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Marine Fisheries Information Service Technical & Extension Series

The Marine Fisheries Information Service, Technical & Extension Series (MFIS) is a quarterly publication of ICAR-Central Marine Fisheries Research Institute disseminating latest research information on marine fisheries and mariculture in India. Research based technical articles, reporting significant new information, knowledge and understanding of marine fisheries and ecosystems as well as new concepts/technologies in marine fish nutrition, hatchery and larval rearing, fish pathology, fish health management, application of genetics in fish conservation and farming, sea farming technologies, seafood trade and fisheries governance are published. To see all issues since 1978, visit:

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Fishing boats berthed at Chellanam Fisheries Harbour

Photo credit: Sidharth Sen

Marine Fisheries Information Service Technical and Extension Series envisages dissemination of information on marine fishery resources based on research results to the planners, industry and fish farmers and transfer of technology from laboratory to the field.

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Marine Fisheries Information Service
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From the Editorial Board

Warm greetings to all our esteemed readers

Sustainable, well-managed fisheries contribute to national good by providing nutritional security and livelihood avenues to the people. Fish and seafood products also form a significant chunk of global trade. Climate change effects and extreme weather events disrupt the ecosystems and affect the lives and livelihoods of fishermen, in direct and indirect ways including changes in fish behaviour, disruption of fish distribution patterns and the fish growth - spawning cycles in certain vulnerable species. To overcome the challenges of such uncertainties in fisheries management, science based data collection and analysis protocols, integrating species level fish biology information in stock assessments and a participatory, transparent assessment frameworks are desirable to ensure that fisheries management decisions are well accepted and implemented. Keeping these points in mind, this issue of MFIS includes some articles of interest.

Marine Fisheries Information Service
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Research Communication

A note on different methods for standardization of fishing efforts

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Abstract

Surplus production models are widely employed to evaluate the condition of fish stocks, encompassing the entire stock, overall fishing effort, and the total yield derived from the stock. These models operate under the assumption that variations in population biomass result from hikes due to growth and reproduction, as well as drops due to natural and fishing mortality. Utilizing Catch-Per-Unit-Effort (CPUE) as input, these models rely on the presumption that CPUE is directly proportional to the biomass of fish stock in the sea. An inherent challenge in fitting such a production model lies in determining CPUE, whether in terms of units operated or in hours of operation/actual fishing hours (AFH) or in any measure of fishing efforts. Given the heterogeneous nature of fishing fleets in tropical regions, they are often categorized into boat-gear categories, where fishing units within each category share similar characteristics and performance. When assessing the collective impact of the fishing operations of the entire fleet on the exploitation of fish stock, nominal addition of the efforts of different boat-gear categories may lack meaningfulness without prior effort adjustment to enhance comparability. In tropical regions, due to the varying capacities of gears and the potential presence of multiple species in each gear, the effort expended to catch a resource cannot be simply considered as the sum of the duration/units of operation of all gears. This paper aims to underscore various effort standardization methodologies found in the literature for different situations, offering insights into the challenges faced in tropical fisheries and proposing a way forward.

Keywords*: Surplus production models, stock assessment, sample-based surveys, standardization of fishing effort, abundance, GAM, GLM, GLMM, delta methods*

Introduction

Fish stock assessments are crucial for understanding the health and sustainability of fish populations. These assessments provide valuable information on the size, age, and productivity aspects of fish stocks, which can help managers make informed decisions about fishing regulations which may be furthered to harvest control rules/ quotas. Additionally, fish stock assessments can help identify areas where habitat restoration or conservation efforts may be needed and play a critical role in maintaining healthy and sustainable fisheries. These assessments as they are practised worldwide, entail determining the parameters of population dynamics models by fitting them to research and monitoring data.

Surplus production models are commonly used for assessing the state of fish stocks and they deal with the stock, the fishing effort and the total yield obtained from the stock in their entirety. These models assume that variation in population biomass results from addition due to growth and reproduction and loss due to natural and fishing mortality. The results of this fitting process are then used to estimate quantities, such as current abundance, that are important for decision-makers. When fitting stock assessment models, a range of data types can be utilized. However, these data sets generally need to include details about removals due to harvesting and an indicator of relative abundance. Ideally, this indicator of abundance should be derived from fishery-independent data collection methods like surveys. However, acquiring fishery-independent data is often prohibitively expensive or challenging. In such cases, reliance on fishery-dependent data becomes necessary. Consequently, assessments of numerous stocks rely exclusively on fishery-dependent data. The most common and easily obtainable form of fishery-dependent data is the catch and effort information from commercial or recreational fishers, typically presented as catch-per-unit-of-effort (CPUE) or catch rate (Maunder and Punt, 2004).

As the fishing fleet is heterogeneous in most cases, it is partitioned into boat-gear categories in each of which the fishing units have similar characteristics and performance. When it comes to measuring the combined effect of the fishing operations of the entire fleet to the exploitation of a fish stock, it becomes apparent that adding together effort exerted by different boat-gear categories is not always meaningful without first applying effort adjustment to increase their comparability (Stamatopoulos and Abdallah, 2015). Hence, standardization of commercial catch and effort data is important in fisheries where in standardized abundance indices based on fishery-dependent data are a fundamental input to stock assessments (Bishop, 2006).

The objective of this paper is to highlight diverse methodologies for standardizing fishing efforts as identified in the literature across various situations. It seeks to provide insights into the challenges encountered in tropical fisheries and put forward potential pathways for addressing them.

Methods for standardization of fishing efforts

There is a lot of literature available on the standardization of the fishing effort. These methods deeply depend on the characteristics of the gear being operated and the availability of the information. This choices/listing is more based on the generic nature of the underlying approach and relevance to multigear multispecies scenarios. Following are the few methods available in the literature for the standardization of fishing effort:

Standard vessel/gear based approach
(Beverton and Holt, 1957)

This method consists of selecting a reference gear/vessel and determining the relative fishing power/effort (RFP) of all other vessels/gears by

$$RFP_i = \frac{C_i/E_i}{C_s/E_s}$$

where RFP_i is the relative fishing power/effort for vessel/gear i, with C_i representing the total catch by vessel/gear i during the specified period when both the standard vessel/gear and vessel/gear i were present in the fishery. C_S represents the total catch by the standard vessel during the same period. E_i denotes the total days fished (or another measure of fishing effort) by vessel i during the specified period, while E_S represents the total days fished by the standard vessel during the same period.

The standardized catch rate for year t, is then defined as

$$I_t = \frac{\sum_i C_{t,i}}{\sum_i RFP_i \, E_{t,i}}$$

where $C_{t,i}$ is the catch by vessel i in year t, and $E_{t,i}$ the number of days fished by vessel/gear i in year t. This approach is a simple method for estimating fishery yields, but it may not be suitable for situations with multiple factors and when no long-term fishing vessels are available for comparison.

Relative effort based approach
(Robson, 1966)

A more direct approach to standardize fishing effort is proposed by Robson (1966), although it necessitates the availability of additional data. The method operates based on the notion of "relative fishing power". With the fishing power of vessel B relative to vessel A means:

$$PA(B) = \frac{\text{CPUE of vessel B}}{\text{CPUE of vessel A}}$$

applied when two boats are fishing under identical conditions (simultaneously and in the same area). Vessel A is commonly referred to as the "Standard vessel." Suppose the boats are participating a certain fishery can be divided into 5 homogenous groups, so that each group consists of boats with similar fishing powers. Suppose also that the CPUE is in units of catch per unit time and further that the following data have been collected:

Boat type	A (Standard)	B	C	D	E
Fishing Power (*PA*)	1.0	*PA (B)*	*PA (C)*	*PA (D)*	*PA (E)*
Number of Boats (*N*)	*NA*	*NB*	*NC*	*ND*	*NE*
Average number of fishing days per boat (*d*)	*dA*	*dB*	*dC*	*dD*	*dE*

The total effort would then be estimated by:

Total effort = 1.0**NA*dA + PA (B)*NB*dB + PA (C)*NC*dC + PA (D)*ND*dD + PA (E)*NE*dE*

In specific instances, one may infer that the fishing effectiveness correlates with certain attributes of the boat or gear, readily accessible, such as GRT (tonnage) or HP (horsepower), or their combination for trawlers, and, for instance, the quantity or length of nets for gill netters. Since the focus typically revolves around relative effort, the fishing power (PA) can be easily substituted with the characteristics of the boat or gear.

Derived effort based approach (Sparre, 1998)

In general, a suitable measure of fishing effort is the one that demonstrates a linear relationship with the catch rate (Sparre, 1998).

The relative effort is

$$\frac{Yield}{CPUE}=Effort \quad or \quad CPUE=\frac{Yield}{Effort}$$

Since the effort of different gears is assessed in terms of units per year and hence to ensure compatibility among various gear types (effort units), each unit needs to be converted into CPUE, which is then further converted into "relative CPUE". The relative catch per unit of effort of gear i (i=1 to k) in year y is defined as follows:

$$R_i(y)=\frac{CPUE_i\,(y)}{Mean\ \{CPUE_i(y1,\ y2,\ ....,\ yn\ )\}}$$

where $CPUE_i\,(y) = Y_i(y)/f_i(y)$ = catch per unit effort of gear i in the year y, $Y_i(y)$ = yield of gear i in the year y; and $f_i(y)$ = effort of gear i in the year y.

The total yield of the species under examination denoted as $Y_T(y)$, encompasses both the catch covered by the catch/effort sampling scheme and the unaccounted yield. When this total yield is divided by the weighted sum of relative CPUE values, it yields a quantity proportional to the total effort $R(y)$, as $Y_T(y)/R(y)$.

The normalized effort for the year y is $E(y) = \frac{Y_T(y)/R(y)}{Mean\,(Y_T/R)}$,

where $Y_T(y)/R(y)$ is the relative effort of year y, $Y_T(y)$= total yield of all gears (including gears for which effort is not known), $R(y) = \sum_{i=1}^{k} [R_i(y) * Y_i(y)/Y_E(y)]$ is the sum of related CPUE weighted by the yields in the year y and $Y_E(y) = \sum_{i=1}^{k} Y_i(y)$ is the sum of yields of gears for which effort is known (yield of sampled gears), per year.

Multigear mean standardization (MGMS) (Daniel et al., 2016)

The method named multi-gear mean standardization (MGMS) combines catch per unit effort data that standardizes catch per unit effort data across gear types (Daniel *et al.*, 2016). The calculation of MGMS begins by standardizing the CPUE data for each gear using a form of mean centering. First, the total catch (TC) of all i species in each observation j per unit of effort e is calculated as $\frac{TC_i}{e}$. Next, for each gear, the mean total catch per unit effort $\frac{\overline{TC_i}}{e}$ is calculated. To standardize the data for each gear, the CPUE of species i in observation j (C_{ij}/e) is divided by the mean total catch per unit effort across all observations, yielding:

$$MSC_{ij}=\frac{C_{ij}/e}{\overline{TC}/e}$$

where MSC_{ij} is mean standardized catch of species i in observation j. Once CPUE data for each gear are converted to MSC_{ij}, they can be combined across gears and the resulting sums provide the basis for further analysis.

