FISH STOCK ASSESSMENT- APPROACHES AND INDIAN EXPERIENCE

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Introduction

Quantitative fish stock assessment has been a subject crossing a century if one strictly goes by the tools and techniques and gets yonder by another 75 years when it comes to its praxis. With assessment and management being viewed as two sides of the same coin, the practice of setting task forces to review the exploitation and related developments dates back to the 19th century. Closely following these developments are the governance interventions like regulations and penalties. Thus, this domain of scientific knowledge with immediate practical relevance is almost as old as any other branch of similar stature. But to anyone having a serious look at this field, it always gives a feel of a subject still nebulous in concept and context. This can be attributed to the type of resource this domain touches, fish. Fishery resources, both marine, brackish water or freshwater, are a bunch of natural resources that have more hidden than what is revealed. When the focus is on marine fisheries, this enigma entangled with surprises is a common sight. Under a thick sheet of water which is contained in a nearly bottomless and brimless container of sorts, identifying, studying, assessing and managing these resources themselves are quite a handful. Be it a researcher or a manager these resources throw up the dichotomy of being too simple to interpret, yet too difficult to manage. Thus logically speaking fish stock assessment is a dynamic admixture of science and art, whose proportions change as per ground reality. If the resources could be successfully brought under the realms of numbers then the science proportion gets to its peak, whilst the existing fishery throws up more diversity in terms of modes, means and status of those earning a livelihood out of this, the dosage of science gives way to what falls under the realms of the art of stakeholder management.

Stock assessment in essence is all about getting a measure of quantified information on any given basic unit under focus, popularly termed as stock, along with the information on the biological stage-based categorization. A typical stock assessment exercise needs to have definite earmarking of the spatial-species unit under focus, both under study and management, as well as a realistic indicator of the biomass of the stock. Again when it comes to indicator of biomass, it could be either an unbiased estimate based on experimental fishing, which is the most preferred form, with direct translation onto realistic estimates or a closely correlated metric like catch rate which is defined by the commercial fishery that targets the stock under focus. Though in Puritan’s book the indices carved out of commercial fisheries will always be ranked low, it’s one source of information, which would be readily available with little nudging on that. There are a plethora of options available to get the picture and related metrics.

Stock assessment methods

Classical methods of fish stock assessment have a couple of generic methodological approaches which are always put in place. They are the estimation of the extent of growth, removal, reproduction recruitment and resilience. These envisage an entire gamut of fishery starting from the fishing fleet, gear, and crew to stock, sub stock and average fish. Various known deterministic or stochastic relationships between relevant cause and palpable effect under each of these stages of assessment are put to the test and the estimates are arrived at. The multiple models/methods for stock assessment can be broadly classified into biomass dynamics (surplus production) models, delay-difference models, depletion methods, length-based methods, dynamic size-structured methods, age-structured methods, multispecies/ ecosystem models, Bayesian approaches etc.

In surplus production models (SPM), biomass is modelled as a function that integrates species recruitment, growth, and natural mortality while ignoring the age or size structure of the population. The Graham-Schaefer model (Graham, 1935; Schaefer, 1954, 1957; Ricker, 1975; Fletcher, 1978; Gulland, 1983), the Fox (1970) model, and the Pella and Tomlinson (1969) model are three traditional models that are frequently used. The biomass declines linearly with an increase in fishing mortality in the Schaefer model, which is based on the logistic equation, but exponentially with fishing mortality in the Fox model, which is based on Gompertz growth. More flexibility was provided by the addition of a third parameter by Pella and Tomlinson (1969), but at a cost: the model may be unstable, resulting in estimates with high variances and parameter confounding. There were several modified or extended forms of surplus production models available in the literature (Shepherd, 1982; Ludwig and Hilborn, 1983, Freon *et al.*, 1990, Punt, 1994; Restrepo and Legault, 1998; Sathianandan *et al.,* 2021 etc.).

By integrating biologically relevant and quantifiable characteristics and taking into account temporal delays in biological processes, delay-difference models expand biomass dynamics models (Hilborn and Walters, 1992). By explicitly modelling age-structured dynamics and the lag between spawning and recruitment, they fundamentally diverge from the aggregate biomass function of biomass dynamics models, but by relying on oversimplified assumptions about growth, survival, fecundity, and selectivity, they avoid the complexity of formal age-, size-, or stage-structured models. The fundamental presumptions are that all exploited fish are completely vulnerable to fishing, have the same natural mortality rate, and are recruited into the fishery and spawning stock at the same age. Deriso (1980) created the initial models, which Schnute (1985, 1987), Kimura *et al.* (1984), Kimura (1985), Fogarty and Murawski (1986), and Fournier and Doonan (1987) improved further.

