty$ (75 – 95 cm).*

## Huachinango Discussion

There are issues to be resolved with huachinango, regarding how to use the length composition data, and which input parameters to prefer, and no way of immediately resolving these issues. A longer process will be required which will involve, evaluating these analyses, continuing to collect data and further evidence, and also incorporating techniques for quantifying irreducible uncertainty.

At this stage, and in my opinion, the analysis that best supports all the available evidence assumes $L_m$ ~ 54 cm and $L_\infty$ ~ 85 – 95 cm and is based on one of the last two subsets of data. This interpretation estimates that the stock is being heavily fished F/M = 2.13 – 27.8, and has low SPR = 0.13 – 0.29 (Figure 102& 103; Table 12 & Table 13).

It can be argued, correctly, that this use of a subset of data for the largest size classes in the catch caught at depth, ignores the impact of the substantial catch of sub-adult fish. This is a well-founded criticism, the implication of which is that the stock is in a worse state than this assessment suggests and this possibility cannot be discounted. Several qualitative observations support the view that this stock is being fished heavily and has been depleted;

- The first of these was the difficulty that Rocha-Olivares et al. (1998) had sampling fish of around asymptotic size more than two decades ago. Remember that with a relatively low average M/K lightly fished stocks of lutjanids are typically dominated by fish around asymptotic size. The lack of larger fish in the samples from two decades ago strongly suggests the stock had been substantially depleted by the mid-1990s.
- The pulsing of recruitment that is evident in the size composition is also suggestive of a stock that has been depleted and in most years is producing relatively low recruitment, so that the exceptional years when conditions for some reason favour good recruitment, are much more evident in the dynamics of the stock. My opinion is that these recruitment pulses would not be so evident if the stock was less depleted.
- The relative importance of the sub-adult catch compared to the catch of adults also adds to the qualitative impression that this is a stock in which the adult biomass was depleted some decades ago. I acknowledge here that the market prefers smaller plate size individuals that can be caught in shallower water, and apparently pays a higher price per kilo. But universally fishers prefer to target the highest catch rates available, which for species like lutjanids are produced by targeting adult aggregations. The higher catch rates compensating for lower prices per kilogram. The evidence we have from these data is that the fishers, like fishers everywhere, are fishing where they are likely to have the most success, so that the relative lack of large fish in the catch indicates the depletion of the adult stock.

Consequently, there can be little doubt that this stock is in a depleted state, and we return to the criticism that by sub-setting the size data we are under-estimating the impact of fishing pressure on this stock. To the extent that the M, or M/K, is assumed to be constant across all size classes this criticism is particularly valid because the impact of the largest portion of the catch on the fishery is being ignored. However, if M and M/K are assumed to be much higher on the smaller size classes, the implication is that the relative fishing pressure (i.e. F/M) on the smaller size classes is lower than estimated, relative to the F/M on the adult size classes, despite the magnitude of the catch. The idea here, is that if M and M/K is higher for the smaller size classes, than for the adults, they experience much greater rates of turnover and are in much greater abundance, and in relative terms, are depleted less by catches of similar magnitude, than are the adult size classes. We must also re-iterate the point made previously, that the slope between the peak of the juvenile size classes and the largest individuals is primarily determined by M and not F/M, while the slope on the right-hand side of the adult portion of the mode is determined by F/M (if a stock is at equilibrium). In which case our sub-setting of the data and focussing on the largest size classes could be the more accurate way of assessing the stock's SPR, and ignoring the impact of fishing on the smaller size classes is of less importance. In the end, the issue of sub-setting and truncating the data, to focus the model on fitting to the right-hand side of the size composition data, is a matter for professional judgement as is often the case for data-poor assessment. We can, however, be certain in this case that our assessment is not under-estimating the status of the resource, although we must bear in mind that our result could be biased high.

There are of course other issues also to be kept in mind with this assessment. The first of which is that the recruitment pulses mean this stock is not in the steady-state, or equilibrium, assumed for LBSPR assessment and other data-poor methods. There can be no doubt that over the next few years the size composition of this stock will keep changing as the two pulses of recruitment already in the system grow to their asymptotic size. Consequently, however we choose to interpret these data, we should expect our estimates to oscillate under the influence of the pulses growing into, and through the adult size classes, so that the actual state of the stock will be best represented by the average of the estimates produced over a longer period of time, which may well be lower than these initial estimates.

In terms of resolving the body size issue, the most informative study would be to provide context for interpreting the existing estimates of size of maturity, by applying the alternative methods of estimating fecundity (number of eggs) at length, and gonadosomic index (proportion of bodyweight comprised by gonad) at length. The assumption underlying stock assessment being that the size of maturity is the size class in which 50% of individuals begin producing gametes in proportion to their body weight. The origin of the fecundity at length relationship, and the size at which the gonadosomic index transitions from low juvenile levels to high adult levels, should both provide superior indications of the size at which fish begin producing adult levels of gametes.

Repeating age and growth studies, should not be ruled out altogether, however these studies will confront the same issue of struggling to sample sufficient fish around and above the asymptotic size to properly inform its estimation. And so likely to result in additional imprecise estimates, which given age and growth studies are more technical and expensive than studies of length and fecundity, is less likely to be as cost-effective as the alternative size of maturity studies suggested above. However, if the sample of larger individuals could be solved improving the existing estimates of age and growth would be useful, and support the size of maturity studies suggested. My suggestion would be, that rather than undertaking a complete new age and growth study, to use Niparaja's catch sampling program to search the catch for the few very largest individuals still being caught, and then to purchase those fish for sampling, and then augment Rocha-Olivares et al.'s original sample, and re-analyse it. In this way as few as 30-40 very large (>800 mm) fish could add great value to the previous analysis and greatly inform its original estimate of $L_\infty$. Further I note that it is possible that the influx of 2012/13 recruits into the adult population in recent years will bolster the abundance of individuals around asymptotic size in $\geq$ 60 fathoms providing the best opportunity for catching and sampling large individuals in several decades.

Systematic synthesis and meta-analysis of all huachinango life history studies would also be informative, to determine whether, or not, there is any evidence from other places for huachinango life history ratios varying systematically from the averages estimated from international literature for lutjanids. Such a comparative study, based on standardized re-estimations of growth, could provide evidence to support, or dismiss, the Barbosa-Ortega et al. estimate of $L_m$ and narrow the range of $L_\infty$ estimates. As it is unlikely that the huachinango LHR would vary so significantly from the global family average in just one location.

More immediately for huachinango, and the other species, there is a need to incorporate uncertainty about the input parameters into the assessment process. Dr Adrian Hordyk has developed the code in R to sample input parameters from a distribution of parameters that define the plausible range, and use the distribution of results to estimate confidence bounds around assessment results which reflect our uncertainty (Prince et al. 2015b & 2020). I recommend that Pronatura liaise with Hordyk and request access to that code so that in the future this can be incorporated into future LBSPR assessments.

Going forward with assessing huachinango, the collection of catch size composition data from $\geq$ 60 fathoms should be prioritized over collecting data from shallower depths, because it will be crucial to the length-based monitoring of SPR in this fishery. This is not to say that there should be no data collected on the shallower catch, but simply to recognize that the catch from depth is smaller and more difficult to sample (in some years very few data have been collected from depth), while the shallow catch is more readily sampled. The intent should be to maximize the proportion of the smaller deeper catch, by increasing its priority. This may require Niparaja and Pronatura developing targeted programs specifically for collecting data on the size composition of the huachinango caught in deepwater.

In continuing to develop this assessment of huachinango it will be essential to develop depth specific CPUE indices (i.e. <60 fathoms & ≥ 60 fathoms) as these will track the abundance of different parts of the huachinango population. The shallower CPUE should index future recruitment pulses, while the deeper CPUE should index the adult population. To this end, it would also be beneficial to improve the actual measure of effort to quantities such as length of the fishing trip in hours or even better, the time spent at specific fishing spots.

## Paralabrax nebulifer - Verdillo Barred sand bass


John Shelton - FishStockPhoto

### Life History Ratios

There is a good-sized sample of high quality LHR estimates available for the family Serranidae from the meta-analysis of Prince et al. (in prep. a) which produce the average estimates;

M/K = 1.16; n=131
$L_m/L_\infty$ = 0.65; n=81

### Life History Parameters

The size of maturity for verdillo ($L_{50}$ = 31.7 cm; $L_{95}$ = 37) has been estimated Guerrero-Bernal (2016) using histological techniques from northern part of the fishery (Area #2).

### Size Composition Data

Examination of the verdillo size composition data reveals quite a degree of structure by depth (Figure 104) and also by fishing location (Figure 105) presumably because the differing fishing locations have different depth profiles. As shown by Figure 104 catches in 10 fathoms are dominated by juvenile size classes ($\leq$ 32 cm), although the sample size is small. The catch in > 20 fathoms is comprised mainly of sub-adult or mature fish ($\geq$ 32 cm).

In aggregate the size composition data appears to be uni-modal (Figure 105a), but when sorted by depth band resolves into being bi-modal with a smaller mode of sub-adults on the left (<32 cm) and a main adult mode on the right (PN Figure 105b) At some of these sites the catch composition exhibits only the adult mode (i.e.Figure 106; Punt Piedra & Barra La Pitaya).

The time series of all data from San Ignacio and Punta Abreojos (Figure 107) suggest some sort of transitional process has affected the size composition. The modal size increases steadily if gradually from ~32 cm in 2010 to ~36 cm in 2020, with a period of bi-modality from 2015 to 2017. Whether or not this is evidence of a pulse in recruitment around 2010, and perhaps a second in 2017, or some evolution of fishing practice is not entirely clear at this stage. The increase in modal size is quite slow but might possibly be explained by the combined effect of two pulses of recruitment, and the slower growth of cohorts around the size of maturity and approaching asymptotic size. Alternately an evolution in fishing gear, or gradual expansion of fishing towards deeper grounds could also be invoked to explain the transition toward catching gradually larger fish.

It is this transitional feature of the data during the early years of the time series, that results in the unimodal appearance of the data set when viewed in aggregate across the time series (Figure 105). Prior to 2017 depth of fishing has not been recorded so that sorting by depth eliminates this transitory feature in the data revealing the underlying, and presumably more permanent, bi-modal nature of these data (Figure 105).