Generalized linear models (GLMs) and generalized additive models (GAMs)

Approaches built on GLMs and GAMs represent statistical approaches employed to model the correlation between catch (response variable) and factors such as effort, environmental variables, and other covariates (predictor variables). These methods are adept at accommodating non-linear relationships and variability within catch data, providing flexibility for capturing intricate patterns. The standardization of catch and effort data is most commonly achieved through the application of Generalized Linear Models (GLMs), as introduced by Nelder and Wedderburn in 1972. Gavaris (1980) is recognized as a pioneer in utilizing the GLM approach for this purpose, marking the first instance of its application. He expanded upon the use of multiplicative models (Robson, 1966) for standardization by explicitly incorporating assumptions of log-normal errors. Gavaris (1980) employed an Analysis of Variance (ANOVA) model, exclusively incorporating categorical explanatory variables, on the natural logarithm of CPUE. Hilborn and Walters (1992) gave an excellent exposition on the use of Generalized Linear Models (GLM) for the standardization of fishing efforts.

GLMs are characterized by the statistical distribution governing the response variable, typically (though not always) the catch rate, and how a linear combination of certain explanatory variables correlates with the anticipated value of the response variable. The fundamental premise of a GLM lies in the assumption that the connection between a function of the expected response variable value and the explanatory variables follows a linear pattern.

$$g(\mu_i)=\boldsymbol{x}_i^T\boldsymbol{\beta} \quad \text{.................................}1$$

where g is the differentiable and monotonic link function, $\mu_i=E(Y_i)$, $\boldsymbol{x}_i$ the vector of size m that specifies the explanatory variables for the i th value of the response variable, $\boldsymbol{\beta}$ is a vector (of size m) of the parameters, and y_i the i th random variable.

To overcome the linearity assumption of GLMs, Generalized Additive Models (GAMs) were developed and are effective models in establishing a relationship between predictor variables and the response. GAMs offer the ability to represent a broader spectrum of response curves compared to GLMs. Many researchers are opting for GAMs over GLMs, particularly in fisheries science, where their predominant application mirrors that of GLMs—specifically, the standardization of abundance data.

Generalized additive models (GAMs; Hastie *et al*., 2001) are extensions of generalized linear models that involve generalizing Eq. (1) by replacing the linear predictor by an additive predictor:

$$g(\mu_i)=\mu+\sum_{j=1}^{p}f_j(x_i) \quad \text{..........................}2$$

where f_j is a smooth function (such as a spline or a loess smoother). The degree of smoothness achieved is balanced against the deviance by a tuning constant, often chosen by cross-validation, so that estimation is by the method of maximum penalized likelihood rather than of maximum likelihood. This gives GAMs a partially non-parametric aspect.

Methods for zero-inflated data

Databases containing information on catch and effort frequently exhibit a substantial proportion of entries where the catch value is zero, despite a recorded non-zero effort. Instances where effort is marked as zero must be addressed, either as trivial cases if they coincide with zero catch or as errors necessitating resolution (e.g., removal) before conducting any analyses. This pattern is particularly pronounced for less abundant species and those categorized as bycatch. Regrettably, these species often represent crucial sources, if not the sole source, of data for standardized catch rate indices that track changes in abundance (Ortiz and Arocha, 2004). The prevalence of zero values can undermine the assumptions underlying the analysis, posing a risk to the reliability of inferences if not appropriately modeled, as emphasized by Lambert (1992). Moreover, the abundance of zeros can introduce computational challenges. The following approaches are commonly adopted to deal with zero inflated data:

(a) Zero-inflated models

Zero-inflated models are often used when dealing with data that has excess zeros. These models typically assume that the observed data is a mixture of two processes: one that generates zeros and another that generates the remaining values. Common models for zero-inflated data include zero-inflated Poisson (ZIP) or zero-inflated negative binomial (ZINB) models. Rochman *et al.* (2017) attempted to standardize CPUE to estimate relative abundance indices based on the Indonesian longline dataset time series using GLM with Tweedie distribution. Setyadji *et al.* (2018) used GLM to standardize CPUE and to estimate relative abundance indices based on the Indonesian longline dataset. Six GLM models were considered viz., negative binomial, zero inflated Poisson, zero-inflated negative binomial, Poisson hurdle, and negative binomial hurdle models. AIC and BIC were used to select the best models among all those evaluated.

(b) Delta methods

Traditional Generalized Linear Model (GLM) analyses, relying on log-transformed data, assume that no CPUE observation equals zero. To address these challenges within a GLM framework, the delta-lognormal method (Pennington 1983, 1996; Lo *et al*., 1992) has been employed. This method handles zero catches separately, modelling them independently, and then employs a GLM for positive catches. The models for zeros and the GLM are then integrated to generate an abundance index. Delta-GLM and Delta-GAM models are extensions of GLMs and GAMs, respectively, used for standardizing catch and effort data. They focus on modelling the differences (delta) between observed and expected catch rates, allowing for better handling of count data and overdispersion.

Generalized linear mixed models (GLMMs)

Generalized Linear Mixed Models (GLMMs), as introduced by Pinheiro and Bates in 2000, expand upon the Generalized Linear Model (GLM) approach by allowing certain parameters in the linear predictor to be considered as random variables. This extension enables more flexibility in modelling and accommodates the inclusion of random effects. In recent analyses of catch and effort data, various studies (Chang, 2003; Miyabe and Takeuchi, 2003; Rodríguez-Marín *et al*., 2003; Brandão *et al*., 2004; Ortiz and Arocha, 2004) have employed GLMMs, treating some of the model parameters as random effects. This utilization of random effects is particularly valuable in addressing interactions between variables, such as year and other categorical factors like area. The incorporation of random effects allows for a more meaningful representation of the underlying complexities in the data, contributing to a more comprehensive and accurate modelling approach. By considering random effects, GLMMs can provide more accurate estimates of catch rates, especially when dealing with hierarchical data structures.

Spatial models

Spatial models are analytical tools used in various fields to represent and analyze the spatial relationships and patterns of phenomena across geographic space and can help to understand, simulate, and predict the behaviour of processes that exhibit spatial dependencies. Spatial Autoregressive Models (SAR) and Spatial Regression Models are two popular models which are useful when analyzing data from different geographic locations and can account for spatial dependence in the standardization process.

Machine learning approaches

Machine learning algorithms, such as Random Forest, Gradient Boosting, and Support Vector Machines (SVM), can be applied to standardize catch and effort data. In a study conducted by Yang *et al.* (2020), SVM was applied to standardize longline catch per unit fishing effort for Bigeye tuna (*Thunnus obesus*) in the tropical fishing area of the Atlantic Ocean. The researchers evaluated three parameter optimization methods: a Grid Search method, and two enhanced hybrid algorithms, namely SVM in combination with particle swarm optimization (PSO-SVM) and genetic algorithms (GA-SVM). These optimization methods were employed to strengthen the performance of SVM, providing a more robust and accurate tool for CPUE standardization in fisheries data.

Like GAMs, neural networks offer increased flexibility in representing relationships between CPUE and explanatory variables. Maunder and Hinton (2006) pioneered a neural network approach for estimating relative abundance based on CPUE data. Their key innovation involved incorporating the year effect as a categorical variable within the neural network framework. Unlike GLMs , which are constrained to linear relationships (with the option of higher-order and interaction terms), neural networks enable the data to determine these relationships, allowing for more nuanced, non-linear modelling. Warner and Misra (1996) provide a comprehensive introduction to the connection between neural networks and regression, elucidating the terminology used in both. However, a drawback of neural networks is the potential existence of multiple solutions arising from common estimation techniques. These diverse solutions stem from different initial weights. Preliminary investigations indicate that these varied solutions yield comparable estimates of the year effect (Maunder and Hinton, 2006).

Environmental data integration

Integrating environmental variables (such as sea temperature, chlorophyll concentration, and ocean currents) into standardization models helps account for environmental influences on fish behaviour and distribution. Hinton and Nakano (1996) introduced a comprehensive habitat-based standardization (HBS) method that establishes an analytical framework, and consequently a statistical framework, for integrating an understanding of the distributions of environmental factors, fishing gear, and species into the standardization of CPUE. The fundamental concept is that if a hook is deployed in an environment preferred by a species, say bigeye tuna, it has an elevated probability of capturing that species. This becomes particularly crucial, for instance, in standardizing the effort of longline gear targeting tuna, given that the depth of the gear has increased over time as fishermen pursued bigeye tuna, which are generally located at greater depths in the water column.

Methods for multispecies multigear fishery

In tropical region, the marine fishery is of complex multi-species nature where in different species are caught by several fishing gears and each gear harvests several species making it difficult to obtain the fishing effort corresponding to each fish species. Since the capacity of the gears vary and each gear may harvest multiple species, the effort made to catch a resource cannot be considered as the sum of duration/units of operation of all the gears, making the nominal figures less relevant or rather intriguing.

As standardising efforts or CPUE stem from the kind of nominal measures of quantification available as basic data, a clear picture of the methodology adopted for landings/catch and effort collection is a mandatory requirement. Hence, as a typical point under focus towards an understanding of the marine fish landings data collection system followed in the Indian scenario is presented in brief.

India has a well-established data collection and estimation system for generating information on species-wise and fishing gear-wise marine fishery resources landings and fishing effort 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 as well as sub regional/zonal levels. 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.

The population that is being attempted to be assessed through the samples is two-dimensional with zone-month as the parametric index. The zones are sub-civic spatially contiguous divisions that may be equated to districts within the administrative provinces, 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 a 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 (Fig. 1).

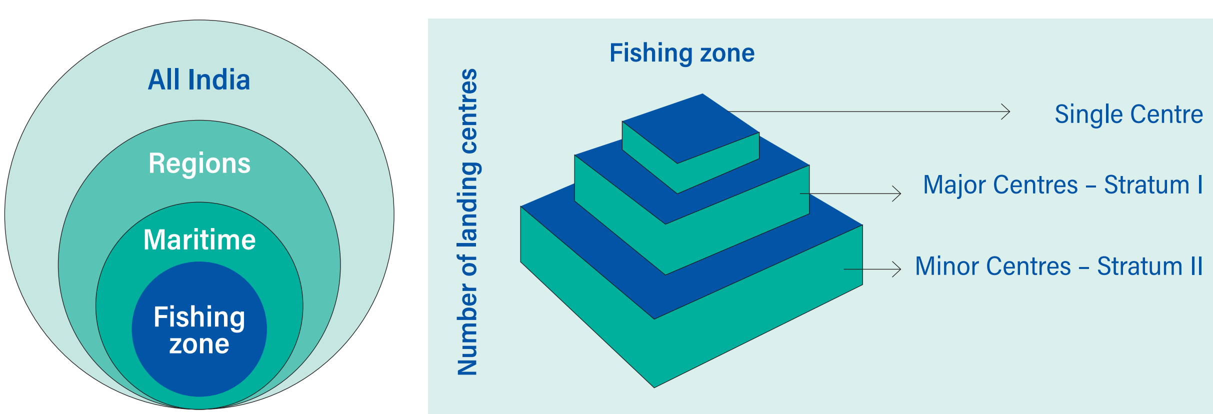

Fig. 1. Spatial stratification

Time strata	Days in a month									
1	1	2	3	4	5	6	7	8	9	10
2	11	12	13	14	15	16	17	18	19	20
3	21	22	23	24	25	26	27	28	29	30

Fig. 2. Temporal stratification

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 (Fig. 2) is more conventional than statistical, wherein the landing centre days to represent the population are ensured to 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.