When there is little data available, depletion methods provide an effective approach to stock assessment. They look at how measured fish removals (catch) affect the relative abundance of fish that remain, which is quantified by an abundance index, frequently catch rate (CPUE), which is typically seen as proportionate to population size. Leslie and Davis (1939), DeLury (1947), Moran (1951), and Zippin (1956, 1958) are credited with developing the classical depletion methods. The simplest depletion estimate is splitting the fishing season in half, assuming that the population is closed and that the catch rate is proportionate to abundance during each phase (Seber and Le Cren, 1967).

Length-based cohort analysis (Jones, 1981, 1984) produces estimates of abundance and fishing mortality at length given growth parameters, assumptions regarding natural mortality and a catch length frequency distribution from a population assumed to be at equilibrium. The yield per recruit model (Beverton and Holt, 1957) estimates the number of individuals in each size class over the course of the cohort by starting with an arbitrary number of recruits and projecting them forward depending on fishing and natural mortality. The "per recruit" estimates are then calculated by dividing the totals by the total number of recruits. Estimating yield, spawning stock biomass (SSB), or number of eggs by size class is done using weight, proportion matures, and fecundity by size. These estimates are then added up across all classes.

From the age-structured matrix representation of Leslie (1945) and statistical catch-at-age analyses, dynamic length- and stage-structured models were developed (Doubleday, 1976; Fournier and Archibald, 1982; Deriso *et al.*, 1985; Gudmundsson, 1986, 1994; Kimura, 1989). These were made general so that the model might be divided into categories for size, developmental stage, sex, or area (Usher, 1966, 1971; Sainsbury, 1982; Caswell, 1989; Sullivan *et al.*, 1990; Sullivan, 1992). The literature describes many statistical catch-at-age and VPA-based techniques. Numerous pertinent references can be found in Hilborn and Walters (1992) and Quinn and Deriso (1999). A more detailed discussion on the above category of models/methods is available in Sparre, *et al.* (1989), Sparre and Venema (1998), Sparre, *et al.* (1999) and Cadima (2003) and further development on the same can be found in Smith and Addison (2003). The length-Based Spawning Potential Ratio (LBSPR) method was proposed by Hordyk *et al*. (2015a, b), and tested in an MSE framework (Hordyk *et al*. 2015c), and further developed a length-structured version of the LBSPR model that uses growth-type-groups (GTG) to account for size-based selectivity Hordyk *et al*. (2016).

A lot of research has been done on models that can incorporate interactions among species and, more broadly, on interactions from an ecosystem perspective, aside from the categories of the models/methods listed above and the improvements that have been made to them in the last couple of decades. Most multi-species and ecosystem models emphasise both the lower trophic levels and the biogeochemical components of a system or the target fish species (and potentially their immediate predators and prey). According to Murray and Parslow (1999), Kishi *et al.* (2007), and Gregoire *et al.* (2008), the former typically includes nutrients, phytoplankton, and possibly zooplankton or filter-feeding groups, while the latter includes one or more species that are targeted by fisheries as well as their immediate prey, predators, or competitors (e.g. Magnusson, 1995, Punt and Butterworth, 1995, Hall *et al.*, 2006, Xiao, 2007).

Such complex integrated modelling approaches have spanned approaches with dominant simulation components.

Traditional Lotka-Volterra equations and complex end-to-end models are typically used to simulate marine ecosystems. According to the objectives, ecosystem models can be divided into three groups: (1) conceptual models that contribute to a general understanding of ecosystem process, (2) strategic models that provide information for strategic decision-making, and (3) tactical models that provide short-term management (FAO, 2008). The size-spectrum model, the model of intermediate complexity for ecosystems, and ecopath with ecosim and ecospace are a few of the well-known multi-species/ecosystem models.