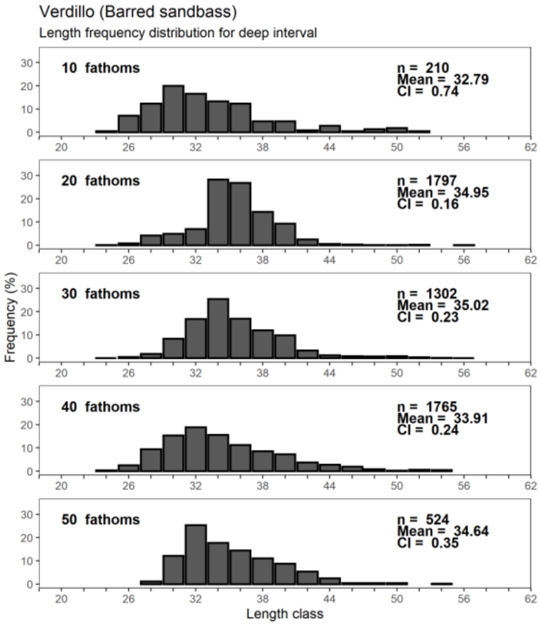


*Figure 104. Verdillo length-frequency data 2017-20 by 10 fathom depth categories illustrating that the smaller size compositions are most prevalent in <10 fathoms.*

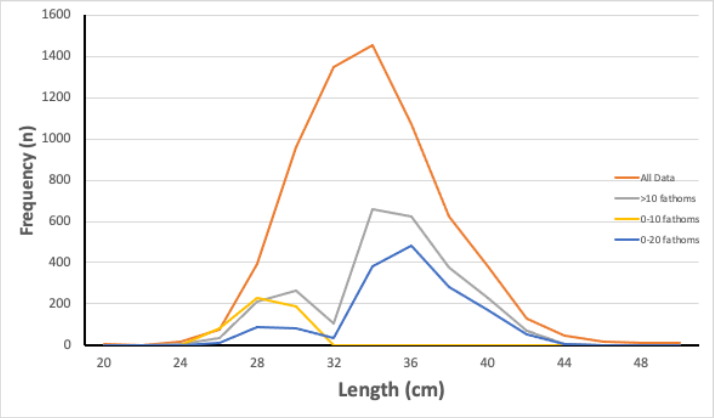


*Figure 105. Various aggregations and subsets of verdillo length-frequency data; all data 2010-2020, 0-10 fathoms 2017-20 (scaled up by 10 x), 0-20 fathoms 2017-20 and > 10 fathoms 2017-20.*

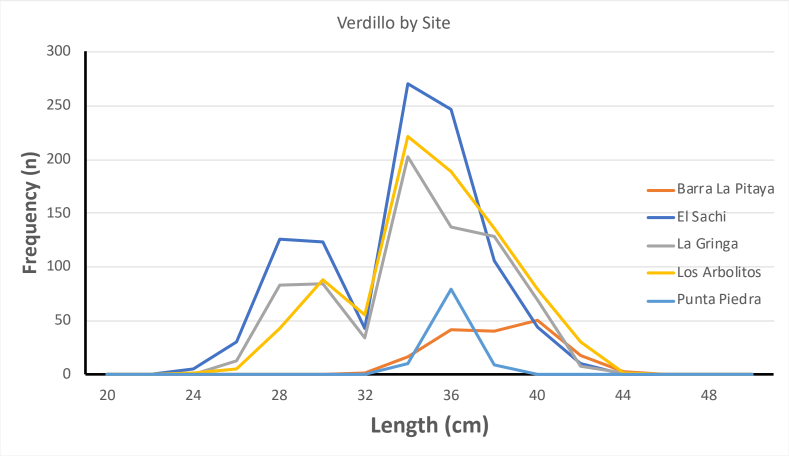


*Figure 106Verdillo catch size composition data 2017-20 plotted and analysed for fishing 5 sites; Barra La Pitaya, El Sachi, La Gringa, Los Arbolitos and Punta Piedra.*

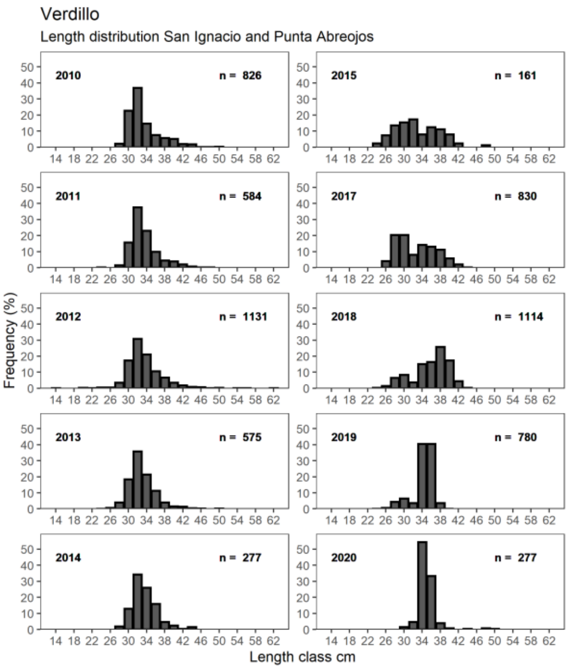


*Figure 107. Verdillo catch size frequency composition from San Ignacio and Punta Abreojos from 2010 – 2020. Note the slow progression of the modal size from~32 cm in 2010 to ~36cm in 2020, transitioning through bi-modal 2015-2017.*

## Initial LBSPR Assessment

In completing the initial LBSPR assessment of the aggregated dataset (all years, depths and fishing locations) with which we assumed M/K = 1.16 and $L_{50}$ = 31.7 cm; $L_{95}$= 37 cm, with which with, based on the family average $L_m/L_\infty$ = 0.65, we inferred $L_\infty$ = 49 cm. With these parameters the LBSPR model can produce a plausible fit to the data (Figure 108) and low initial estimates of SPR = 17%, and a correspondingly high fishing pressure F/M = 3.16. These same aggregated data were also analysed by year (Figure 109& Figure 110;Table 14) which resulted in a range of similar SPR estimates (0.12 – 0.22) but the transitional affect and bi-modality in the data in some years resulted in some very poor model fits to the data (Figure 110), along with a broad range of imprecise F/M estimates (Table 14).

**All Data**
**All Depths**
**No Truncation**

| SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|
| 0.17 (0.16 - 0.18) | 30.63 (30.4 - 30.86) | 35.18 (34.79 - 35.57) | 3.16 (2.96 - 3.36) | 1.16 | 49 | 32 | 37 |

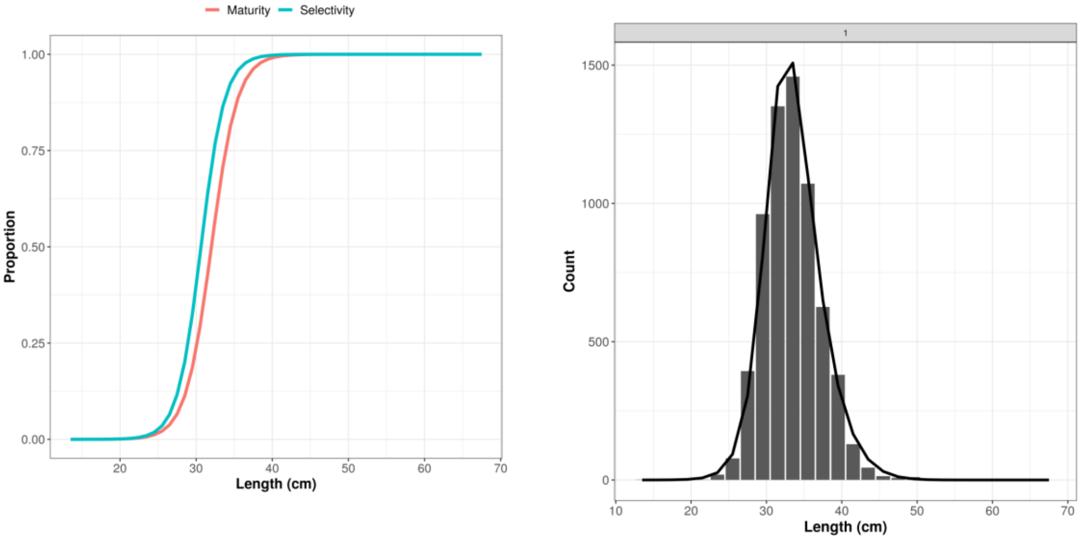


*Figure 108. Initial LBSPR assessment using size composition of all the catch data aggregated across fishing areas and depths and fitted (no truncation). As above the table shows derived estimates and input. The top left-hand panel presents plots of assumed size of maturity ogive (black) and the estimate size of selectivity (coloured). The bottom left-hand panel plots the size composition data analysed (black bars) and the LBSPR modelled fit to those data. The bottom right-hand panel plots estimated trends in SPR (upper) and relative fishing pressure (F/M) by year.*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.15 (0.13 - 0.17) | 29.18 (28.96 - 29.4) | 30.85 (30.48 - 31.22) | 2.94 (2.59 - 3.29) | 1.16 | 49.2 | 32 | 37 |
| 2011 | 0.14 (0.12 - 0.15) | 29.93 (29.67 - 30.19) | 31.96 (31.44 - 32.48) | 3.81 (3.28 - 4.34) | 1.16 | 49.2 | 32 | 37 |
| 2012 | 0.16 (0.14 - 0.17) | 29.77 (29.47 - 30.07) | 33.15 (32.59 - 33.71) | 3.06 (2.7 - 3.42) | 1.16 | 49.2 | 32 | 37 |
| 2013 | 0.12 (0.1 - 0.14) | 29.88 (29.52 - 30.24) | 32.67 (32.03 - 33.31) | 4.34 (3.67 - 5.01) | 1.16 | 49.2 | 32 | 37 |
| 2014 | 0.13 (0.11 - 0.16) | 30.45 (29.9 - 31) | 32.9 (31.88 - 33.92) | 4.43 (3.39 - 5.47) | 1.16 | 49.2 | 32 | 37 |
| 2015 | 0.22 (0.14 - 0.3) | 26.86 (25.33 - 28.39) | 30.84 (27.93 - 33.75) | 1.55 (0.93 - 2.17) | 1.16 | 49.2 | 32 | 37 |
| 2017 | 0.2 (0.17 - 0.23) | 26.4 (25.98 - 26.82) | 27.93 (27.07 - 28.79) | 1.65 (1.42 - 1.88) | 1.16 | 49.2 | 32 | 37 |
| 2018 | 0.22 (0.08 - 0.36) | 43.71 (41.53 - 45.89) | 52.69 (50.36 - 55.02) | 39.25 (14.14 - 64.36) | 1.16 | 49.2 | 32 | 37 |
| 2019 | 0.12 (0 - 0.32) | 39.23 (36.16 - 42.3) | 43.82 (40.67 - 46.97) | 278.59 (0 - 803.94) | 1.16 | 49.2 | 32 | 37 |
| 2020 | 0.16 (0.14 - 0.17) | 32.98 (32.61 - 33.35) | 34.71 (34.12 - 35.3) | 8.64 (6.17 - 11.11) | 1.16 | 49.2 | 32 | 37 |