Suppose there are 10 landing centres in a zone, there will be 300 landing centre days (10 centres x 30 days) in a month. A month is divided into three groups, each with ten days. A day is selected at random from the first five days of a month, and the next five consecutive days are chosen automatically and form cluster groups of two consecutive days. In the remaining ten-day groups, the clusters are systematically selected with an interval of ten days. Normally, in a month, there will be nine clusters of two days each. Among the total number of landing centres in the given zone, nine centres are selected with replacement and allotted to the nine cluster days described earlier. Thus, nine landing centre days are observed in a month. The observations are made as per Table 1.

Table 1. Data collection during a landing centre day

24 hrs landings (One landing centre day)	Data collection method
1200 hrs to 1800 hrs of 1^{st} day	By observation on the first day
0600 hrs to 1200 hrs of 2^{nd} day	By observation on the second day
1800 hrs of the 1^{st} day to 0600 hrs of the 2^{nd} day (night landing)	By enquiry on the second day

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 2 is adopted (Alagaraja, 1984):

Table 2. Number of boats/crafts to be observed

Number of boats/crafts landed	Fraction to be observed
≤ 15	100 %
Between 16 and 19	First 10 and 50 % from 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) is 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.

With the introduction of computers and information technologies, the access and dissemination of information have become easier. ICAR-Central Marine Fisheries Research Institute took the lead in developing an online system for the collection and retrieval of data on marine fish landings and other related parameters named Fish Catch Survey and Analysis (FCSA) and the system has been operational since 2018 and was proven to be an excellent system for the data collection and estimation of marine fishery resources (Mini *et al.*, 2023).

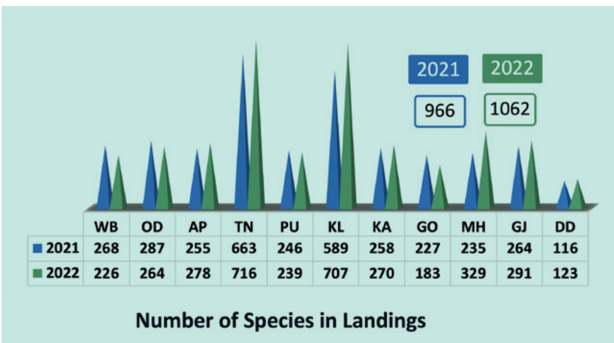

Fig. 3. Species distribution in landings along the coastal states

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.

The diversity of the fishery along the Indian coast is most probably reflected in the number of species documented in the fished taxa in recent years (FRAD-CMFRI, 2022; FRAEED-CMFRI, 2023), as illustrated in Fig. 3. Despite the source being commercial fishery, due to the fact that the record of landings was done by qualified and neutral enumerators with species level exhaustive identification as mandate, this can be viewed as measure of diversity of taxa. Additionally, the variety of gears in operation, as observed even on the southwest coast of India (Varghese *et al.*, 2021), serves as an indicator of the intricate nature of the fishery. The combination of high species diversity and the utilization of multiple types of fishing gears contribute to the complexity of fisheries in tropical countries like India.

As indicated earlier, due to varying capacity of gears and also the incidence of multiple species in some of the gears, a customized method is needed for the standardization of the fishing efforts. The following two approaches can probably handle the situation mentioned above:

a) A simple analytical framework

(Varghese *et al.*, 2020)

This method of standardization requires the species catch, total catch and total fishing effort. Let Y_{ijk} represents the catch of k^{th} species ($k = 1, 2, ..., s$) from i^{th} ($i = 1, 2, ..., g$) gear at the j^{th} ($j = 1, 2, ..., t$) time point (say year) and the corresponding effort is expressed as X_{ij}.

To calculate the component of standardized fishing effort for the species corresponding to each gear, the proportion of catch in the total catch by each gear for each year and a weighting factor for each gear is required. Following is the step-wise procedure of effort standardization:

Step1: Calculate $P_{ijk}=\frac{Y_{ijk}}{Y_{ij.}}$, where $Y_{ij.}=\sum_{k=1}^{s} Y_{ijk}$

Step 2: Obtain the mean and variance of P_{ijk} for each gear and for each species

$$\overline{P_{i.k}} = \frac{1}{t}\sum_{j=1}^{t} P_{ijk} \text{ and } \sigma^2_{i.k} = \frac{1}{t}\sum_{k=1}^{s} (P_{ijk} - \overline{P_{i.k}})^2$$

Step 3: Calculate the weighting factor as

$$W_{i.k} = \frac{\overline{P_{i.k}}}{(\sigma^2_{i.k}+1)} \text{ and } W'_{i.k} = \frac{W_{i.k}}{\sum_{i=1}^{g} W_{i.k}}$$

The weighting factor is then adjusted for unit sum. The decomposition of fishing effort for the species is then obtained by multiplying the corresponding total fishing effort for the gear in the year with the proportion of the species for the year corresponding to the same gear and the weighting factor.

Step 4: Obtain the standardized gear-wise fishing effort as

$$E_{ijk} = W'_{i.k} \times P_{ijk} \times X_{ij}$$

Here, the sum of all the gear efforts would give a total effort. But, the efficiency of gears varies so also the capability to catch in an hour which demands scaling the fishing efforts into a single scale. Hence, it is better to express all gears in terms of a single gear (which may be the least efficient or the most efficient) by deriving a suitable multiplication factor for each fishing gear.

Step 5: Calculate the catch per unit effort (gear-wise) as

$$CP_{ij} = \frac{Y_{ij.}}{X_{ij}} \text{ and } \overline{CP}_{i.} = \sum_{j=1}^{t} \frac{CP_{ij}}{t}$$

The multiplication factor is $\overline{CP}_{i.}'' = \frac{\overline{CP}_{i.}}{\overline{CP}_{i.}'}$ where $\overline{CP}_{i.}'$ is the least efficient or the most efficient gear

Step 6: Obtain the standardized fishing effort for k^{th} species at j^{th} time point as

$$\sum_{i=1}^{g} E_{ijk} \times \overline{CP}_{i^{''}.}$$

For ease of computation, an R package named **F**ishing **E**ffort **Sta**ndardization (**FESta**) (Available at https://CRAN.R-project.org/package=FESta) for standardizing the fishing effort was developed. This package provides a function named "StdEffort" for the standardization of fishing effort expended by various fishing gears to obtain the Catch Per Unit Effort (CPUE) for a particular fish species using the time series of the total catch (landings) by each fishing gear, catch (landings) of a particular species (for which the CPUE is required) by each gear and total effort expended by each gear.

To install the FESta package in R, use the following code below:

```
install.packages("FESta")
```

And the usage of the "StdEffort" is:

```
StdEffort(sp_catch, tot_catch, effort, meg)
```

Where,

- sp_catch = Time series of catch/landings of a particular species (for which the CPUE is required) by each gear
- tot_catch = Time series of total catch/landings by each fishing gear
- effort = Time series of total effort expended by each gear
- meg = Most efficient gear (it takes value either FALSE (for least efficient gear) or TRUE (for most efficient gear))

An example of fishing effort standardization is given below:

A list named "Example" has been taken for illustration. It contains three data frames named sp_catch (Quantity of the fish species, in tonnes), tot_catch (Quantity of total catch, in tonnes), and effort (Fishing duration, in hours) with the same dimension.

To standardize the fishing efforts expended by various gears, the following codes can be used:

```
library(FESta)
data("Example")
StdEffort(sp_catch=Example$sp_catc,tot_catch
=Example$tot_catch, effort=Example$effort, meg=FALSE)
```

Remark: It is to be mentioned here that, as the method revolves around an identified gear, be it most efficient or otherwise, as reference amongst the gears with some significant contribution to the species landings may be selected for standardization and the gears with very negligible amount of species catch may be computationally insignificant. This always makes it mandatory to select the candidate gears by a strict rigour of pre-processing before reaching the standardization stage.

(b) Biodynamics model-based framework

(Sathianandan *et al.*, 2021)

The basic surplus production model takes the following expressions, one for the calculation of biomass of a species for successive periods termed as the process equation (Eq. 3) and the other relating biomass to catch and fishing effort known as the observation equation (Eq. 4).

$$B_{t+1}=B_t+r\ B_t\left(1-\frac{B_t}{K}\right)-C_t \quad \ldots\ldots\ldots\ldots 3$$

$$C_t=q\ B_t\ f_t \quad \ldots\ldots\ldots\ldots 4$$

In the multispecies and multigear fishery situation prevailing in tropical regions, a species is usually caught by multiple fishing gears (fishing fleets) and similarly, a fishing gear catches many species. Here, the fishing effort expended by a specific fishing gear results in the catching of many fish species and attributing the total fishing effort expended by the fishing gear to individual species-level effort is a challenging task. This issue is addressed here by incorporating an additional set of gear standardization parameters (λ's with its values summing to unity) in the catch equation in addition to the proportion of catch of the species in the total catch by the gear (Sathianandan *et al.*, 2021). Thus, for each species the expression for standardized fishing effort f_t was derived considering the fishing effort of all the g fishing gears in which the species is caught (Eq. 5). By replacing f_t in equation 4 we get the modified catch equation suitable for the multigear situation (Eq. 6).

$$f_t=\sum_{i=1}^{g} \lambda_i\ P_{i,t}\ f_{i,t} \quad \ldots\ldots\ldots\ldots 5$$

$$C_t=\sum_{i=1}^{g} \left(\lambda_i\ P_{i,t}\ f_{i,t}\right)\ q\ B_t \quad \ldots\ldots\ldots\ldots 6$$

The symbols used for the above models are described below.

B_t	biomass of the stock corresponding to year t
C_t	quantity harvested in year t
$f_{i,t}$	fishing effort in hours spend by fleet type i in year t
$p_{i,t}$	observed proportion of the species/resource in the catch by gear type i in year t
r	the intrinsic annual growth rate in biomass of the species/ resource
q	overall catchability coefficient in catching the species/resource
K	carrying capacity for the species/resource
λ_i	gear standardization parameter introduced for gear type i

The model parameters can be estimated after incorporating the observation error term ϵ_t in the catch equation (Eq. 7). The error terms ϵ_t were assumed to be distributed identically and independently as N(0, σ^2) leading to the expression for the negative log-likelihood (excluding constants) given as equation 8, which was minimised for estimating all the model parameters with $\sum_{i=1}^{g} \lambda_i = 1$ as an additional constraint for λ during minimization.

$$C_t = \sum_{i=1}^{g} \left(\lambda_i\, P_{i,t}\, f_{i,t}\right) q\, B_t\, e^{\epsilon_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

$$\ln(L) = \frac{n}{2}\ln(\sigma^2) + \frac{\sum_{t=1}^{n}\left(\ln(C_t) - \ln\left(\sum_{i=1}^{g}\left(\lambda_i\, P_{i,t}\, f_{i,t}\right) q\, B_t\right)\right)^2}{2\sigma^2} \quad \ldots\ldots 8$$

The model fitness can be assessed using appropriate statistical measures of goodness of fit or by verifying the closeness of the observed landings time series and its model-predicted values.