Size-spectrum model, developed by Andersen and Beyer (2006), is a physiologically structured process model. The model takes into account two processes involved in the dynamics of fish populations, namely food-dependent growth and size-dependent predation (Hartvig *et al.*, 2011; Persson *et al.*, 2014). The model provides wide use of the application in the context of food web dynamics (Hartvig *et al.*, 2011), to evaluate the effects of fishing activity and management strategies (Blanchard *et al.*, 2014), to develop multi-species size spectrum models on the ecosystem of the data-poor region (Zhang *et al.*, 2016). This model is more suitable for short-term projections and to make the model more robust and suitable for long-term projections, seasonal dynamics, environmental variability at both spatial and temporal scales, and economic and social dimensions of fisheries should be addressed in the model.

Model of Intermediate Complexity for Ecosystems (MICE) are intermediate between traditional single-species stock assessments based on the integrated analysis paradigm and whole-of-ecosystem models. MICE attempt to explain the underlying ecological processes for a limited group of populations (<10) subject to fishing and anthropogenic interactions and include at least one explicit representation of an ecological process (e.g. interspecific interaction or spatial habitat use). The major components of MICE comprise a model of the ecological system and explain the ecological process of a given population, how it is impacted by anthropogenic factors, and how the ecological and human processes are represented in the model. The MICE model evaluates the effects of the predator–prey dynamics and the impacts of fishing activity on their biomass (Plaganyi *et al.*, 2014).

Ecopath with Ecosim (EwE) (Christensen and Pauly, 1992, Walters *et al.*, 1997, Walters *et al.*, 1999, Walters *et al.*, 2000, Christensen and Walters, 2004) is an ecosystem modelling software that helps to understand complex marine ecosystems (started at National Oceanic and Atmospheric Administration (NOAA) and developed at the Fisheries Centre of the University of British Columbia (UBC), Canada). EwE has three main components: Ecopath – a static, mass-balanced snapshot of the system; Ecosim – a time dynamic simulation module for policy exploration; and Ecospace – a spatial and temporal dynamic module designed for exploring impact and placement of protected areas. With the progress of time, EwE has also incorporated EcoBase, an open-access repository of trail-blazing models fitted using the software and their metadata.

More examples of these kinds of models include multi-species virtual population analysis (MSVPA) approach (Magnusson, 1995), ERSEM (Baretta *et al.*, 1995), ERSEM II (Baretta-Bekker and Baretta, 1997), OSMOSE (Shin and Cury, 2001a &b, Shin and Cury, 2004), Atlantis (Fulton *et al.*, 2005, Fulton *et al.*, 2007), InVitro (Gray *et al.*, 2006), SEAPODYM (Lehodey *et al.*, 2003), APECOSM (Maury *et al.*, 2007), NEMURO model (Kishi *et al.*, 2007), LeMans (Length-based Multispecies analysis by numerical simulation) (Hall *et al.*, 2006), SSEM (Sekine *et al.*, 1991), CAEDYM (Reichert and Mieleitner, 2008), TEM (Raich et.al, 1991), CEM & SEM (Cluer and Thorne, 2014, 2015) etc. A detailed discussion of these models was given in Fulton (2010).

Another category of stock assessment methods is the Bayesian method. As the classical methods are more or less rooted in the deterministic domain with some invocation of frequentist stochasticity-based estimations ventured out as in the case of separating normally distributed cohorts from a mixture of populations as represented by the length frequency samples, the counters were always raised on these two counts leading to a plethora of opportunities in stochastic non-frequentist methods of analysis.

Although frequentist approaches do not provide a coherent method for incorporating prior knowledge, they do provide non-parametric techniques, which allow for the relaxation of the assumptions surrounding error distributions. In Bayesian approaches, parameters are thought to have a (posterior) probability distribution that depends on the prior probability distribution and the likelihood of the parameter given the data. Prior probability distributions provide a formal method for incorporating knowledge from additional sources and are formally distinguished from data, but specifying prior distributions is not straightforward, and results may be sensitive to the assumed prior distributions. Additionally, the methods require a significant amount of computation.

Bayesian methods alongside Monte Carlo simulation and bootstrapping were applied to each of the stages of modelling, thereby expanding the scope of inferential possibilities and more robust estimation of standard errors of parameters estimated. Hence with the evolution of computational power and the advent of more powerful multi-parameter optimization routines like Automatic Differentiation Model Builder (ADMB) and Template Model Builder (TMB), all these traditionally opted methods were subjected to new kinds of analyses thereby enhancing the possibilities of universally optimum solutions for the key parametric nonlinear formulations. There are also cases involving other interesting optimization concepts like Simulated Annealing and Genetic Algorithm (TropFishR).