*Table 14. Initial LBSPR assessment of verdillo using size composition of the catch data aggregated fishing areas and depths and fitted by year. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

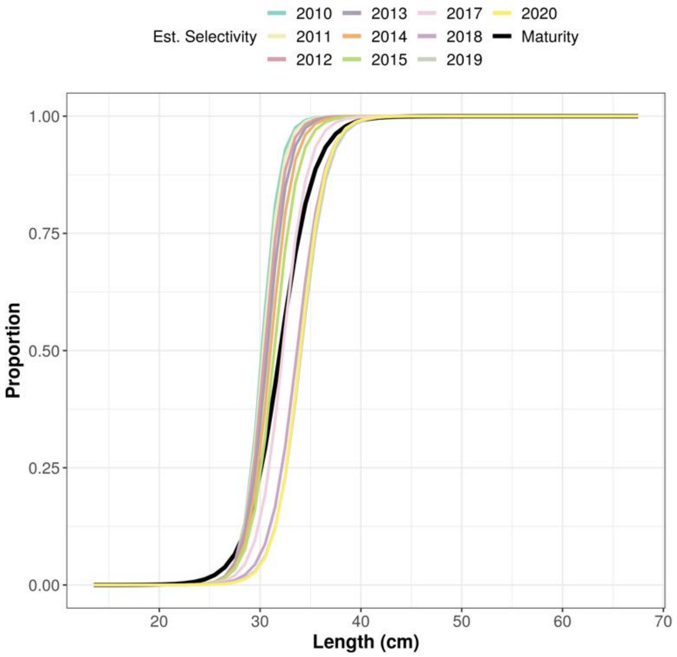


*Figure 109. Results of initial LBSPR of verdillo using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

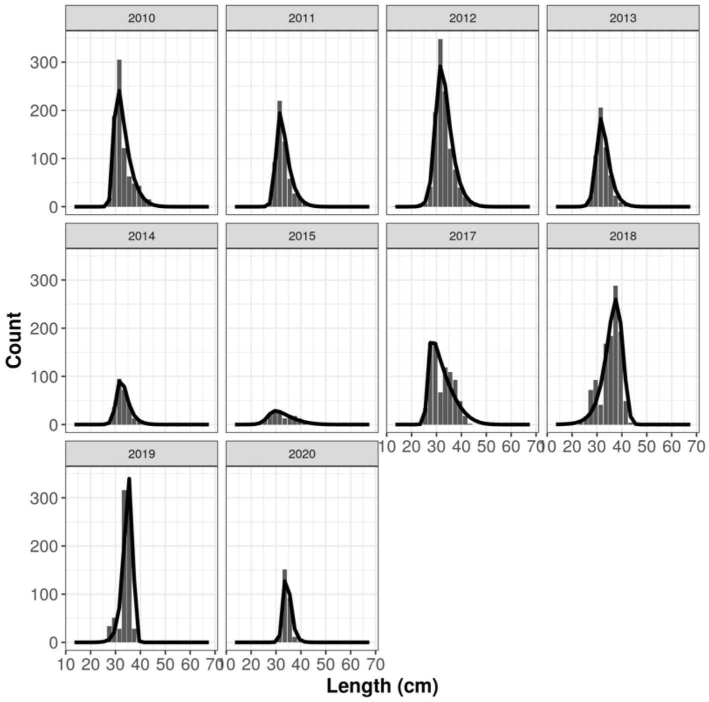


*Figure 110. Initial LBSPR assessment of verdillo using size composition of the catch data aggregated fishing areas and depths and fitted by year. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

Next, we focussed the analysis on the subset of 2017 - 2020 data with depth data > 10 fathoms using the same input assumptions (Figure 111).

Using the data in aggregate produced an estimate of SPR = 24% and F/M = 8.33 but a poor fit as the LBSPR attempted to describe the bi-modal size composition with a single mode (Figure 111; top panel). When we truncated the data at 30cm the fit of the model to the single mode was greatly improved, the estimate of SPR = 0.25 was similar and the estimates of F/M = 3.76 was reduced to more realistic levels.

When the untruncated data from 2017-2020 are analysed by fishing site the estimates of SPR ranged from 16 – 33% and F/M from 6.32 – 28.29 (Figure 112).

When the truncated data from 2017-2020 are analysed by year the estimates of SPR ranged from 17 – 28% and F/M from 6.17 – 20.55 (Figure 113- 115;Table 15).

| Selection Criteria | SPR | SL50 | SL95 | F/M |
|---|---|---|---|---|
| >10 fathom | 0.24 (0.19 - 0.28) | 37.61 (36.66 - 38.56) | 45.43 (44.24 - 46.62) | 8.33 (6.38 - 10.28) |
| >10 fathom > 30cm | 0.25 (0.24 - 0.26) | 33.18 (33 - 33.36) | 35.34 (35.01 - 35.67) | 3.76 (3.42 - 4.1) |

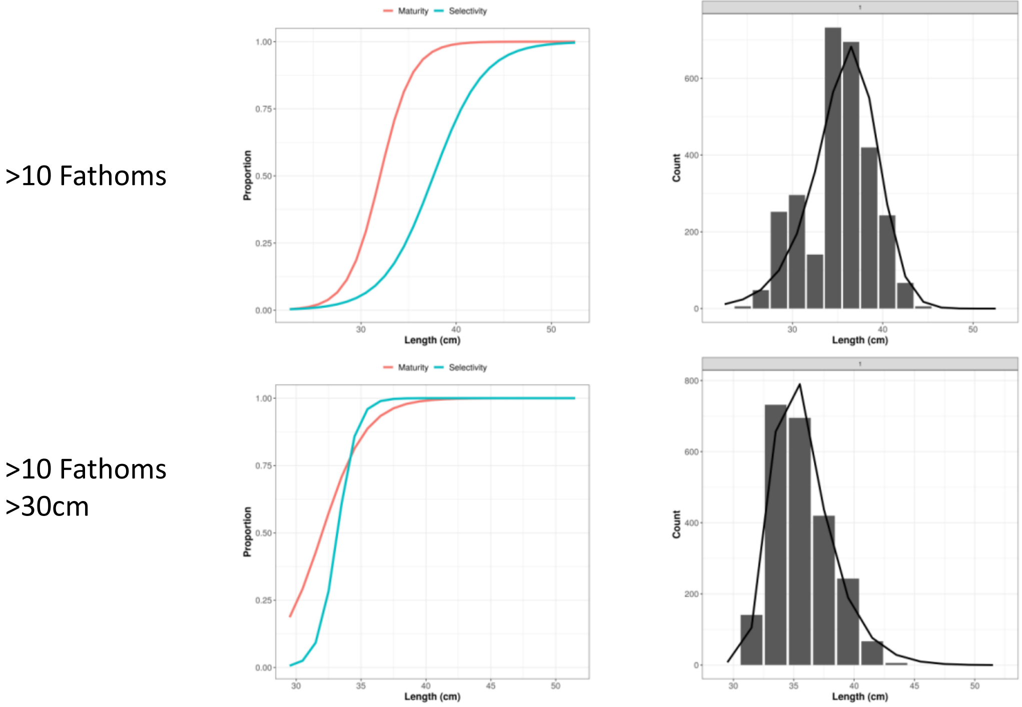


*Figure 111. Initial LBSPR assessments using size composition of the catch data aggregated for 2017 - 2020, and fishing areas from depths ≥ 10 fathoms (upper panel), and (lower panel) truncated at 30 cm. The table shows derived estimates of spawning ratio potential (SPR) and the size of 50% and 95% selectivity ($SL_{50}$ & $SL_{95}$) and relative fishing pressure (F/M). The estimated 95% confidence intervals around these mean estimates are shown in brackets. The input parameters assumed are indicated to the right; life history ratio M/K, asymptotic size ($L_{\infty}$), size at 50% and 95% maturity ($L_{50}$ & $L_{95}$). The left-hand panels present plots of assumed size of maturity ogive (red) and the estimate size of selectivity (blue). The right-hand panels plot the size composition data analysed (black bars) and the LBSPR modelled fit to those data*

| Site | SPR | SL50 | SL95 | F/M |
|---|---|---|---|---|
| Barra La Pitaya | 0.33 (0.18 - 0.48) | 38.83 (36.28 - 41.38) | 43.78 (40.43 - 47.13) | 8.53 (0.65 - 16.41) |
| El Sachi | 0.16 (0.08 - 0.23) | 37.28 (35.49 - 39.07) | 45.41 (43.26 - 47.56) | 13.14 (7.17 - 19.11) |
| La Gringa | 0.18 (0.07 - 0.3) | 38.53 (35.86 - 41.2) | 47.05 (43.93 - 50.17) | 13.13 (4.45 - 21.81) |
| Los Arbolitos | 0.21 (0.16 - 0.26) | 35.78 (34.48 - 37.08) | 42.56 (40.79 - 44.33) | 6.32 (4.25 - 8.39) |
| Punta Piedra | 0.2 (0.11 - 0.29) | 35.36 (33.57 - 37.15) | 36.72 (33.98 - 39.46) | 28.29 (0 - 74.99) |