Conclusions

The standardization of commercial catch and effort data holds significance in fisheries, especially in cases where standardized abundance indices, derived from fishery-dependent information, play a crucial role in stock assessments. The primary objective of standardization is to minimize bias resulting from the intertwining of apparent abundance patterns with fishing power. Fisheries, particularly those where the fleet has undergone changes in fishing technology over time, face a heightened risk of confounding between fishing power and abundance. In tropical marine fisheries, due to varying gear capacities and the potential presence of multiple species in each gear, considering the effort exerted to catch a resource as the simple sum of the duration of fishing operation or units of operation of all gears is not feasible. An attempt has been made in the paper to highlight various effort standardization methodologies found in the literature for different situations, providing insights into the challenges faced in tropical fisheries. It is important to note that the specific methods and models used for standardization can vary based on the fishery, available data, and research/management objectives. Fisheries scientists and managers need to collaborate to determine the most appropriate standardization techniques for a particular study or assessment.

The way forward

In the past few years, there has been an increasing inclination towards the integration of diverse approaches and the amalgamation of various modelling techniques to enhance the precision and dependability of standardized catch and effort data. The selection of a particular method frequently hinges on the distinct characteristics of the data, the research/ management goals, and the computational resources at hand.

Fishing effort inherently also includes the fishing behaviour of fishers, be it in terms of which fish to target based on demand (indirectly fishing ground selection), scouting for fish (part of actual fishing hours) or selection of what fish catch should be retained (which eventually translates into landings). A Bayesian approach to standardizing fishing efforts could be an option to address these uncertainties in fishing effort brought about by fishing behaviour and variability in the standardization process. As the standardization of fishing efforts aims to account for factors such as changes in fishing practices, gear efficiency, and other variables that may affect the observed catch rates, the Bayesian methods provide a flexible framework for modelling these uncertainties and incorporating prior knowledge into the analysis.

Exploring innovative methods to standardize CPUE in anticipation of changing management requirements and fishermen's responses must be carried out. These elements together constitute a holistic strategy to propel advancements in research within this domain, with the overarching goal of refining the precision and applicability of CPUE standardization techniques. Simultaneously, the strategy needs to be designed to ensure flexibility and adaptability to accommodate shifting management needs and the dynamic nature of fishing practices. Assessing the general applicability of currently available CPUE standardization methods in tropical fisheries and identifying the conditions under which they outperform other methods is also important.

Integration of advanced technologies, such as satellite imagery, artificial intelligence, and machine learning may be handy in improving the accuracy and efficiency of measuring fishing effort. This could enhance data collection and provide real-time information for more dynamic standardization models. Incorporation of spatial and temporal dynamics into standardization models to understand how fishing effort varies across different locations and seasons is crucial for accurate stock assessments and sustainable management.

Integrating environmental factors into the standardization of fishing efforts can help to account for influence of environmental variables such as temperature, ocean currents, and habitat characteristics etc. on fish behaviour and distribution thereby fisheries management can better understand and respond to the dynamic nature of marine ecosystems. This strategy extends beyond merely focusing on the target species and considers the broader ecological context.

Refining the standardization models/methods that account for the impact of fishing effort on multiple species simultaneously is necessary especially in mixed-species fisheries where the catch of one species may affect the abundance of others. Future research efforts in the standardization of fishing effort should aim to enhance the robustness, accuracy, and adaptability of methodologies to contribute to the sustainable management of tropical fisheries resources.

Standardization of fishing effort is only a part of the entire assessment process which includes a number of steps starting from fish catch data collection, its collation, correction, analysis, inferences and use of outputs. While researchers attempt to fine-tune each step of the process, efforts also should be made to adhere to a unified, comprehensive and locally attuned process of assessment genuinely reflective of the targeted fishery scenario. For this to happen effectively, a seamless collaboration between fishers, department officials, trade organizations, fisheries researchers, fishery managers and policy makers is needed.

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Brief Communication

Gonad staging for tropical marine finfishes- Good practices and procedures

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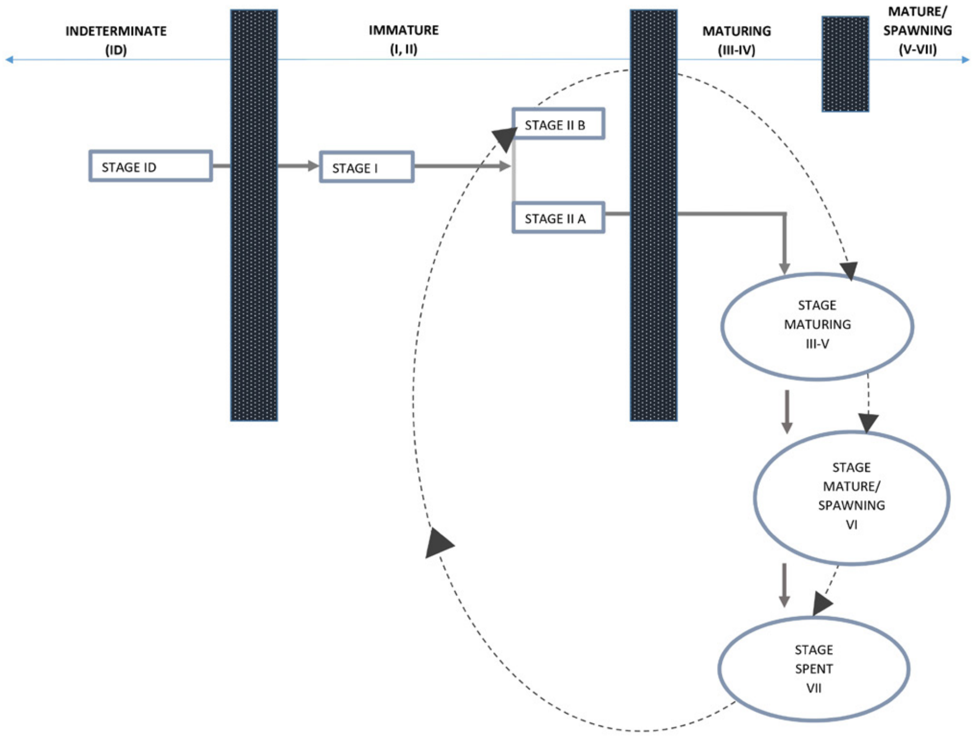
Introduction

Studies on fish reproduction are important as they are related to the regeneration and productivity of the fish populations. The long-term as well as short-term implications of knowledge base on fish reproductive biology for fisheries management, conservation and stock sustainability is increasingly recognized as also the need for collecting such data of various marine fishes with diverse reproductive traits and strategies. In wild capture fisheries information on fish reproduction is crucial in stock assessment exercises and fisheries management decisions that follow. Determining species-specific legal sizes of fish to prevent recruitment (caused by catching too many older fish) or growth (caused by catching too many juvenile fishes) overfishing; seasonal fishing regulations to protect fish spawners, estimating the spawning stock biomass and egg production potential to forecast fisheries production and determine catch limits, if necessary are common approaches to ensure sustainability. Fish breeding programmes in hatcheries also require information on various aspects of reproductive biology of concerned species, as it is related to sourcing of brooders as well as development of a captive broodstock. In all these cases, a simple, consistently used terminology for the various development stages of the fish gonads is essential for comparisons and validation of results across labs and timelines.

Finfish gonad staging

In fishery science, various disciplines typically describe reproductive process at different levels which require an understanding of the context in which they have been used. While whole-gonad development stages take priority in fisheries biology/aquaculture, studies on gamete development related to hormones, stress factors, genetics are more important in fish physiology studies. Fixing the criteria for a fish to be considered as a spawner, based on the cyclical gonad development milestones that apply to all fishes can bring more clarity to fishery biology studies. With specific histological and physiological markers, Brown-Peterson *et al.* (2011) identified and defined critical phases in the reproductive cycle of teleosts, irrespective of their phylogenetic placement, gender or reproductive strategy. Accordingly, fish enter the reproductive cycle (or become sexually mature) when it first becomes gonadotropin-dependant, which enables gonad growth and gamete development. Also, in fishes undergoing multiple spawning, once the fish has attained sexual maturity, it cannot exit the reproductive cycle but re-enters the gonad development cycle through a recrudescence (IIR) stage. Based on this concept, the proposed maturity classification for a sexually differentiated fish will be either of the following states: Immature (stage I & IIA); Maturing (stage III & IV), Mature / Ripe spawner (stages V & VI), Spent (stage VII) and Resting (II-B). The existing species-specific terminologies / stages have to be suitably aligned to this maturity state classification in studies on identification of spawning season, duration and related information.

Studies of fish maturity require large samples that can be easily and rapidly processed which leads to preference for macroscopic staging. While histological validation of the gonad stages is desirable, it is time consuming and expensive. Hence, except for certain species of specific interest, it is seldom employed on a routine basis for all fish species landed. The diagnosis of ovarian development stage at the macroscopic level (gonad appearance, size & colour, development of blood vessels on the gonads, egg size, whole oocyte appearance, gonado-somatic



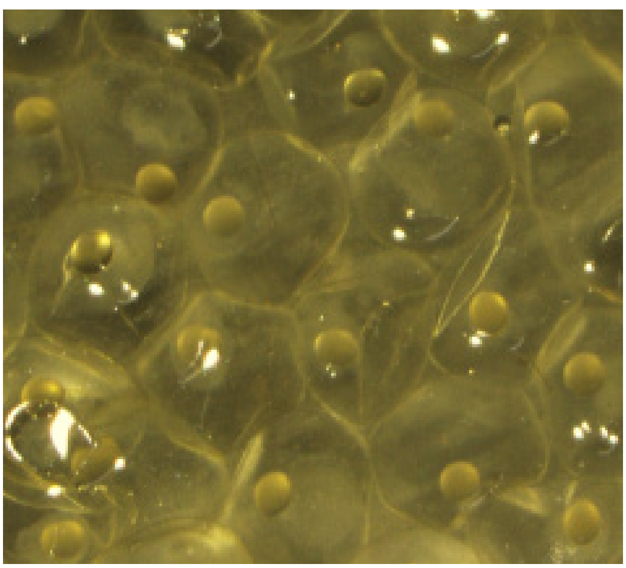
Maturation cycle in fin fishes

index etc.) can be supplemented by microscopic criteria whenever possible (Rhody *et al*., 2013). Most of the bony fishes (teleosts) are gonochoristic, with separate sexes. Initially there is no specific characteristic (Stage 0-Indeterminate/ Undifferentiated with no identifiable gonadal development) associated with the reproductive system. Only at a certain size, through hormonal chemical signaling, the gonadal tissue initiates and completes its differentiation to become physiologically either male or female and the gender of the fish is established. In multiple or continuous spawners, almost all stages of maturity occur in the population throughout the year and hence sampling schemes should ensure that the fishes selected for the analysis are representative of the population on a temporal and spatial scale. Any study that compares species specific spawning trends over time should carefully evaluate the classification scheme followed and ensure that the methodologies reported are uniform to allow such comparisons. Due caution must be exercised in interpreting the observations and reaching conclusions for such comparative studies based on historic databases and secondary information. Also, species specific validated gonad staging through macroscopic and microscopic methods should ideally be prepared for as many species as possible to aid interpretations of seasonal gonad maturation processes.