The Bayesian approach to stock assessment calculates the likelihood of various hypotheses based on data for the stock in question and conclusions drawn from data for other stocks or species. These probabilities are necessary if the outcomes of various management activities are to be assessed using decision analysis. It is possible to admit the whole range of uncertainty and leverage the collective historical experience of fisheries science when using the Bayesian method to stock assessment and decision analysis to estimate the effects of proposed management actions (Punt and Hilborn, 1997). Recently, Bayesian approach has been rigorously implemented in developing stock assessment strategies (ParFish (Medley, 2006; Wakeford *et al.*, 2009), CMSY (Helias, 2019; Palomares and Froese, 2017), CMSY++ (Froese, 2021), AMSY (Froese *et al.*, 2020), LBB (Froese *et al.*, 2018), JABBA (Winker *et al.*, 2018), BayesGrowth (Smart, 2020)) as it provides reasonable estimates even for fairly complex stock assessment models.

Pros and cons of the methods

Any assessment model must rely on simplified representations of the real system and make fewer assumptions. For both basic and complex models, there should be a trade-off between the number of parameters to be estimated and the model assumptions. Comparative studies have shown that less complex strategies can sometimes outperform more sophisticated ones (Richards and Schnute, 1998). Because they are typically more visible than sophisticated methods and are more likely to yield solid results, simple models that maintain biological realism should not be overlooked.

Even though several multi-species/ecosystem model frameworks are available in the literature, it requires more effort to translate the model output for tropical fisheries management. Most of the multi-species/ ecosystem models are more suitable for closed ecosystems where interactions can be easily modelled. Besides, multi-species/ecosystem models have several limitations due to their size and complexity, as the data needs can be challenging to meet in the majority of the scenarios.

The significance of including dynamic environmental drivers in the framework for stock assessment modelling should also be underlined, as most conventional models do not explicitly account for the impact of environmental trends or stochasticity. There is still a knowledge gap when it comes to maximising the effectiveness and accuracy of the current stock assessment methods as well as evaluating the synergistic effects of climate change on stock status. The main challenge, however, is gathering spatial-level information at the required resolution. The way forward could be to attain a gridded estimate of abundance through passive geo-referencing coupled with predictive modelling along with a participatory validation of the same with the involvement of fishermen from various marine fishing sectors.

The Bayesian approach could be useful in reducing the uncertainty associated with the choice of model parameters. Instead of taking point initial estimates for the parameters in the model equation, interval estimates may give a wider search space for getting a better fit. However, care must be taken when choosing prior distributions to prevent drawing erroneous conclusions. It is advised to use Bayesian approaches for decision analysis in fisheries Punt and Hilborn (1997), but they also highlighted the necessity to use a variety of alternative methodologies, emphasising that outcomes that are resistant to model selection will be given greater weight.

Summing up the Indian waters, which often witness the conundrum triggered by a huge quantity of data extremely focussed on one facet of information aquifers of fish stock assessment, the landings and size sample datasets collected by research institutions like ICAR-CMFRI from commercial vessels. Such information is quite vital and quantitatively sufficient for deputing most of the methods discussed above and the publications and research reports documented in the past two and a half decades are a case strong enough to buttress this (Eprints@ICAR-CMFRI, 2022). But the intertwining of common factors that support resources of similar ilk and the fact that they have a high probability of being netted by diverse modes of fishing keeps the evolutionary quotient of researchable components of our waters unique.

Environmental Performance Index (EPI)

One of the earliest, easiest, and most practical ways of analysing fish stock health is by way of observing commercial landings. A widely used indicator which gives a fair representation of fish stock status is the Stock Status Plot (SSP) and a modified SSP was used in this analysis which categorizes marine fisheries into 3 categories – Developing, Fully Exploited and Overexploited. An analysis of time series of marine fish landings from 2007 to 2021 was carried out using SSPs for all of India as well as for four regions (North East-NE, South East-SE, South West-SW and North West-NW). For all India, SSPs indicated that 75% of India's assessed marine resources are optimally exploited based on tonnage as well as the number of groups. For the four zones, the percentage of healthy stocks was 75- 88% (NE), 75-80% (SE), 76% (NW) and 72% (SW).