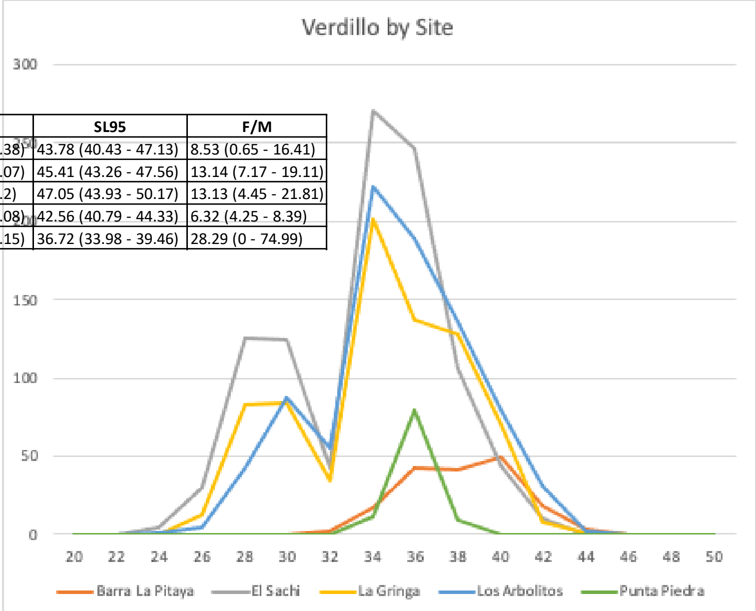


*Figure 112. Verdillo length-frequency data plotted and analysed for fishing 5 sites (Barra La Playa, El Sachi, La Gringa, Los Arbolitos, Punta Piedra)*

| Years | SPR | SL50 | SL95 | F/M | MK | Linf | L50 | L95 |
|---|---|---|---|---|---|---|---|---|
| 2017 | 0.29 (0.12 - 0.46) | 36.96 (33.7 - 40.22) | 43.16 (38.83 - 47.49) | 6.17 (0.62 - 11.72) | 1.16 | 49 | 31.7 | 37 |
| 2018 | 0.29 (0.22 - 0.36) | 38.02 (36.84 - 39.2) | 43.28 (41.78 - 44.78) | 10.98 (6.31 - 15.65) | 1.16 | 49 | 31.7 | 37 |
| 2019 | 0.17 (0.15 - 0.18) | 34.08 (33.81 - 34.35) | 36.03 (35.6 - 36.46) | 20.55 (15.32 - 25.78) | 1.16 | 49 | 31.7 | 37 |
| 2020 | 0.18 (0.17 - 0.2) | 31.69 (31.56 - 31.82) | 31.82 (31.62 - 32.02) | 6.77 (5.66 - 7.88) | 1.16 | 49 | 31.7 | 37 |

*Table 15. Initial LBSPR assessment of verdillo using size composition of the catch by year for 2017 - 2020, and fishing areas from depths ≥ 10 fathoms and truncated at 30 cm. This table shows input assumptions (M/K, $L_\infty$, $L_{50}$, $L_{95}$) which are explained in the text, and derived estimates by year (SPR, $SL_{50}$, $SL_{95}$, F/M) which are also explained in the text, and are shown with their estimated 95% confidence intervals in brackets.*

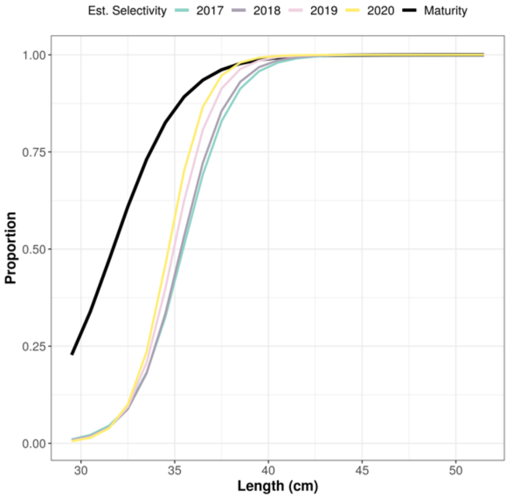


*Figure 113. Results of initial LBSPR of verdillo using size composition of the catch by year for 2017 - 2020, and fishing areas from depths ≥ 10 fathoms and truncated at 30 cm. Plots of assumed size of maturity ogive (black) and estimated size of selectivity (coloured).*

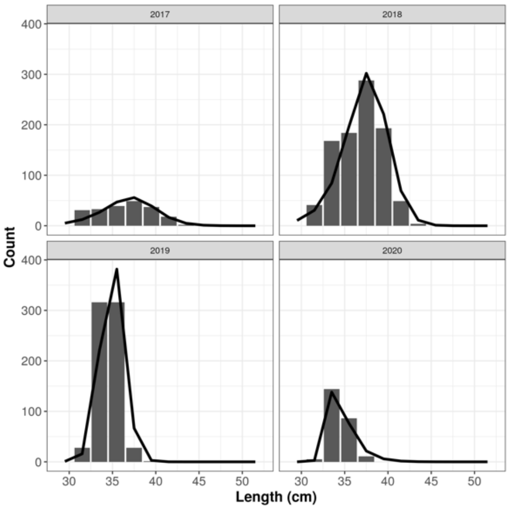


*Figure 114. Initial LBSPR assessment of verdillo using size composition of the catch by year for 2017 - 2020, and fishing areas from depths ≥ 10 fathoms and truncated at 30 cm. Plots of the size composition data analysed (black bars) and the LBSPR modelled fit to those data (black line).*

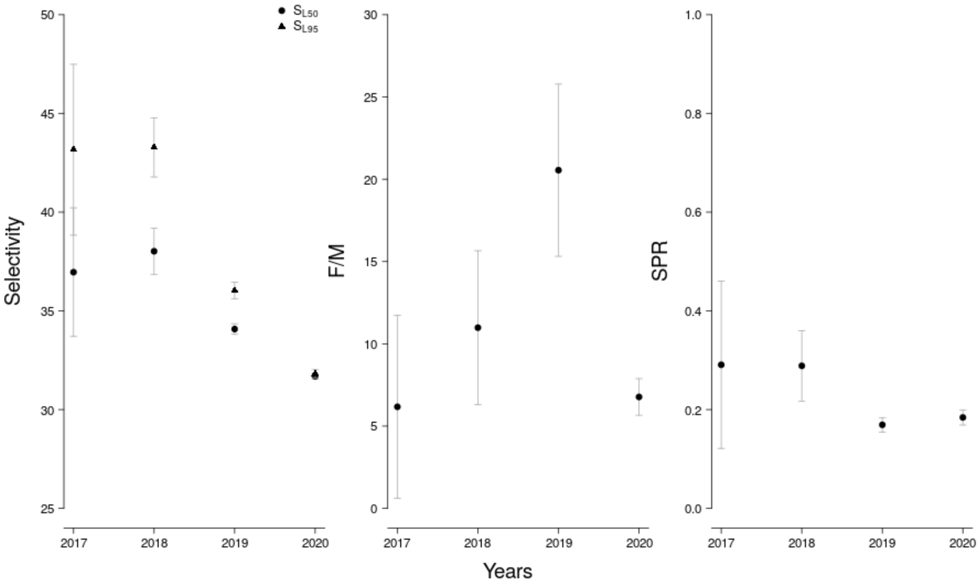


*Figure 115. Initial LBSPR assessment of verdillo using size composition of the catch by year for 2017 - 2020, and fishing areas from depths ≥ 10 fathoms and truncated at 30 cm. The plot on the left shows annual estimates of size selectivity ($SL_{50}$ circle; $SL_{95}$ triangle), in the middle plot annual estimates of relative fishing mortality (F/M), and on the plot on the right annual estimates of SPR. Estimated 95% confidence intervals are indicated by the bars in all three plots.*

## Verdillo Discussion

All the assessments based on these data and assumptions produce estimates of SPR ranging between ~15 – 30%. The range was lower than expected by some workshop participants provoking discussion around three issues concerning how data are used, and results interpreted. Specifically, how to deal with:

1. The bi-modality observed in the length frequency histograms,
2. The transitional dynamics observed through the time series, which seems to indicate a pulse of recruitment growing through the population, and
3. The potential for dome-shaped selectivity influencing the results.

### Bi-modality

The issue of dealing with bi-modality in length-frequency histograms inconsistent with the LBSPR model’s assumptions has already been discussed with other species. In the case of verdillo the issue seems to be more straightforward than for huachinago, as the juvenile and sub-adult portion of the catch is a relatively small, so that the impact of this catch on the stock is unlikely to be great, especially if these smaller size classes suffer higher M. So that, focussing the assessment on the adult portion of the catch, by sub-setting for the catch from > 10 fathoms, and truncating those data at 30 cm, which clearly improves the model’s fit to the data, is unlikely to have a great influence on our assessment, and this seems to be borne out by the results, with and without truncation, being very similar.

### Transitional dynamics

As with huachinango the size composition of verdillo seems to be relatively dynamic and we infer that this is due to variation in the strength of recruitment entering the stock. Given the relatively short time series of data it is not possible to say whether or not this is a regular feature of the stock, but the fact that we have observed it during our short time series, and in several other of stock assessments, makes that seem likely. Meaning that our assessment procedures and harvest strategies will need to be designed to deal with that aspect of stock dynamics. As discussed elsewhere, pulses of recruitment make annual estimates of SPR cycle around their true level with SPR estimates, with estimates of SPR being biased lower as high recruitment enters the smaller adult size classes, and increasing as the pulse of recruitment grows through the largest adult sizes classes. Using a trend in annual SPR estimated over 3-5 years, rather than focussing on single annual estimates in isolation, should allow these effects to be lessened, and this idea will be discussed further in the section on developing harvest strategies.

### Dome-shaped selectivity

Being mainly caught with traps the potential for dome-shaped selectivity to impact this assessment also needs to be considered, as there is a wide-spread belief that the dimensions of the trap entrances prevent the largest size-classes of verdillo from being caught. If this is actually protecting a reservoir of larger verdillo from being caught, it will impact our assessment, causing us to under-estimate actual SPR and over-estimate the relative fishing pressure (F/M). If this is the case our current estimates would need to be regarded as proving that there is at least some minimum amount of SPR existing in the stock, but not estimating its true extent above that minimum.

We should however, stop and seriously question whether or not dome-shaped selectivity is actually impacting our analyses, or whether this belief is simply a product of wishful thinking, as is so often the case. Fishers are resourceful and inventive, and unless tightly regulated, are likely to adapt fishing gear to maximise, rather than limit, their catches. In this context they are likely to experiment with the dimensions of their trap entrances to maximize catches, and the most successful dimensions are likely to be the one used by the fishery. Such a process of trial and error is unlikely to have resulted in a trap that excludes large bodied individuals and reduces catch rates. A feature that prevents larger individuals from being caught is only likely to be an industry standard if the largest size classes of fish are already very rare or non-existent in the population.