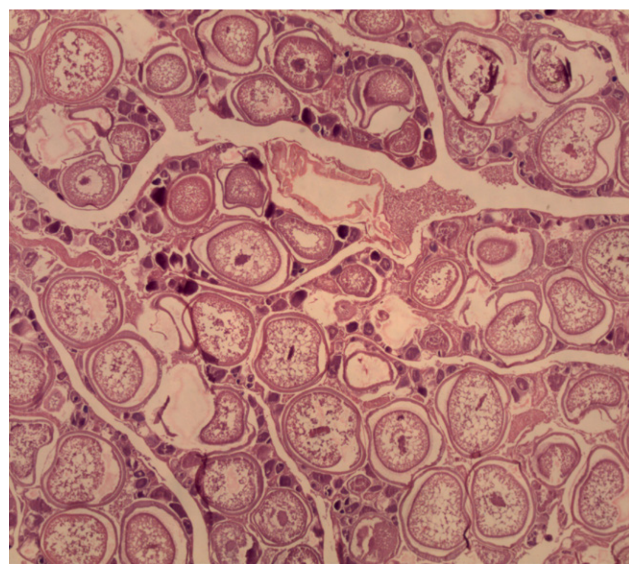
Table 1. Gonad stages of gonochoristic teleost fishes

Stage Number	Stage Descriptor	Macroscopic Stage description	Whole-oocyte appearance	Histology	Gonad identity
Stage 0	Indeterminate or Undifferentiated with no identifiable gonad development	No identifiable gonad	NA	NA	Indeterminate
I Immature	Immature	Small, thin ribbon like transparent ovaries, no blood vessels/ oocytes visible	NA	NA	'Immature"
II A (Immature)	Virgin Developing, never spawned juvenile	Ovaries enlarging, with signs of developing oocytes	oocytes small, transparent and visible under magnification only	Unyolked oocytes in PG phase	

Stage Number	Stage Descriptor	Macroscopic Stage description	Whole-oocyte appearance	Histology	Gonad identity
II R (Regenerating Adult)	Adult but reproductively inactive	Small ovaries with thick ovarian wall, blood vessels and residual eggs inside flabby ovary	Flaccid ovary	Unyolked oocytes in PG phase and more space and interstial tissue around PG oocytes, Post -ovulatory follicles and thicker ovarian wall.	"Resting"
III maturing	Early maturing	Ovaries firm with blood vessels, barely visible eggs present inside.	Oocytes become bigger, numerous small lipid droplets appear.	Oocytes with lipid droplets and cortical alveoli	
IV maturing	Late maturing	Ovaries change colour to deeper tones (red, orange), prominently visible eggs inside. Fully firm and opaque oocytes visible with naked eye, without magnification	oocytes with lipid droplets coalescing progressively	Oocytes with yolk deposition/ vitellogenesis stages (Vtg1 -3)	"Maturing"
V mature	Spawning capable fish (developmentally)	Turgid ovary filling the body cavity and containing ripe translucent oocytes	Oocytes with lipid droplets coalesced and generally, a single oil droplet present	Oocyte maturation process as indicated by germinal vesicle migration and larger oil droplets through coalescence	"Spawning"
VI Ripe/Spawning	Spawning capable fish (developmentally as well as physiologically)	Turgid ovary with transparent oocytes oozing out with slightest pressure	Hydrated oocytes which look transparent	Oocytes with single clear oil globule	
VII Spent (Partially/fully)	Regressing ovaries with cessation of spawning	Flaccid ovaries with prominent blood vessels. Oocytes are few or absent	No hydrated oocytes, post-ovulatory follicles and atretic eggs present	Post-ovulatory follicles and occassionally pre-vitellogenic eggs present.	"Spent"



Hydrated oocyte of a ripe stage cutlass fish *Lepturacanthus savala*



Mature gonad of *Rachycentron canadum* with oocytes in different stages of maturation

Data collection and processing

For following the maturity stages, regular fish samples (monthly, fortnightly or preferably weekly), representative of the population must be sampled. Gonads are to be staged based on macroscopic appearance (colour, shape, size in relation to body cavity, oocyte development stage/diameter etc) with species-specific microscopic (histology sections of gonads) validations, wherever possible. Histology based validation will include oocyte characteristics such as the formation of cortical alveoli, degree of yolk accumulation and nuclear migration in females and the presence/absence and relative proportion of spermatogonia, spermatocytes and spermatozoa in males. For the estimation of spawning season, only the gonads in stage V & VI among the adult, spawning capable females (in Stages III, IV, V, VI and VII) is to be considered (Table 1). Immature fishes that have not entered the reproductive cycle (stage I & II) and spent-recovering adults (IIR stage) with gonads superficially resemble that of a juvenile fish are not included. Based on the monthly percentage of mature fish /spawners, the spawning period and the peaks can be identified based on the formula below.

$$\text{Mature spawners} = \frac{\text{Stages (V+VI)}}{\text{Stages (III+IV+V+VI+VII)}} \times 100$$

Gonad staging in hermaphroditic fishes

Hermaphroditism, defined as the presence of the male and female function (i.e., sperm and egg production, respectively) in the same individual, occurs either sequentially or simultaneously in 34 teleost fish families comprising 370 species. The transition of the functional gonad from one sex to another involves not only the morphological changes in the gonads, but also social and behavioural changes which is manifested as species specific reproductive strategy. Sex change definitions include protandry (individual initially male changes into female later) or protogyny (from female to male) which is the category of "sequential hermaphroditism" and in some cases, bidirectional (individual switches between male and female) which is in the category of "simultaneous hermaphroditism". In the latter, there may be no clear demarcation between the male and female gonadal tissue or a clear demarcation separating the two regions within the ovary (ovotestes), with either male or female tissue dominating at any particular time in a mature fish (Adolfi *et al.*, 2023). Sequential hermaphroditism is explained by a model that predicts sex change occurs when reproductive success of one sex increases more rapidly with size (or age) than for the other eg, reef fishes like serranids, polynemids and sparids. The 'simultaneous hermaphroditism" model suggests that it is associated with low probability of finding a partner and associated reproductive success in certain environments and is common in several deep-sea fish families including lancetfishes (Alepisauridae) and greeneyes (Chlorophthalmidae).

Hermaphroditism is most common in perciform fishes of the families Epinephelidae, Latidae, Lethrinidae, Polynemidae, Pomacentridae and Sparidae. Estimating the spawning season for a sequential protogynous hermaphrodite such as *Epinephelus diacanthus* where female changes sex into male in the early year classes (< 2 years), followed by transitional stage (2-5 years), and males become dominant in higher year classes (> 5 years). Spawning season identification will involve assessment of monthly gonadosomatic index (GSI) of the reproductively capable female (stage III onwards) as monitored throughout the year. The months with higher GSI values and highest percentage of females with ripe gonads (stage V & VI oocytes) among the fishes in stage III and above, can be considered as the spawning season of such species.

Gonad staging in fishes showing parental care

In catfishes, parental care and males incubating eggs in their buccal cavity are indicators of their spawning activity and onset of spawning season. However, they are rarely encountered in commercial catches as possibility of dislodging during capture of the specimens in gears like trawls is high. Peak spawning season of marine catfishes based on macroscopic gonadal staging in female specimens into six identifiable stages based on Vazzoler (1981) is recommended as follows.

Stage 1: Immature

Ovary small, slender & thread-like. The gonads occupancy is less than 1/3rd of the abdominal cavity. The ovary appears whitish or translucent. Oocytes are barely visible to naked eye.

Stage II: Early maturing

Ovary slightly enlarged with occupancy of ½ of the abdominal cavity. Gonads with marginal granulation and oocyte are visible to the naked eye. The ovary appear white to cream colour.

Stage III: Late Maturing

Ovary enlarged especially in anterior portion occupying 2/3rd of the abdominal cavity. Prominent oocyte with whitish yellow colour.

Stage IV: Ripe

Ovary enlarged especially in anterior portion occupying over 2/3rd of the abdominal cavity with prominent presence of blood vessels. Prominently large oocyte with golden yellow colour.

Stage V: Spent

Ovary flaccid and wrinkled with hemorrhagic appearance. The ovary occupying ½ of the abdominal cavity. Heterogeneous in color: some bright colour and some pale cream/whitish.

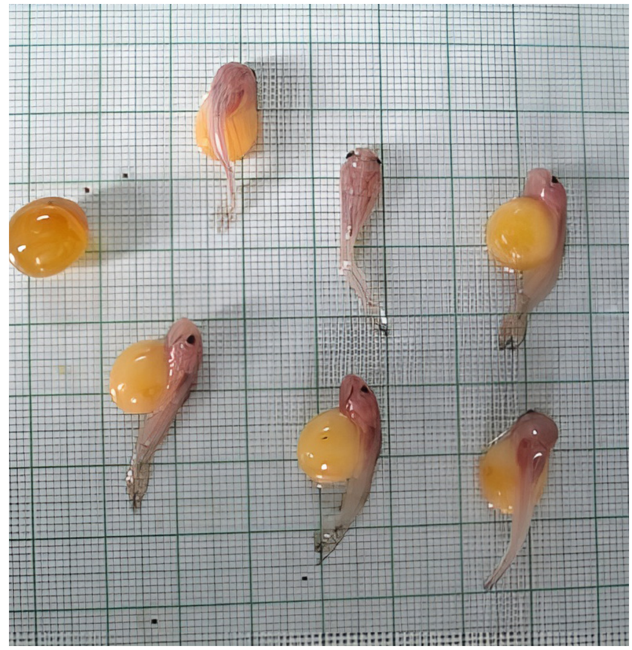
Stage VI: Recovery

Ovary marginally enlarged, ovary occupying > ½ of the abdominal cavity. Oocyte cream to brown colour

$$\text{Monthly mature \%} = \frac{(\text{III} + \text{IV})}{(\text{II} + \text{III} + \text{IV} + \text{V})} \times 100$$

and peak spawning season as months with higher presence of fully mature specimens can be used to identify peak spawning season.

Ripe eggs of *Plicofollis layardi*



Larvae collected from incubating males of *P. layardi*

Fertilized eggs collected from incubating males of *P. layardi*

Gonad staging in elasmobranchs

Elasmobranchs are well known for their wide range of reproductive strategies i.e., viviparous, ovoviviparous and oviparous species; viviparous species are further recognized as exhibiting placental and aplacental viviparity. In viviparous species, embryos develop inside the female's body, and they receive nutrients directly from the mother through a specialized structure called a placenta. Ovoviviparity is an intermediate reproductive strategy where eggs develop and hatch within the female's body, but the embryos rely on yolk sacs, not a placenta, for nourishment. Oviparous elasmobranchs lay eggs. The developing embryos rely on the yolk sac for nourishment until they hatch. Variations among elasmobranchs in the reproductive mode, and the period between consecutive birth events and laying of egg clutches make it difficult to determine the exact maturity stages (Walker, 2005). The meaning of the term "maturity" in recent elasmobranch literature ranges from defining the onset of maturation to the period of time when a female elasmobranch undergoes parturition and produces a litter of pups. Since in many elasmobranch species the period between the beginning of the maturation process until pupping can take some years, it is important to define the term "maturity" in an elasmobranch reproductive study

(Conrath, 2005). The sexual maturity stages in females considered for identifying the reproductive seasons are estimated following the criteria of ICES, 2010 and Serra-Pereira *et al.* (2011) prescribed for viviparous and oviparous species. Females are identified as mature or immature by examining the physical and anatomical condition of ovary with the ova, uterus and oviducal glands as described in the Tables 2&3. The females are considered mature if they are ready to reproduce within a short period of time with the evidence of a current or previous pregnancy. In females that are not pregnant, maturity stages are determined by assessing the ova condition in the ovary, uterus condition and the size of oviducal gland (Conrath, 2005).