The Kobe plot approach is a four-quadrant display that has two axes focussing on fishing effort and biomass and is an effective method to infer the ratios of the current rate of FMSY and the current biomass to BMSY. The common inference is that a stock that falls in the bottom right quadrant is sustainably exploited and the top two boxes indicate over-exploitation at two degrees, viz., overfishing and overfished. The bottom left box indicates that both the biomass and effort are at such a state that either the fishery is in infancy or a stock that has collapsed is slowly crawling back.

To overcome the limitations of the methods detailed above, a new EPI-FSS index was developed which is based on the landings of a resource and optimal biological removal of the resource. A Weighted Tropic Level Index (WTLI) was also developed based on landings of a resource and its mean trophic level. Simply put, these two are proportions to the Potential Yield (PY) computed based on a rigorous analytical methodology and the weighted averages of trophic levels. Values of EPI-FSS of 4 and above indicate an early phase, between 3 and 4 indicate a developing phase, between 2 and 3 sustainable phase and below 2 an overfished phase. For 2019, 2020 & 2021, the FSS for India was 2.42 (Developing phase to Sustainable phase), 2.43 and 2.35 respectively. The WTLI was 3.4082 (in a range of 1 to 5, which is not precisely ordinal); a higher value indicates the substantial presence of apex-level animals indicative of a healthy ecosystem. From this, it was further estimated that 86.2% of the marine fish stocks in the Indian EEZ remain at the sustainable/early/developing phase of harvesting.

The FSS index was then fortified with the inclusion of vulnerability values for both species and regions to arrive at a Standardized Stock Class Ratio (SSCR). This was then used to re-estimate the EPI-FSS which resulted in a value of 2.88 (NE), 3.24 (NW), 3.35 (SE) and 3.40 (SW) for the year 2021.

Indian marine fisheries are often subjected to the scrutiny of variable levels on the count of the intensity of fishing and the stock status. The number of crafts registered and the number of fishermen often are reasons for intense speculation as regards overcapacity-triggered overfishing. With regular landings data available for a very long time and equally well-informed research-based stock assessment reports available on major resources, it was always just a matter of time before these questions were answered with finality. With the windfall of resources usually hinting at enhanced abundance, there is often a parallel thought process that runs across the sector that the future may not be so bright. In all such deliberations, the immediate common ground struck by administrators and fishermen is the pressing rationale for the measures and their impact assessment. Thus the ground is fertile for preparing a well-balanced, quick-tocompute and regularly implementable measure that would assess the stock health of all or important resources that form the fishery. The two indices viz., EPI- FSS and Fortified FSS are simple, repeatable and easy to use and can be easily estimated for the regional level which can then be used for fisheries management at the state or regional level by the line departments.

Data

The data that defines any kind of assessment has to be qualified on two counts viz. precision and continuity. Even if it is cross-section data, a sort of range continuity is to be ensured for better inference. But stock assessment data traditionally fall under the category of time series, and hence both these integrities are equally pronounced and must be adhered to. Starting from relative appraisals to trend analyses to much more in-depth computations, data on marine resource dynamics can be both alluring and challenging at the same time. With the information on fisheries spreading from sea to land, biomass to landings, there could be more than one criterion to define data as sufficient or otherwise. The usual data-poor situations are usually defined both by qualitative as well as quantitative norms. Starting from experimental cruise-based data to secondary data on exports and processed fish, anything and everything can constitute data as of date.

While data richness can always be contested, the concepts and methods have been quite open and accommodative when it comes to dealing with limited to moderate datasets. For multi-gear-fleet multi-species fisheries, the minimum data one requires is the catch and effort time series. The species-wise area-wise (sub-stock) catch or landings and the corresponding nominal efforts of gear fleets may be the least one can look forward to when it comes to assessing such a fishery. Though catch-only methods are quite popular as data-limited fishery assessment options, the ideally suited for a mixed resource fishery using multiple gears, not all selective, could be a time series of five years and above of this catch and effort. The nominal efforts need to be processed for their differential catchability, which forms one major sub-domain called effort standardization. In literature, methods varying from proportion-based comparison alongside a standard gear to Nelder-Mead algorithm-based optimization of the various nominal catch rates against gears are available. Also proposed are methods like adopting a general linear model-based approach alongside utilizing uniquely relevant distributions like Tweedie distribution too is in vogue. For Indian waters, the best-suited method would be the one that generically combines the gears' nominal values and categorizes them based on their summary hierarchy viz month, year, region etc. and creating an ensemble involving them with the main model that is put to use for estimating the reference points like MSY. The best example is the one adopted in the Pella- Tomlinson kind surplus production function fitted for estimating optimum fleet size (Sathianandan et al. 2021). However, a simpler and easy-to-use method which is based on the measures of central tendency and dispersion of the data is recommended for resources which are caught by a limited number of gear types (Varghese et al., 2020).