A dynamic that is commonly observed over time in gillnet fisheries is relevant here. Gill-nets normally have dome-shaped selectivity, with the selected size-range of fish being proportional to the mesh size. Normally gillnet fisheries develop using a uniformly, and relatively large, mesh size to target the largest heaviest size classes of fish and maximise catch rates, at the expense of letting the smaller size classes swim through. Over-time, however, as the largest size classes of fish become depleted and rare, the fishers attempt to maintain catches by adopting smaller mesh sizes to more effectively target smaller fish. The point being that the size selectivity of the fishing gear is adapted over time to the size range of the fish in the stock, in order to maximise catch rates. And that this rarely, if ever, results in the largest size classes being excluded from the catch, if in fact they still exist in the stock. Most commonly fish stocks targeted with gear that has dome-shaped selectivity, only experience the logistically-shaped, left-hand side of the dome-shaped selectivity curve. Because the original accumulation of larger size classes, that could have been protected by the dome-shaped selectivity, has already been depleted, and on-going fishing pressure prevents small fish growing into those protected larger size classes. It can normally be safely assumed that should fishing pressure to decline to a level that allows larger size classes to reaccumulate in the stock, the fishers will track that trend and adopt gear that more effectively selects for the larger fish. Thus, based on my own experience of other fisheries, and without any form of effective regulation to control the design of the fishing gear, I am sceptical of the idea that dome-shaped selectivity will be protecting some significant biomass of larger fish from being caught, without some form of independent evidence to allay my scepticism.

Never-the-less I note that, a new version of LBSPR has been created by Hommik et al. (2020) with which dome-shaped selectivity can be specified and taken into account for LBSPR assessment. This version could always by applied in this situation, although that will require studies to be conducted so that the form of the dome-shaped selectivity to be specified. In support of the views expressed above, I also note that when Shepherd et al. (2020) applied Hommik et al.’s version of LBSPR to Nile tilapia in Lago Bayano in Panama, they obtained the same result as with the standard logistic form of LBSPR. Precisely because fishing pressure was heavy enough to prevent fish growing to a size that would have been protected by the right-hand side of the dome-shaped selectivity. So that while the gillnets being used were documented as having dome-shaped selectivity, the only effect on the stock was from the logistically shaped left-hand side of the dome-shaped selectivity curve.

In this context I also note that through discussions about this fishery I have gained the impression that at least in some areas there may have been a transition from fishing with hooks to fishing with traps. If that is correct, such a transition might be interpreted as a transition from a gear that that was more effective at targeting larger size classes of fish to one that is more effective at catching smaller size classes. If this has indeed occurred it could well be consistent with the general observation that fisheries transition gear types to track the depletion of the resource being fished, and the inference that the traps currently being used are probably not excluding larger size classes of fish from being caught, because those size classes are already rare in the stock.

Interviews with fishers could potentially shed further light on this issue. Interviewers should enquire about whether hook and line were at times, and in places, ever used to fish for verdillo. If they were, why are they no longer used, or are not used more generally? If the answers suggest this to have been the case, questions should be asked about the size range of fish that were previously caught and typical catch rates. If an area of the fishery can be found where hooks are occasionally used it would be interesting to obtain length-frequency samples from the catch made by the differing fishing gear, for comparison to each other and the data from other areas where only traps are used.

To empirically decide this issue a program of experimental fishing would be required which should trial in parallel, fishing with the standard traps, and a form of fishing that is expected to catch the larger size range postulated to be excluded from the traps. If a larger size range of fish can be caught, then this would be proof showing dome-shaped selectivity is likely to be having a significant impact on the stock, and our LBSPR assessment. If structured properly, such a research program could also be used to document the form of that some shaped-selectivity so that the Hommik et al. (2020) adaptation of LBSPR could be parameterised and applied.

Accepting that the current catch is materially impacted by dome-shaped selectivity, and the form of the selectivity is impossible to estimate, preventing application of the Hommik et al. (2020) adaptation, we may still proceed using the standard LBSPR methodology. In this case we could recognise that the LBSPR assessment has a limited ‘dynamic’ range for SPR estimation and incorporate that assumption into the design of a harvest control rule. In this case we would accept that the SPR assessment can only establish that, ‘at least’ some level of SPR exists in the stock, and that higher levels of SPR are not measurable by our assessment. Our analyses above demonstrates that ~ SPR 35% can be estimated from some of the catch compositions. This level could be proposed as an upper bound for our estimates, it being impossible to estimate levels higher than that due to dome-shaped selectivity, but as SPR declines towards levels below this which are of concern to management, we would be able to detect this and respond. In the following section discussing the development of harvest strategies we will proceed on this basis to develop these ideas.

## Towards Developing Harvest Control Rules

Harvest Control Rules (HCRs) define how management regulations are to be incrementally adjusted in response to varying assessment results over time. It has yet to be decided how our fisheries of interest will be managed, and so which management components will be adjusted, but potentially it will be some mix of:

1. Input Controls which adjust fishing pressure by changing how many boats, fishers, units of fishing gear are used, and / or the length of time allowed for fishing.
2. Size Selectivity Controls which regulate the size of fish that can be landed, either directly with legal size limits and / or indirectly by regulating the types of fishing gears that can be used.

Consequently, the HCR's illustrated here are being developed generically for these types of management, rather than any specific form of management.

### Assessment Metrics

The assessment metrics available for evaluation with the available data are:

- SPR provide indices of the risk of recruitment collapse,
- F/M which provides an indication of exploitation pressure, and
- CPUE which is commonly used as a qualitative indicator of the trend in stock abundance.

The metric of SPR can be evaluated within the context of an internationally accepted framework of reference points, which has been discussed above briefly in the introduction. On the basis of implementing MSC's default SPR RPs we suggest adopting a target for management of maintaining stocks with the range SPR = 30-50% which should keep the stock around levels that optimize sustainable yields and economic returns, In this context the metric of SPR is being assessed by the size composition of the stocks, meaning that the effect of changing fishing pressure will take time to grow through the stock and be fully assessed, a time period equivalent to the time each recruiting cohort takes to pass through the fishery. This means that SPR is a backward-looking index, providing an index of fishing pressure over the previous 3-10 years of the fishery.

The metric of F/M is closely related to SPR and its impact on the stock is mediated through the size of selectivity, with higher size selectivity higher F/M can be sustainable and *vice versa*. Thus, it is a relative index (relative to size selectivity) and cannot be evaluated against any international reference points, for this reason and because it is so closely related to the estimation of SPR, it adds relatively little information to our evaluation of stock trends. In this context, and at this point of development little use is being made of this indicator. Potentially with a slightly more complex form of HCR than is being proposed here, it could be used to inform the size of the iterative changes being made to management with each application of the HCR.

The metric of CPUE also, cannot be evaluated against any accepted reference points, and can only be used qualitatively; trending down is bad, steady is OK, trending up is good but cannot continue indefinitely, steady after a period of trending up is best. In contrast to SPR and F/M which index a previous period in the fishery, the trend in CPUE may (theoretically at least) provide a more immediate and direct indicator of current trends in biomass. One which is derived independently of the size composition, and so providing us with an additional source of information about stock trends that is independent of our assessment of SPR and F/M.

## Schematics of Harvest Control Rules

The logical framework for three Harvest Control Rules (HCRs) are presented here schematically as decision trees (e.g.Figure 116). A logical sequence of decisions that are followed from top-to-bottom, with the parallel branches of the tree being intended to describe every possible combination of stock status metrics (SPR and CPUE). The concept being that with every cycle of stock assessment the logic of the HCR would be followed from top-to-bottom of the decision tree with the branch of the decision tree followed most closely describing the stock metrics of that time.

The HCRs described here with text and decision trees, will eventually need to be codified into algorithms, probably based on some slope-to-target formulation adapted to our purpose. In these schemata, indicative incremental adjustments to management, determined through each branch and level of the decision tree, are shown with numeric notation. For brevity in the discussion and diagrams these changes are denoted as values of ‘F’ which are to be summed down each branch of the decision tree. By addition of the individual F values that are encountered on any path down the tree an eventual incremental change to the previous management setting is computed for application to the previous management setting. The magnitude of the final F value, at the bottom of each branch of the decision tree indicates the relative magnitude of the incremental changes suggested by the HCR. A final positive F-value indicates that the next incremental change to management should be a relaxation of restrictions allowing fishing pressure to increase (e.g. higher fishing pressure, smaller size of capture, increased catch), while negative F-values denotes tightened management restrictions to reduce fishing pressure (e.g. reduced fishing pressure, larger size of first capture, lower catch). These final F values are shown at the bottom row of Figure 116as a range of F because the exact final F value depends upon the route taken down to the base of the decision tree. At this stage of our process these F values are purely meant to be indicative (up / down; bigger / smaller) so that chains of logic and relativities can be qualitatively explored and tested.

Laid out as decision trees in this way it becomes possible to transparently examine, test and discuss the logic implicit in these HCRs. Providing a more inclusive way of begin the process of designing and developing HCRs for these fisheries. Having agreed a form of HCRs for these fisheries, the next part of the process would be to convert the qualitative logic into quantitative algorithms that can then be tested with MSE modelling, presumably with MERA. At that stage of the process these indicative F-values will need to be determined as absolute values (e.g. 10% reduction or increase in fishing pressure) but that is a process best done within the quantitative construct of MSE modelling, as it will depend upon the likely responsiveness of the stocks as well as the periodicity of re-assessment and form of management being incrementally adjusted.

The second and third HCR schematics (Figure 119 & 120) are simply variations of the first more generic HCR (Figure 116), which has been modified to better account for issues of dome-shaped selectivity (verdillo) and pulsing recruitment (huachinango), respectively. Consequently, for the purpose of this text, we will commence by describing the first HCR schematic in some detail (Figure 116 - 118), and the subsequent schematics in less details, as most of the first description can be applied by readers to the second and third. In discussing the second and third schemata (Figure 119 & 120) this text will simply focus on how the original decision tree has been modified to address the issue of dome-shaped selectivity or varying recruitment in the second and third schemata respectively.

## Generic Harvest Control Rule Schematic

The generic form of HCR being proposed here has two levels of assessment (Figure 116):

1. At the first level SPR is initially evaluated in terms of its absolute level relative to agreed target range, and subsequently its trend over a previous period of time (~5 years) as; increasing, steady, or decreasing.
2. At the second level of assessment the CPUE trend is used as a tertiary level of evaluation also being assessed as; increasing, steady, or decreasing. CPUE is used in this way as a tertiary level of assessment, to qualify previous levels because it is assumed be a leading indicator of how SPR can be expected to trend in the future.