Viviparous and ovoviviparous elasmobranchs

For viviparous and ovoviviparous species (Table 2), females in stage 3a or above are considered as mature (ICES, 2010). Mature females have well developed yolky eggs in the ovary, developed oviducal gland and expanded uteri. For estimation of breeding season, we have considered the individuals with stage 3c and 3d where we can determine the timing of the reproductive event by directly observing the reproductive tract and tracking the size of the ovarian eggs (ovarian cycle) and the pups within the uterus (gestation cycle) over the months. The resting phase is determined by comparing the timing of the ovulation and gestation cycles following Conrath, 2005. The mean maximum ova diameter (MOD) is estimated for each sampling month and based on the size of ova diameter the peak ovulation season is calculated. Further the timing and length of gestation of viviparous species is determined by following the size of eggs and embryos found within the uterus through time. The gestation time is also determined by observing the size of embryo at birth and the timing of birth.

The parturition time for the elasmobranchs is considered as the spawning period. The parturition time is estimated by observing the time between the observed females with the largest uterine embryos and smallest uterine eggs. The exact size at birth is validated from data on the smallest free-living individuals observed throughout the year in the fishery. The months with an increase in the number of pregnant females carrying near-term embryos and preparing to give birth and followed by a rise in the number of postpartum females are considered as the parturition months. Also, the month with higher mean size of the embryos in the uterus is also considered as major parturition month for the species.

Monthly maturity percentage for viviparous and ovoviviparous species is calculated as:

$$\text{Monthly mature \%} = \frac{\text{Stages (3c+3d)}}{\text{Stages (3a+3b+3c+3d+4a)}} \times 100$$

Table 2. General classification of gonadal stages for viviparous and ovoviviparous elasmobranchs

Females

Stage	Maturation state	Maturity classification	Gonad characteristics	
			Ovary	Uterus and Oviducal gland
Stage 1	Immature	Immature	Ovaries small and whitish in colour, with undistinguishable ovarian follicles.	Uteri very small in size, narrow, thread like and flaccid. Oviducal glands not visible.
Stage 2	Maturing/ Developing	Immature	Ovaries enlarged with different sizes of follicles sometimes present in anterior part of the ovary and small yolked ova filled in ovary,	Uteri begin to enlarge but mostly thin and flaccid and oviducal glands begin to develop.
Stage 3a	Mature, capable to produce, non-pregnant	Mature	Mature ovaries containing fewer visible enlarged yellow coloured follicles/ova of all same sizes, along with smaller maturing white-yellow oocytes.	Uterus developed but not dilated and without yolky matter and embryo. Oviducal gland developed.
Stage 3b	Maternal, early pregnant	Maternal/Pregnant	Ovaries filled with eggs	Uteri with yolked fertilized eggs and general segments cannot be distinguished and small embryos cannot be observed. Oviducal gland size increases.
Stage 3c	Maternal, mid-pregnant	Maternal/Pregnant	Ovaries filled with eggs	Uteri well filled and rounded often with visible segments and embryos are small in size and visible with relatively a large yolk sacs. Oviducal gland further increase in size.

Females

Stage	Maturation state	Maturity classification	Gonad characteristics	
Stage 3d	Maternal, late pregnant	Maternal/Pregnant	Ovaries with less number of eggs	Uteri with fully developed embryos having reduced yolk sacs or absent. Embryos reach a measurable length and sexed.Oviducal gland fully enlarged.
Stage 4a	Regressing	Mature (spent)	Ovaries shrunk with small amount of eggs and degenerating follicles.	The oviducal glands start to reduce in diameter. Very enlarged uteri, reddish in colour, flaccid and empty having recently released young ones.
Stage 4b	Regenerating	Mature (resting)	Ovary with small follicles in various stages of development along with the presence of degenerating follicles.	Uterus enlarged and flaccid. Oviducal glands very small but distinguishable.

Table 3. Maturity stages classification for oviparous elasmobranchs

Females

Stage	Maturation state	Maturity	Gonad characteristics	
			Ovary	Uterus and Oviducal gland
Stage 1	Immature	Immature	Ovaries small and whitish in colour, without distinguishable follicles.	Uterus narrow, thread- like and flaccid. Oviducal glands are absent.
Stage 2	Maturing/Developing	Immature	Ovaries enlarged with small yellow follicles, sometimes present in anterior part of the ovary.	Uterus enlarged, mostly thin and flaccid and oviducal glands developing.
Stage 3	Mature, non-pregnant/ Spawning capable	Mature	Large mature ovaries containing large follicles/ova of all same sizes,	Uterus and oviducal gland well developed.
Stage 4	Mature, early pregnant/ Actively spawning	Mature/Pregnant	Ovary filled with eggs,	Both uteri with yolked fertilized eggs. In some cases, egg capsules present in the uterus and may attach or not attached to oviducal gland. Capsules may be fully developed, dark in colour, hard / begin to develop. Oviducal glands may contain fertilized yolked eggs.
Stage 5	Mature, Spent/ Regressing	Mature (spent)	Ovaries large with few follicles not covering entire surface.	Uterus and oviducal gland enlarged.
Stage 6	Recovering/ Regenerating	Mature (resting)	Ovary with small follicles in various stages of development.	Uterus and oviducal gland enlarged.

Oviparous elasmobranchs

For the oviparous species, the spawning season is determined by considering only actively spawning females using individuals greater than the minimum length at maturity and looking at the ovaries and oviducal conditions (Table 3). The presence of developing or fully developed hard thickened egg capsules attached to the uterus or to the oviducal glands indicates oncoming parturition time. The months with an increase in the number of pregnant females carrying hard thickened egg capsules attached to the uterus or to the oviducal glands and followed by a rise in the number of postpartum females are considered as the parturition months. These parturition months are considered as the spawning months or season for the species (Serra-Pereira *et al*., 2011)

Monthly maturity percentage for oviparous species is calculated as:

$$\text{Monthly mature \%} = \frac{\text{stage (4)}}{\text{stages(3+4+5)}} \times 100$$

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Brief Communication

Methods for identifying maturity and spawning season in commercial crustaceans: an overview

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Understanding the spawning peaks/spawning seasons of commercial crustaceans is crucial for informing policy decisions related to their management. Maintaining a healthy spawner biomass during the breeding season is a fundamental requirement to ensure the success of the fishery in subsequent years. A field-oriented methodology for identification of the maturity of different crustaceans can aid in determining the spawning season for each species and proposing protective measures for spawners. The identification of spawning seasons for each species can also contribute to making policy decisions regarding the appropriate timing for fishing closures to safeguard the reproductive stock. The recruitment of new individuals into the population ensures a continuous supply of resources for harvesting. Preserving the reproductive stock and preventing overfishing are essential for the sustainability and long-term viability of the fishery.

Coastal penaeid shrimps

The inshore penaeid shrimps are dioecious, and different species have distinct sizes at which they attain maturity. Maturity in inshore penaeid shrimps is classified generally into five stages – Immature (IM), early maturing (EM), late maturing (LM), maturing or ripe (M) and spent (SP) and can be ascertained externally. The ovary extends from the base of the rostrum to the end of the abdomen and consists of the anterior, middle and posterior lobes.

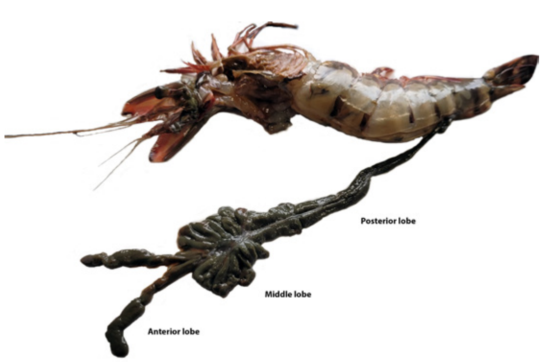
Maturity stages

1. Immature (IM): The ovaries are thin, thread-like, and colourless, and lobes do not appear to be differentiated.

2. Early maturing (EM): The ovary starts showing pigmentation as the lobes of the ovary begin to develop.

3. Late maturing (LM): The anterior and middle lobes expand and acquire a diamond shape; the colour is dark green.

4. Mature (M): In this stage, the anterior and middle portions of the ovary fill up the cephalothorax and the posterior lobe, too, is well formed and occupies all of the abdomen; they are visible as dark green through the exoskeleton.



Ripe ovary in penaeid shrimp ready for spawning

Late maturing and early maturing stages

5. Spent (SP): The appearance of the ovary is similar to that in the immature stage of shrimp, being colourless and, in some cases, with slight pigmentation in the posterior lobe. They are distinguished based on size, those above the size at maturity being spent.

Immature (IM), mature (M) and spent (SP) stages

The late maturing and mature/ripe stages are considered for determining the spawning season in coastal penaeid shrimp. The monthly percentage of these two stages in the total four stages (excluding the immature stage) is estimated, and the months having the highest percentage are the species' peak spawning month/months.

$$\text{Mature \%} = \frac{LM+M}{EM+LM+M+SP} \times 100$$

Where LM – late maturing, M – mature, EM – early maturing, SP – spent stages

Penaeid shrimps spawn throughout the year and may have a secondary spawning peak in addition to the primary spawning peak.

Portunid crabs

In India, the commercial crab fishery is composed of portunid crabs. The majority of these species breed throughout the year along the east and west coasts of India. Male and female crabs can be identified easily from the shape of their abdomen i.e., ventral side of the carapace. In both sexes, the abdomen becomes freely open once the crab attains maturity. If the abdomen is open, one can see two paired pleopods in males and 4 paired pleopods in females. Matured females store sperms in their spermatheca and once the matured ovary releases ova, simultaneously sperms are released and fertilization takes place. The fertilized eggs are released during spawning and they get attached to the setae of the abdominal pleopods, this egg mass is known as 'berry' and the crab with a berry is called a 'berried crab'. A good berry will be compact and rounded in shape and it is attached to the mother till hatching. Newly spawned eggs are bright orange or yellow. The colour of the eggs gradually changes to dull yellow/light brown, then to deep grey, at this stage, eggs are ready for hatching. This duration is the embryonic development period or the incubation period and depending on the size of the berry and water temperature the number of days taken also varies. In Indian waters, it is observed that the developmental period required for portunid species varied between 8-12 days.