Marine fishery data assimilation and estimation in India

India has a well-established data collection and estimation system for generating information on species-wise and fishing gear-wise marine fishery resource landings and fishing efforts for different maritime states every month using skilled observers in fish landing ports. The method was developed by ICAR-Central Marine Fisheries Research Institute jointly with ICAR-Indian Agricultural Statistics Research Institute following a scientific sampling scheme named "Stratified Multistage Random Sampling Design (SMRSD)" (Sukhatme et al., 1958; Srinath et al., 2005), where stratification is done over space and time. This system of data collection and estimation has been in use since 1960. The sampling frame was created by gathering information on marine fishing villages, landing centres, crafts, and gears, among other things, and it is updated on a regular basis to reflect changes in the sector through all India frame surveys. Species-wise catch, fishing effort, details of fishing crafts and gears and other related information are collected through this sampling scheme. This sampling design has been successfully performing while evolving ever since and has been accredited by international institutions like FAO.

The population that is being attempted to be assessed through the samples is two-dimensional and is zone-month. The zones are sub-civic spatially contiguous divisions that may be equated to districts within the administrative provinces, and states, in India. The parameters like total catch, effort and catch rates pertaining to these zone-month populations are estimated through a two-stage sampling procedure, with the first one having strata and pseudo-strata of time intervals within a month. The sampling units are accordingly the fishing vessel or unit selected at the second level after the selection of a landing centre/ fishing harbour on a particular day (lcd) of the zone- month.

In spatial stratification, based on the fishing intensity, geographical boundaries and number of landing centres, each maritime state is divided into suitable non-overlapping regions called fishing zones. These zones have been further stratified into substrata, depending on the intensity of fishing. The number of centres may vary from zone to zone.

The landing centres are classified into High-Intensity Landing Centres (number of vessels in operation 300 or more), Major Landings Centres (number of vessels in operation between 100-299) and Minor Landing Centres (number of vessels in operation less than 100). The sampling coverage is more for High-Intensity Landing Centres than that for Major Landings Centres and it is still less for Minor Landing Centres. Among the fish landing centres, the major fisheries harbours/centres are classified as single-centre zones for which there is exclusive and extensive coverage.

The temporal stratification is more conventional than statistical, wherein the landing centre days to represent the population are spread evenly throughout the month, which is a major component defining the population. This gives enough support to take into account all the periodic oscillations noticed in resource availability within a month.

During an observation period, when the number of boats/craft landings is high, It may not be practically possible to record the catches of all boats landed. Hence, the following procedure given in Table 1 is adopted (Alagaraja, 1984):

Table 1. Number of boats/crafts to be observed

Number of boats/craft landed	Fractions to be observed
£ 15	100 %
Between 16 and 19	First 10 and 50 % of the remaining
Between 20 and 29	1 in 2
Between 30 and 39	1 in 3 etc.

In the case of single centre zones, sixteen to eighteen days are selected randomly in a month and the units (fleets) landed on a selected day (either as a cluster of 2 days or a single day itself) are enumerated.

In the data collection system, dedicated technicians (harbour-based observers) with species identification skills visit the landing centres according to work schedules generated under SMRSD and record different aspects of the fishery from sampled boats.

Based on observed landings and fishing efforts, an estimate of fish landings and fishing efforts for all fleets for a landing centre in a day is made. Monthly zonal landings are estimated using these data. Furthermore, estimates at the District, State, and National levels are obtained on a Monthly, Quarterly, and Yearly time scale. Detailed estimation methodology is provided in (Srinath et al., 2005).