Through the middle of Figure 116small box plots are shown depicting the various possible evaluations of SPR trends indicated with notation immediately above, in terms of SPR above, within or below, the agreed target range, and with and rising, falling or steady trend. Similarly, at the bottom of the HCR schema (Figure 116) is a second tier of small box plots depicting the evaluation of the relative trend in CPUE detailed above, in terms of trending up, down or steady.

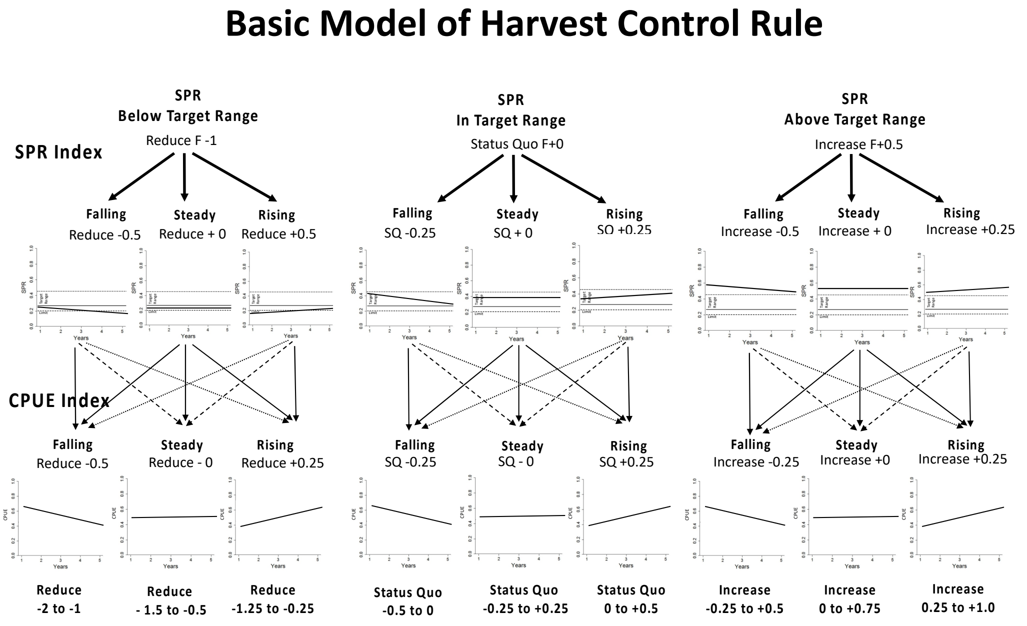


*Figure 116. Basic model of Harvest Control Rule*

## Evaluation of Spawning Potential Ratio

Across the top of these HCR schematics (uppermost level ofFigure 116) SPR is initially assessed as being:

1. below the target range (left) in which case fishing pressure should be reduced (F=-1)
2. in target range (centre) in which case fishing pressure should remain the same (F=+0)
3. above target range (right) in which case fishing pressure could be increased (F=+1).

At the next level of the decision tree (upper middleFigure 116) for each of the three absolute levels of SPR (below the target range, within the target range, or above the target range), the trend in SPR is evaluated (falling, steady, rising) and the initially indicated change to F added to accordingly. This is illustrated in more detail inFigure 117, which focuses in on the component of the HCR from the upper right of Figure 116, which assesses SPR initially as being below target range, so that a decrement to fishing pressure (F = -1) is initially indicated. The three small box plots at the base of each SPR module depict the three generic assessments possible within this component, or region of the decision tree. Which in the case of Figure 117 is that SPR is below the target range and either:

a. Declining, in which case the incremental change to F indicated at the first level of assessment is decreased (i.e. F reduced), in this case F = -1.0 - 0.5 = -1.5,
b. Steady, in which case the incremental change to F indicated at the first level of assessment is confirmed (i.e. F unchanged), in this case F = -1+0 = -1.0, or
c. Rising, in which case the incremental change to F indicated at the first level of assessment is increased (i.e. F increased), in this case F = -1+0.5 = -0.5

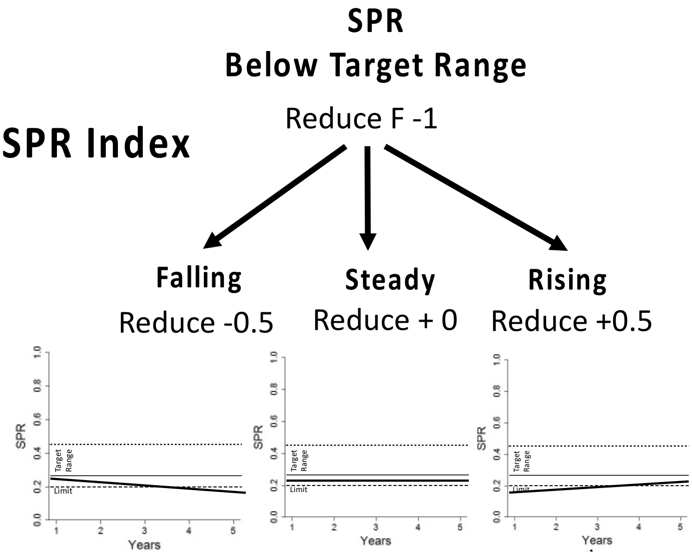


*Figure 117. Close-up of one component, or region of the Harvest Control Rule shown in Figure 114. In this component SPR is evaluated as being Below Target and an initial decrement (F=-1) allocated, next the trend in SPR is evaluated as being falling, steady or rising and an additional adjustment to fishing pressure is indicated, reduction (F=-0.5), status quo (F=0) or increase (F=0.5).*

Zooming back out from this focus on the 'Below SPR Target Range' component depicted in Figure 117, and returning to the broader HCR schema depicted in Figure 116, the effect of secondarily assessing the trend in SPR is seen to be;

1. where SPR is already below the target range and an incremental reduction in fishing pressure was initially indicated (F = -1.0) that reduction will be; made larger if SPR is also trending downward (F = -1.0 - 0.5 = -1.5), maintained at the same decrement if SPR has steadied (F = -1+0 = -1.0), or made smaller if SPR has already started trending upwards (F = -1.0 + 0.5 = -0.5)

2. where SPR is within the target range and no incremental change to management was initially indicated (F=0) the effect of secondarily evaluating the SPR trend is to; impose a small incremental reduction in fishing pressure if SPR is trending downwards (F = 0 - 0.25 = -0.25), maintain the status quo if SPR remains trendless (F = 0 - 0 = 0), and allow for a small incremental increase in fishing pressure if SPR is already trending upwards (F = 0 + 0.25 = 0.25).

3. where SPR is above the target range and a small incremental increase to fishing pressure was initially indicated (F = 0.5) the effect of the second level of evaluation is

to; negate that increase and maintain the status quo, while SPR continues trending downward (F = +0.5 - 0.5 = 0), confirm the initially small increase in F if SPR remains trendless (F = 0.5 + 0 = 0.5), and allow for an additional small incremental increase in fishing pressure if SPR continues trending upwards (F = 0.5 + 0.25 = 0.75).

### Secondary Assessment of Catch per Unit Effort Trend

At the tertiary level of assessment (Figure 116 lower level) the trend in CPUE over the previous 3-5 year time period is evaluated as a leading indicator of what SPR is likely to do in the future. This is illustrated by Figure 118which zooms in on the component of the decision tree at the bottom left hand-side of Figure 116, which evaluates CPUE trends when SPR is below the target range.

As illustrated by the arrowed lines each of the three generic SPR trends could theoretically be accompanied by either a falling, steady or rising CPUE trend, which respectively merit further incremental changes to F, a reduction (F = -0.5), no further change (F = 0) or a slight increase (F = 0.25).

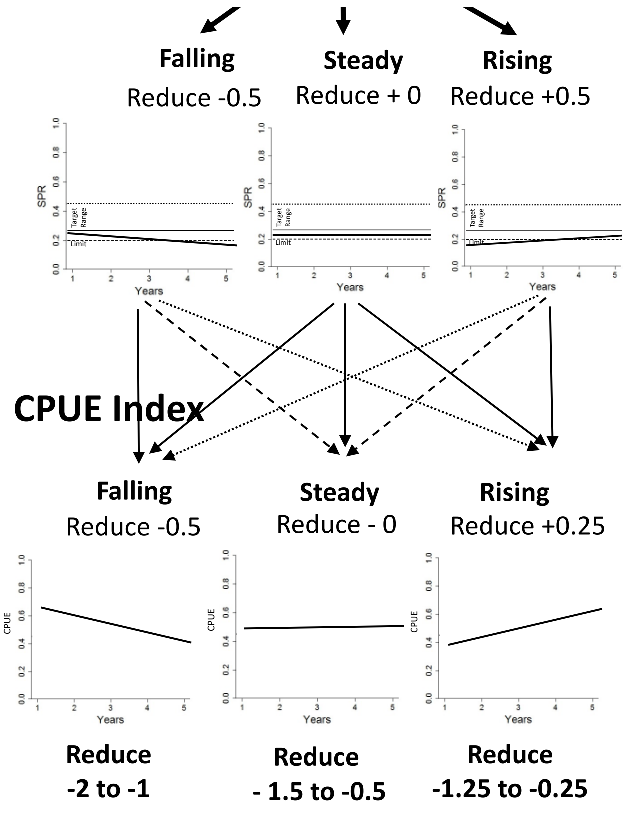


*Figure 118. Close-up of CPUE trend evaluation within the SPR Below Target assessment module of the Harvest Control Rule schema.*

In fact, fisheries dynamics mean that some of these logical links should be less likely to occur than others, which is indicated by the strength of the connecting arrowed lines. For example, a rising trend in SPR on the right-side of Figure 118, should always be accompanied by an increasing trend in CPUE. Never-the-less, observation error, time lags and transitory effects might at times determine that ‘less-likely’ combinations of metrics, do at times occur. In other cases, ‘less-likely’ combinations of metrics might indicate certain dynamics are occurring, which are real but contrary to standard fisheries assumptions. For example, despite declining SPR and depleting biomass, increases in the effectiveness of fishing could maintain, or even increase CPUE, thus degrading the presumed relationship between biomass and CPUE.