Crab with berry on the 1st day of spawning

Same crab on the 10th day of spawning

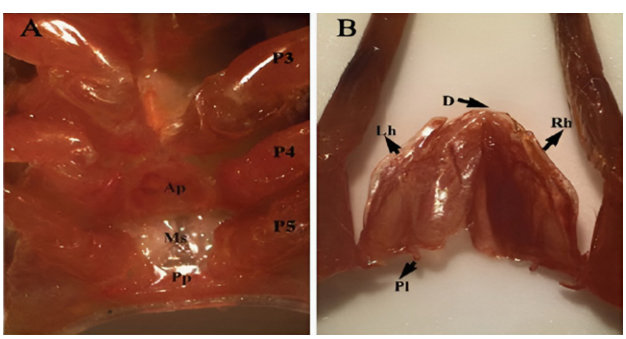
For identifying the spawning period of a commercial crab, the best method is to monitor the occurrence of berried crabs in the landings. Record the number of berried crabs (irrespective of the colour of the egg mass) during the sampling and analyse the month-wise percentage for each species. This is the easiest and most reliable method to record the spawning season of a crab. If we assume the spawning time based on the ovarian stages, there are chances of misidentification of the stages and that may lead to erroneous estimation. Moreover, it is not certain that all the matured ovaries may lead to successful spawning which is dependent on many direct and indirect factors. Hence, the best method to study the spawning period is to monitor the berried females in the landings. This methodology will also help in keeping uniformity in the reporting. This data will give a clear picture of the spawning period of a species in a region. Earlier studies clearly showed that in most of the species, there are major and minor peaks of spawning. The formula to be followed for estimating the percentage of berried crabs is:

$$\text{Berried \%} = \frac{B}{IM+MNB} \times 100 \quad \text{where}$$

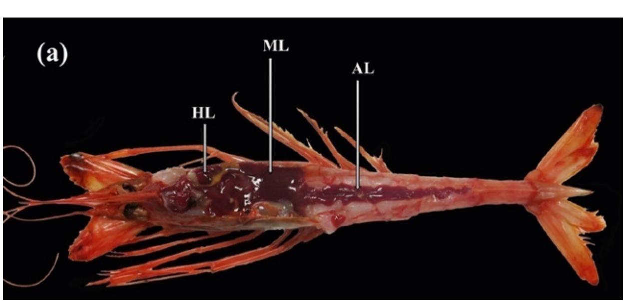
B – berried, IM – immature, MNB – mature not berried.

Deepsea penaeid shrimps– *Aristeus alcocki*

The developmental stages of the ovary are determined by both macroscopic and microscopic analysis. Macroscopic analysis was used to categorize the developmental stages based on the shape, structural dimensions, and colour of the gonads. Five stages were distinguished in females of *Aristeus alcocki.*



Reproductive morphology of *Aristeus alcocki*: ventral view of thelycum (A); P3, third pereopods; P4, fourth pereopods; P5, fifth pereopod; Ap,anterior portion; Pp, posterior portion; Ms, median surface; petasma (B): Lh, left half; Rh, right half; D, distal end; Pl, papilla;



Reproductive organelles: (a) Female (HL-Head lobules, ML-middle lobules, AL-abdomen lobules)

Stage I (Immature-IM)

The ovary is thin, translucent, colorless, tubular, and located postero-dorsally from the carapace to the fifth abdominal segment in two parallel, empty branches.

Stage II (Early Mature-EM)

The ovary size increases, extending antero-posteriorly with light pinkish coloration.

Stage III (Late Mature-LM)

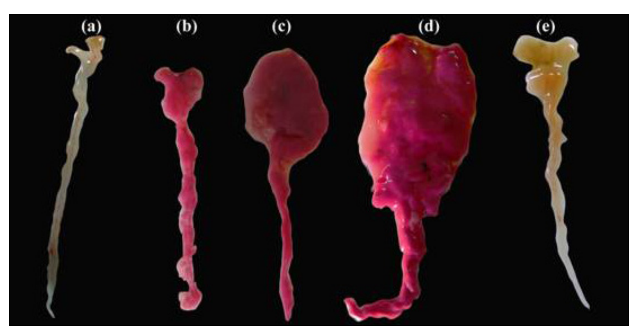
The two lobes of the ovary expand towards the cephalothoracic, hepatopancreatic, and abdominal regions above the gut; pinkish; clearly visible through exoskeleton.

Stage IV (Mature-M)

Ovary dark pink or violet, distinctly visible through exoskeleton from cephalothorax to sixth abdominal segment. The ovary expands, with anterior and middle lobes occupying 50% of cephalothorax.

Stage V (Spent-SP)

After maturation, eggs were extruded and ovary was found to be flaccid and pale white.



Macroscopic view of the ovary in *A. alcocki* during maturation process a) Stage I: IM; b) Stage II: EM; c) Stage III: Late Mature; d) Stage IV: Mature; and e) Stage V: Spent.

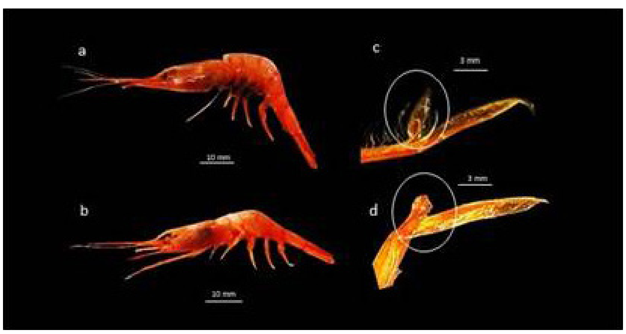
Based on the ovarian development the Mature includes stages III and IV (LM+M) and the peak represents the spawning peak which varies from species to species and with time in deepsea penaeid shrimps. Females are classified into five groups based on ovarian maturation: Stage I: Immature (IM); Stage II: Early maturing (EM); Stage III: Late Mature (LM); Stage IV: Mature (M); and Stage V: Spent (SP).

$$\text{Maturity \%} = \frac{LM+M}{EM+LM+M+SP}$$

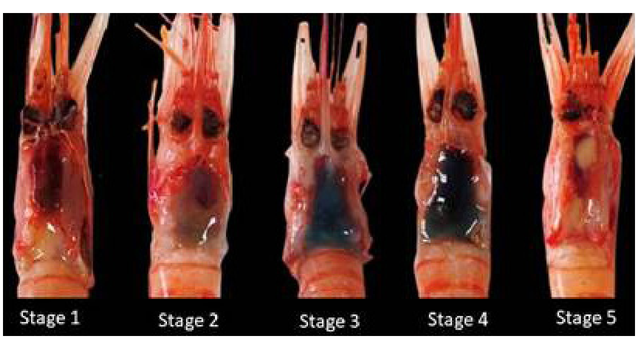
The month(s) having the highest maturity % is considered as peak spawning period.

The Immature (IM) is not included in the calculation of maturity % and spawning peak. The Spent (SP) stage is also not included to calculate the proportion of maturity as the shrimps have already released the eggs and thus not contributing to the spawning peak.

Deepsea non-penaeid prawn– *Plesionika semilaevis*



Ovigerous (a) and non-ovigerous (b) females of *Plesionika semilaevis*, (c) leaf-shaped endopod of first pleopod in females (c) and blunt-shaped endopod of first pleopod in males (d).



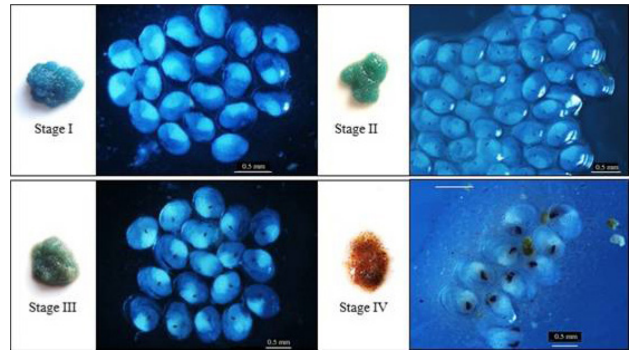
Macroscopic variation in different stages of ovarian development: Stage 1: IM (Immature); Stage 2: EM (Early Mature), Stage 3: LM (Late Mature); Stage 4: M (Mature); Stage 5: SP (Spent)

Calculation of maturity % based on the ovarian development:

$$\text{Maturity \%} = \frac{LM+M}{EM+LM+M+SP}$$

Calculation of maturity % based on the on the berried and non-berried shrimps:

We can classify all the females into three groups
IM=immature= size below the LM50
MNB=Matured but non berried



Macroscopic and microscopic variation in different stages (I-IV) of berried shrimp, *P. semilaevis*. (color of the berry varies from species to species)

B=Berried= all the colours of the berry

$$\text{Maturity \%} = \frac{B}{MNB+B}$$

The month/s having highest maturity % is considered as peak spawning period

Inshore lobster– *Panulirus polyphagus*

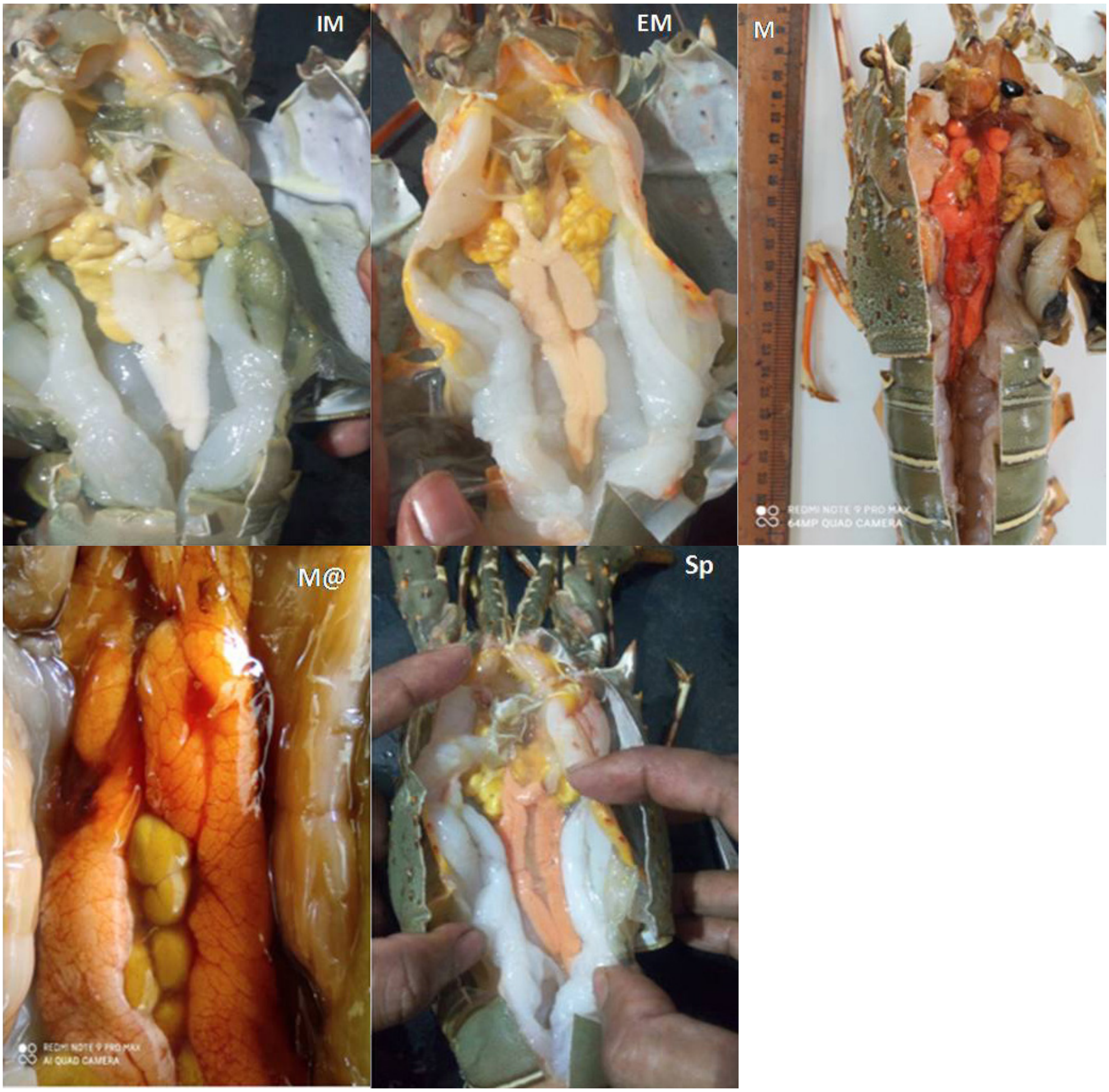
According to Silva and Landim (2006), the developmental stages of ovaries are:

1. Immature stage (IM): Ovaries with slender anterior and posterior lobes restricted to the body cavity. Ovaries are whitish and difficult to distinguish from surrounding muscles.