The unique traits of this methodology are summarised below:

- The core method is advocating sampling at two strategic stages viz. landing centre -day (first stage) and vessels (second stage). The same can be easily extended to more stages depending upon the ground exigencies.
- The coverage and sampling variances are quite straightforward to calculate at each stage and in combination
- The fisheries defining gears or resources or both can be seamlessly introduced at the population level. If the zones have clear-cut demarcations based on unique fisheries, they can be taken as the base while defining the population alongside spatial and temporal blocking and this plan can be executed.
- The major benefit of this sampling plan is the inherent provisions for creating additional strata within zones depending upon sudden palpable enhanced fishery returns during specific seasons and also to drop the landing centres out, wherein due to seasonality the activities have ceased. The constituent units of strata can be re-stratified, updated and dropped at any stage of the sampling exercise.
- Unexpected spikes in landings for a short duration or even for a particular kind of craft-gear combination in a given zone can still be estimated in isolation. The basic randomness at the first and second stages ensures their additivity to the figures estimated through other landing centre days.
- The methodology is also capable of yielding basic statistics like average yield per vessel daily average catch rate or even resource-wise means at the finest granularity with aggregation possible at each higher level.
- This methodology offers flexibility to include all kinds of craft-gear combinations and all possible innovations that uniquely define fisheries as they exist on a given day and thus have proven to be conceptually robust.

The best part of the whole design is its statistical rigour coupled with ease of adoption. Added to these is the dynamic nature of this methodology, which paves the way for self-evolution.

The kind of sampling strategies can very well be extended to collect samples to estimate/ study life history traits, which leads to robust stock assessment.

Indicators

The main hurdle or moot question in any stock assessment exercise in a typically data-constrained environment is the selection of indicators of biomass abundance. The biomass, either expressed as weight or in numbers, is the real component of the latent part of most of the commonly used methods like delay difference models or state space models. The biomass being in the realms of components to be estimated themselves poses a distinctive challenge when it comes to estimating the interim function that leads to the computation of biological or economic reference points. Hence proper selection of the indicator for the same is very much essential. Though it is always a practice to use catch rate, either as catch per unit effort catch per unit fishing hour catch per unit of HP effort or per unit of fuel utilized, would always be popping in one's mind, it is to be handled very carefully. Occurrence of frequent zeros in catch rates, especially when the same resource is landed by multiple gears must be approached with a lot of deftness. One such option is provided by zero-inflated model fitting involving distributions like Tweedie or Poisson. However, it is always advisable, that wherever possible, landing independent estimation of biomass by utilizing methods like VPA or SRR may be attempted for the various size groups and the same may be combined towards the end to arrive at an independent estimate of SSB. The indicators may also vary from the most commonly targeted production or value. Just like the yield per recruit method indicates the MSY equivalents can be arrived at by utilizing other criteria like Spawning Potential Ratio and other similar measures of relevance to abundance.

Another interesting expansion of the concept of MSY from single species to multi-species based on these indicators is the multivariate MSY based on the agglomeration of multi-fleet simultaneous capture of many species. One of the most prominent methods of such computation is based on Nash Equilibrium, wherein the stage at which any given species doesn't get influenced after attaining an optimum irrespective of the variation in the capture of competing and cohabiting resources (Thorpe, 2019). Such approaches coupled with full extraction and utilisation of prior knowledge of the species being studied would always come in handy while assessing stocks of our subcontinent.

Strategy options

The immediate state of transition for these indicators of stock health is the management strategies. Depending upon the quantum and direction of the reference points, strategies for either input control-regulation of size, number and kind of fishing gear output control measures, like precautionary levels of fishing and limitations on the size of fish caught during specific seasons, are spelt out. Such strategies can always be evaluated computationally by following a sequential set of analytical and simulation manoeuvres.

A typical effort to evaluate management strategy would involve collating a set of relevant sets of growth, reproduction and ecosystem-level scenarios of fishery resources of the zone under focus and their most probable fishing fleet generically categorized based on the gears, bound by mathematical or statistical relationships, known as operating models (OM). These OMs are then constrained and conditioned to match the various real-life scenarios like admissible range of CPUEs etc., which would make the OMs more realistic to the zone under study. Uncertainty is added as stochastic error generated as part of what is called observation error to these thereby preparing the simulated dataset to the next level. Thus the simulation process that is taken care of at the OM level gets transformed into a stage wherein the resultant data gets amenable to stock assessment of any predetermined kind to arrive at the reference points as the derived input or output control rules. Then follows the most curious stage of the exercise wherein the outputs of the assessment-based manoeuvres are subjected to possible implementation errors like overages and the results are refed into the OMs and the cycle gets repeated. Based on these closed looping trials the best management strategy as reflected in input and output control mechanisms is zeroed in on and finalised. As these are computationally intensive such a combination of simulation and looping is executed by routines custom-made for such purposes, MSEtool (Carruthers & Hordyk (2018) being an example.

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