In that case the stabilisation, or increase, in CPUE would be ‘rewarded’ with the addition of either F = 0 or F = 0.25, but this is a relatively small final adjustment, a maximum of F = 0.25, which guards management to some extent against rewarding creeping fishing efficiency, instead of improving stock status. The increase (F = 0.25) being suggested at this tertiary level of evaluation in this component of the decision tree is smaller than the incremental changes awarded on the basis of SPR trend (F = -0.5 & F = 0.5), or the decrement suggested (F = -0.5) if CPUE is falling. So that should effort creep be driving rising CPUE while SPR is falling, the HCR still recommends incremental reductions in fishing pressure, just smaller reductions than would occur if SPR were below the target range, with CPUE and SPR both declining.

Once more, zooming back out from this focus on one component of the decision tree, at the bottom left hand-side of Figure 116. We can look across the bottom of the three main branches of the decision tree (Figure 116) and compare the range of possible outcomes. While SPR remains below the target range, with each iteration of the HS, the HCR will recommend additional incremental reductions in fishing pressure, ranging from a maximal reduction of F = -2 relative units of fishing pressure, if SPR and CPUE are falling. To a minimum F = -0.25, if SPR and CPUE are rising. At the other extreme, while SPR remains above the target range, the HS recommendations can range from small decrements in fishing pressure (F = -0.25), if SPR and CPUE are falling. To an increase in fishing pressure (F = 1.0) if SPR and CPUE are rising. Between these extremes, while SPR remains within the target range, the HCR may recommend anything from a F = -1.5 reduction in fishing pressure if SPR and CPUE are both declining, to a F = 0.5 increase if SPR and CPUE are both increasing.

### Harvest Control Rule Schematic for Dome-Shaped Selectivity

In the case of a fishery where dome-shaped selectivity is known to be occurring the effect on LBSPR assessment will be to impose some upper limit for SPR estimation. When significant numbers of fish are surviving to be bigger than the right-side of the selectivity curve, so that some significant numbers of fish in the stock are big enough to be relatively invulnerable to being caught, the estimate of SPR will plateau, and estimates of F/M stabilise above actual levels.

Turning specifically to verdillo, the species of interest we think most likely to be affected by dome-shaped selectivity. Our preliminary assessments for this species range up to SPR 30-35%, depending on the sub-set of size composition data used. Proving that, whether or not significant numbers of fish are growing big enough to become invulnerable to fishing, we could demonstrate with LBSPR that at least this level of spawning potential is being preserved in the fishery. This is a fortunate level of SPR to be able to establish, being generally regarded as just within the target range for optimising sustainable yields. So that while we may not be able to demonstrate higher levels of SPR, if dome-shaped selectivity is having an impact, we can at least demonstrate a basic level of sustainability. In this situation, with the higher range of SPR values being precluded by the dome-shaped selectivity the right-hand limb of the generic HCR decision tree (Figure 116) will be made redundant, but the middle and left-hand limbs can still be applied effectively.

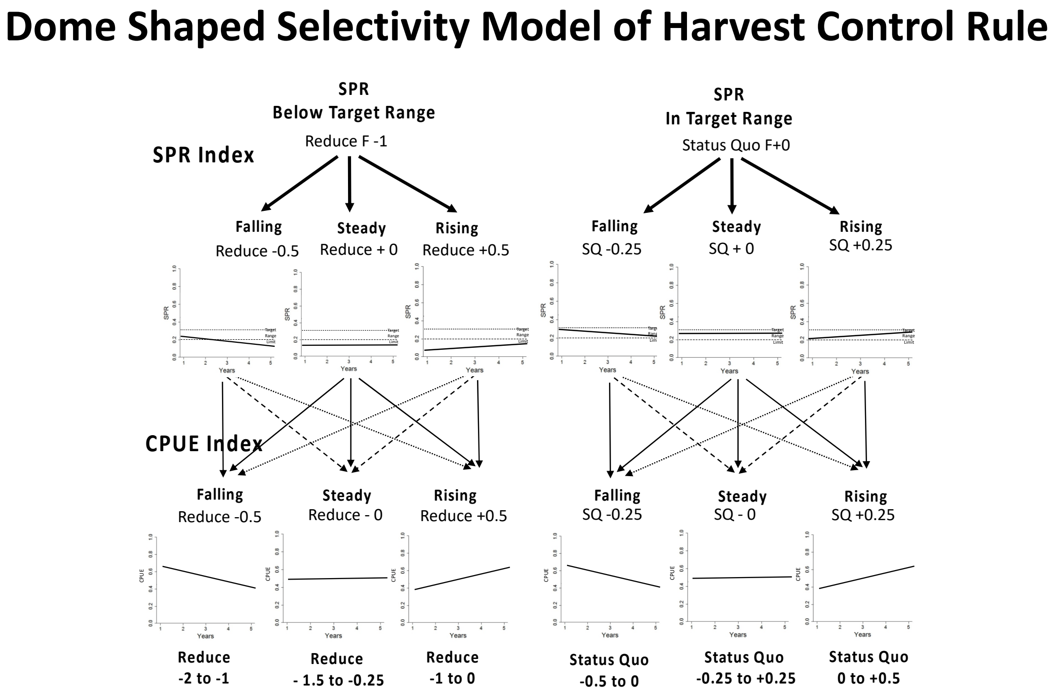


*Figure 119. Model of Harvest Control Rule adapted for fisheries with dome-shaped selectivity.*

As a consequence, our HCR decision tree for domed shaped selectivity has the same form as the generic version, simply lacking the right-side limb for evaluating scenarios when the SPR target is above the target range, as we no longer believe that to be a possible outcome of our LBSPR assessments (Figure 119). In all other respects the dome-shaped schema is virtually identical, the only difference being a slight rebalancing of the consequences for when below SPR remains below the target range, and with SPR and CPUE either steady or rising. In those circumstance the management recommendations are slightly less negative, ranging from F = -1.5 – 0 compared to F = -1.5 – -0.25, reflecting our expectation that some reserve of breeding biomass is protected from fishing pressure by dome-shaped selectivity, so that the HCR can be slightly less re-active.

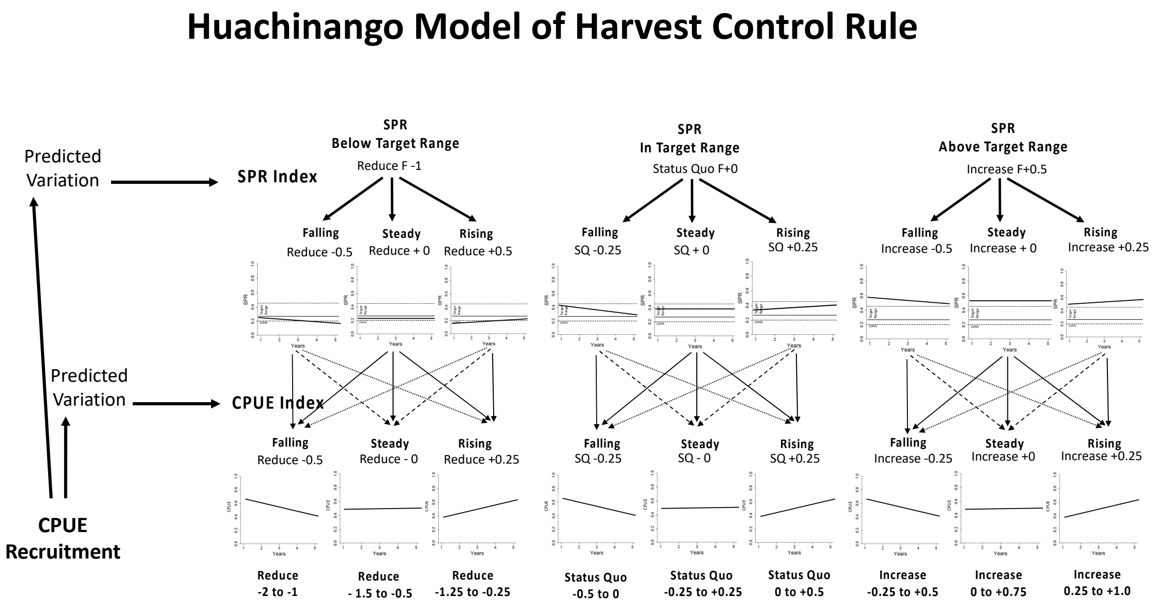


*Figure 120. Model of Harvest Control Rule adapted for fisheries with periodic recruitment pulses.*

## Harvest Control Rule Schematic for Variable Recruitment

In the case of a fishery strongly influenced by recruitment variability like huachinango apparently is. Pulses of recruitment must be expected to result in varying estimates of SPR, with lower SPR estimates being produced as strong cohorts enter the adult size mode, and then rising as they grow through the adult size range. The truest estimates of SPR will result when the adult size range does not have strong or weak cohorts transition through it, or by estimating average values from across the time period taken for recruitment pulses to pass through.

The ontogenetic distribution of size classes by depth in this species, means that with the existing depth structured CPUE and size composition data, fluctuations in recruitment should be observable growing through the stock, so that, to some extent their impact on the SPR estimates might be anticipated. New pulses of recruitment should be observable in the years prior to their impacting the adult part of the stock as higher catch rates of < 45 cm fish for fishing grounds < 40 fathoms deep. Variations in SPR predicted by previous signals in the catch of smaller fish, could be identified with purposefully developed ‘break-out-rules’ in the Harvest Control Rules defining periods when the assessment is being impacted by recruitment pulses, which could justify a more flexible interpretation of the SPR estimates SPR (Figure 120). While changes in SPR assessments that are uncorrelated with pulses of recruitment would be treated within the framework of our standard Harvest Control Rule (Figure 120). The simulation framework provided by the Mera program should provide an ideal test-bed to explore the dynamics underlying this phenomena and how HCRs algorithms with breakout rules might be developed to account for them.

# Concluding Discussion

This project has demonstrated the potential of the LBSPR technique for providing data-poor assessments for the finfish fishery of the San Cosme – Punta Coyote Corridor, and has begun the process of developing agreed assessments and methodologies. It has provided close to final results on the status of the species; triggerfish (*Balistes polylepis*), pierna (*Caulolatilus princeps*), yellowtail (*Seriola lalandi*), cadernal (*Cephalopholis colonus*) and more preliminary assessments for leopard grouper (*Mycteroperca rosacea*), red snapper, (*Lutjanus peru*) and barred sand bass, (*Paralabrax nebulifer*). For these latter species, issues around body size remain to be resolved, and in the mean-time some expert judgements need to be agreed about body size and the sub-setting of the size composition data, in order to refine estimates of stock status.

## Pulsing Recruitment

An interesting feature that emerges from this body of data and analysis is the evidence that some ecosystem wide mechanism is influencing productivity across the assemblage of species, causing periodic variations in recruitment, catches and CPUE. The size composition data provide evidence of periodic pulses of recruitment for jurel in 2013 & 2018, verdillo in 2010 and 2017, and huachinango in 2011/12 and 2016/17. With huachinango these pulses of recruitment appear to have coincided with increases in CPUE, but sharply lower catches. While catches of cardenal peaked in 2006, 2011, 2015, 2017, and pargo amarillo in 2009/10 and 2016/17, without evidence of recruitment variation. Noting that we are talking about recruitment that is occurring at various ages for the differing species, as well as perturbations of catch and CPUE, there remains some similarity in timing across stocks, suggesting some eco-system wide mechanism/s driving pulses of primary productivity up through the marine ecosystem in the region.

## Overall Assessment

Overall, although still preliminary, when taken together our assessments suggest this species assemblage has been heavily fished for several decades. With only a few exceptions (i.e. pierna) the assessments suggest SPR is below the default target reference range (30 – 50%) and declining, under relative high and increasing fishing pressure high. With some results suggesting some stocks could <20% SPR. At this stage of development our assessments are, however, uncertain enough to permit a wide range of expert interpretation. When presented with a broad range of plausible assessments for each species, the workshop participants mostly found the more optimistic end of our assessments, more plausible than the lower end. There are, however, grounds beyond our results, for thinking that interpretation is overly optimistic.

The local studies of size at age used to inform these assessments were mostly conducted in the 1990s and 2000s, and we were commonly forced to note that their estimates of $L_\infty$ are unfortunately precise, because the samples they relied upon contained very few specimens around the maximum size of the population. The implication being that the size and age structure of the stocks they sampled had been truncated by fishing several decades ago, lending weight to our more pessimistic assessment results.

The fact that the pulsing of recruitment is so evident, also serves to strengthen the impression that these fisheries are heavily fished and relatively depleted. Many of the species in the assemblage have relatively low M/K (< 1.2) indicative of species, that when lightly or moderately exploited have populations dominated by accumulations of many adult cohorts.

When populations are comprised of many adult cohorts, the annual influx of a single age-class of new recruits adds only a small proportion to the adult population. Consequently, these low M/K species are generally expected to form relatively stable populations that exist in balance or 'equilibrium' with the carrying capacity of their environment. The implication being that if there were still a larger number of adult cohorts present in these populations, recruitment pulses would tend to be less evident, because they would be a proportionally smaller part of the catch. In this context, that the growth of a single strong cohort of huachinango recruiting to the fishery in 2011/12 has, since then, apparently supported a steady increase in annual catches is not a good sign for this fishery without the incoming of a new strong cohort. If managed around accepted target reference points, this stock would contain ~20 age cohorts, ~10 or less? of which would comprise most of the catch. That the catch in this fishery has for the last decade been driven by the growth of two cohorts, suggests that these two cohorts comprise almost the entire biomass of the stock. Of course, we are considering a pulse of recruitment into the biomass, but the inference can only be that prior to the 2011/12 recruitment pulse, the biomass in this fishery was very depleted, probably to < 10% unfished levels.

## Research Priorities

### Body Size

At this stage of developing these LBSPR assessments, revising or confirming our estimates of body size ($L_m$ and $L_\infty$) will improve, and build confidence, in our initial analyses of all species.

#### *Growth studies*

Growth studies are more technical and expensive than the other forms of research, discussed below, that could be used to inform us about the body sizes of this assemblage, and if only for this reason, they are recommended less strongly than the methods suggested below. Particularly in the context of this relatively heavily fished assemblage additional growth studies they will continue to struggle to sample sufficient individuals around the asymptotic size to adequately define asymptotic size. If this challenge cannot be overcome, they will continue to result in imprecise estimates of growth parameters, and for all their expense are likely add little to our knowledge base. If, however, the issue of adequately sampling individuals of around asymptotic size could be resolved, they could be worthwhile supporting.

To this end, for some species I would recommend that rather than repeating an entire age and growth studies, augmenting existing data sets be searching for the rare largest size classes, adding these to the existing data-sets and re-analysing would be the most cost-effective way for improving these assessments. In the case of huachinago the data-set of Rocha-Olivares et al. (1998) contains very few fish > 800 mm, and while very rare the data suggest a few animals of this size are still encountered by Niparaja's sampling program every year. Searching the catch for a few years for an additional 30-40 individuals > 800 mm in length, adding these to the Rocha-Olivares et al. data-set and then re-analysing would add great value to the earlier study. It is possible that the influx of 2012/13 recruits into the adult population in recent years, might over the coming years rebuild numbers of older fish to such an extent that for a period at least, individuals around asymptotic sizes might be more easily found.

A similar approach, recommends itself with Pierna, for which Elorduy-Garay (2005) have already compiled a length-at-age data set for La Paz, but one which is similarly limited by its relative lack of the largest size classes. It contains few individuals in the length-at-age sample > 400 mm. The data analysed here suggested higher catch rates and larger fish at depth in remoter parts of the fishery, and it appears that Niparaja's sampling program regularly measures individuals up to 600+mm. Again, I recommend using the Niparaja sampling program to search the catch from those areas over a period of time for another 30-50 fish > 500 mm, so that the existing data set can be augmented and re-analysed.

The same principal applies to cabrilla sardinera, for which the Diaz-Uribe et al. (2001) length-at-age study contains only 4 specimens > 800 mm. In 2019 the sampling program Niparaja apparently measured more or less this many individuals > 800 mm. Using the Niparaja sampling program to find 30-40 specimens > 800 mm over several years and adding these to the existing length-at-age sample would greatly improve these growth estimates.

There are no local studies of growth for cardernal, cochito, pargo amarillo or jurel. If conducted in close partnership with the Niparaja sampling program so that adequate sampling of the largest size classes in the catch occurred, they would also very usefully inform our assessments.

### *Functional Size of Maturity*

Studies of the size of maturity can also be used to improve knowledge about the body size of these species and are generally easier and less expensive to conduct. Most previous studies of size of maturity in this region, have used histological techniques, as is common throughout the field of fisheries assessment. However, as discussed throughout this report, there is an emerging mismatch between the histological definition of maturity being the size the first gametes are produced by 50% of individuals, and the assumption in stock assessment that it is the size at which 50% of individuals begin producing gametes in proportion to their body weight. The concern being that this latter size is being systematically under-estimated by histological studies.

In terms of resolving the body size issue, the most informative studies, would provide context for interpreting the existing estimates of size of maturity, and in parallel apply two alternative methods of estimating size of maturity.

1. Estimating the relationship between the number of eggs (fecundity) and length would enable the stock assessment definition of LM to be estimated directly from the origin of the fecundity at length relationship.
2. Estimating the proportion of bodyweight comprised of gonad (gonadosomic index) by length relationship would provide an alternative measure of the size at which gamete production becomes proportional to body weight, from the size at which the gonadosomic index changes from a low juvenile level to the stable higher adult level.

Both these methods should provide a superior indication of the size at which fish begin producing adult levels of gametes which could place the existing histological techniques into context.

### Meta-Analysis of Geographic Variation in the LHP of the Baja Species Assemblage

The body sizes of species (i.e. $L_m$ and $L_\infty$) are expected to vary systematically between locations; being larger in cooler water with higher oxygen content (Brown et al. 2004; Pauly 2010). Being linked to water temperature, the LHP for each species in assemblage, should vary between locations, by similar proportional margins. Systematic meta-analysis to quantifying the inter-species proportionality of LHP, and how they vary by location, could provide a further piece of weight-of-evidence data for our data-poor assessments. Having established average relativities in body size between locations, observed deviations and conformities, will suggest specific LHP estimates are less, or more reliable, respectively.

Systematically studying regional differences in $L_m$ and $L_\infty$ for a range of species might make it possible to establish average relativities in body size between locations, and the deviations from, or conformity with, those average relativities, could be used to infer the reliability, or otherwise, of various LHP estimates.

## Further Data Analysis

The CPUE trends in this fishery will provide an important tertiary indicator in the HCRs proposed for these fisheries. For this purpose, what has been simply an initial exploration of structure will need to be extended into a more complete analysis. For some species it will be important to identify and distinguish the CPUE typical of targeted catching, from incidental catching, and between the various gears. It is also clear that depth and fishing area has an important impact for some species. A range of techniques for standardizing CPUE data are commonly applied and could usefully be applied to this situation. More immediately focussing the descriptive approach that has been commenced with this analysis, on specific depth ranges, fishing gears and seasons to sub-set the data more cleanly on either targeted, or incidental catch rates, should make the estimation of CPUE trends more accurate. Specific issues for each species regarding the structuring of the CPUE data that will need to be taken into account for this purpose have been discussed with the sections on each species.

There will also be a need to formally incorporate uncertainty into the LBSPR assessments. Adrian Hordyk has developed a boot-strapping methodology for estimating confidence intervals around the estimates of SPR and F/M which can quantify the level of uncertainty around input assumptions and data (e.g. Prince et al. 2020). I suggest that Adrian Hordyk be consulted directly on getting access to the R-code he uses for this purpose and would be happy to facilitate that request.

## Continued Development of Harvest Strategies

In terms of the broader process of developing HCRs for these fisheries so that adaptive management can be implemented with harvest strategies the next steps should involve:

Beginning the collaboration with Tom Carruthers and the Mera program to translate the proposed HCRs into algorithms, for evaluation and iterative testing and developing.

The specific type of management that is going to be applied (i.e. control on boat days, number of fishers, size limits, amount of gear) will be important in determining the how the proposed HCRs are formulated for tested and developed with the Mera software. So an important next step is to be facilitating a dialogue with the fishing communities of El Corredor, and the relevant government agencies involved with its management, to decide on the specific forms of management that can, or could be implemented to control fish pressure. This important detail needs to be scoped out at least to identify a preferred range of options, which could be supported by existing legal frameworks and mechanisms, before this broader process of HCR development can proceed too much further. Longer term that dialogue will also need to initiate a process of developing the human capacities need to implement and enforce the chosen form of fisheries management. These processes of selecting and developing appropriate and feasible forms of management with INAPESCA could potentially be facilitated and co-ordinated by working with TNC'S FishPath process.

Finally, a summary of these results could be prepared in more succinct form for submission to a peer reviewed journal of fisheries science.

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