2. Early maturation stage (EM): Ovaries have grown in volume and extension with pinkish or light yellowish in color, the organ appears distended and firm to touch indicating multiplication of germ cells (early stage vitellogenesis).

3. Mature stage (M): The ovary is fully developed and occupies all available space in the body cavity; it becomes more sinuous and may extend onto the second abdominal segment. The color of the ovary is orange or reddish and the nodes or cysts give the surface a nubbly look.

4. Spawning or resorption stage (SP): After spawning, oocytes and other cells may be resorbed by the ovaries. The gonad becomes transparent and flaccid with pigmented areas and empty spaces internally. The color and size of the ovary are more or less similar to the immature or pre-mature stage.



Ovarian development (IM,SP); immature ovary (IM), early maturation stage (EM), matured stage (M,M@), resorption stage (SP)

Calculation of maturity % based on the ovarian development:

$$\frac{M}{M+SP}$$

Calculation of maturity % based on the development of berry:
Females can be classified into three groups
IM=immature= size below the LM50
MNB=Matured but non-berried
B=Berried= all the colours of the berry

$$\text{Mature \%} = \frac{MNB+B}{IM+MNB+B}$$

Berry- of all colours, (yellow, orange, bright orange, brown/ black) is considered for calculating the spawning peak. Immature specimens are excluded for the calculation of spawning peak. The month/s having highest maturity % is considered as peak spawning period

The methodology reported above may be suitably adopted for all species occurring in the various groups such as deep sea penaeid and non-penaeids and lobsters.

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Economic prosperity and environmental sustainability through seaweed culture

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Introduction

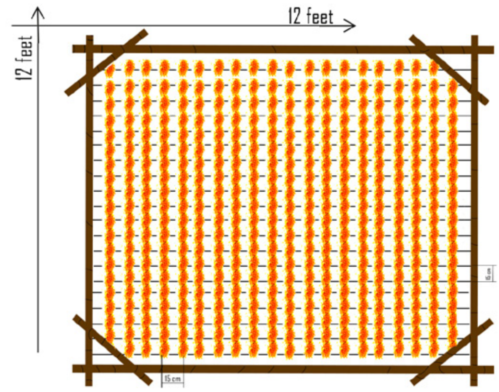
Seaweed farming is a climate-resilient aquaculture practice that provides a sustainable, diversified livelihood option for coastal communities. This cultivation does not require land, freshwater or fertilizers. It reduces the effects of oceanic eutrophication and acidification and oxygenates seawater to create a healthy ecosystem. Seaweeds are valued commercially for their cell wall polysaccharides, such as agar, algin, and carrageenan, and for their bioactive metabolites, manure and fodder. They have a variety of commercial applications in food, pharmaceutical, cosmetics and mining industries. Some seaweeds are also gaining importance as healthy food for human consumption. There are almost 10,000 species of seaweeds available globally that are divided into three main types; red, brown and green seaweeds. India is bestowed with a rich seaweed diversity of nearly 700 species and of these, nearly 60 species are commercially important owing to their high content of polysaccharides. Worldwide, 35.1 million tonnes wet weight of seaweed were produced during 2020, with the first sale value estimated at 16.5 billion USD (FAO, 2022). In India, nearly 47,000 tonnes wet weight of seaweeds are harvested annually from natural seaweed beds (species of *Sargassum, Turbinaria, Gracilaria* and *Gelidiella*) (FRAD, CMFRI, 2023). Estimated Potential Yield of seaweeds from the Indian seas is approximately 0.26 million MT/ year (wet weight) (Kaladharan *et al.,* 2019). India contributes less than one percent of global seaweed production having an annual turnover of around ₹200 Crores. Among the global seaweed production through farming, *Kappaphycus alvarezii* and *Eucheuma denticulatum* contributes to 27.8% of the total seaweed production. Harvesting from natural seaweed beds along the Indian coast is carried out primarily in Tamil Nadu, where the system supports the livelihood of almost 5000 families. In India, seaweed farming is being carried out with *Kappaphycus alvarezii.* It is an economically important red algal species that yields carrageenan, a commercially important polysaccharide. Farming of *K. alvarezii* by the fisherfolk of Tamil Nadu coast had the highest yield; 1,500 tonnes of dry weight, in 2012-13. However, production sharply declined after 2013 due to mass mortality. Approximately 400-500 tonnes of dry weight per year are currently being produced, involving approximately 1,500–2,000 families along the Tamil Nadu coast.

Farming techniques

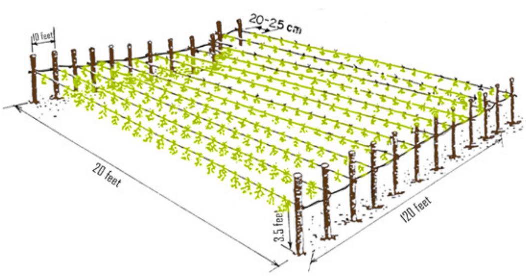
The floating bamboo raft method (12 × 12 feet bamboo poles) is ideal in calm and shallow places. The monoline method of seaweed farming is ideal in places characterized by moderate wave action, shallow depth and less herbivorous fishes. The tube net method is being adopted in places with higher wave actions.

Economics of *Kappaphycus* farming

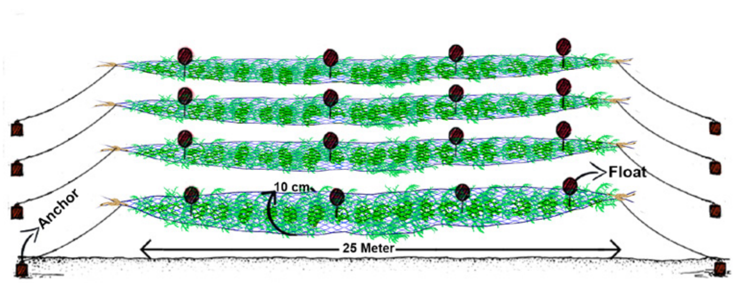
The crop duration for *Kappaphycus* farming is 45-60 days. In a year, four to six crops or cycles (6 to 9 months) can be harvested depending upon the climatic conditions.



Bamboo raft method



Monoline method



Tube net method

Harvested seaweed *Kappaphycus alvarezii*

After seeding, 150 g of plants were grown to 500 to 1000 g in 45 days. The average seed requirement for one 12 × 12 ft raft is 60 kg, whereas for a 25 m long tube net, the average seed requirement is 15 kg. The average dry weight percentage of the harvested seaweed was 10%. Farmers currently receive ₹16/- to ₹18/- and ₹80/- to ₹110/- per kg for fresh and dried seaweed, respectively.

Table 1. Economics of *Kappaphycus alvarezii* farming in bamboo raft system

Components	Details/Cost
Seaweed production: 1,000 kg/raft/year minus 240 kg, which is used as seed material for 4 crops/year	760 kg (wet weight)
Price of seaweed	₹96/ kg/dry weight (Dry weight = 10% i.e., 76 kg)
Total revenue generated	₹7,296/year/ raft @ ₹96/kg/dry weight
Total cost of production (including capital cost)	₹2,000/raft/year
Net revenue	₹5,296/raft/year (₹7,296 minus ₹. 2000)
Total Net revenue (45 rafts*) in dry weight	45 x Rs 5,296 = ₹2,38,320/year
Net revenue from one hectare (400 rafts) in dry weight	₹21,18,400/year

*A person can handle an average of 45 rafts (12 ft x 12 ft)

Economics of *Gracilaria* farming

Seaweed farming trials by ICAR-CMFRI on various islands of the Lakshadweep since August 2020 under the ICAR-sponsored National Innovations in Climate Resilient Agriculture (NICRA) revealed a promising daily growth rate for the indigenous red algae *Gracilaria edulis* and *Acanthophora spicifera*. The experiments focused on farming using PVC net cages, PVC rafts and bamboo rafts. To scale up the trial farming to a large-scale demonstration with people's participation, the Lakshadweep Administration has initiated a commercial-scale demonstration programme involving women Self Help Groups (SHGs) and the seaweed industry with the technical support of the ICAR-CMFRI.

Bamboo, a natural material, was preferred for the scaled-up demonstration of *G. edulis* by the Lakshadweep Administration. However, grazing by green turtles and fouling by filamentous algae are deterrents in bamboo raft-based farming. The crop duration of *G. edulis* farming is 45 days, and five to six crops or cycles (9 months) can be harvested in a year depending on the weather conditions. After being seeded, 50 g of plants reached 500 to 1500 g in 45 days. For one 12 × 12 ft raft, the average seed weight requirement is 20 kg. The average dry weight percentage of the harvested seaweed was 15% and the farmers receive ₹60/- per kg of dried seaweed.

Harvested seaweed *Gracilaria edulis*

Table 2. Economics of *Gracilaria edulis* farming

Components	Details/ Cost
Seaweed production (average 20 folds growth)	2400 kg/raft/year minus 120 kg as seed material for 6 crops/year = approximately 2,280 kg (wet weight)
Dry seaweed (Dry weight = 15%)	342 kg
Price of seaweed	₹60/ kg/dry weight
Total revenue generated	₹20,520/year/ raft @ ₹60/kg/dry weight
Total cost of production (including capital cost)	₹3,600/raft/year
Net revenue	₹16,920/raft/year (₹20,520 minus ₹3,600)
Total Net revenue (25 rafts*) in dry weight	25 x ₹16,920 = ₹4,23,000/year
Net revenue from one hectare (400 rafts) in dry weight	₹67,68,000/year

*A person can handle an average of 25 rafts (12 ft x 12 ft)

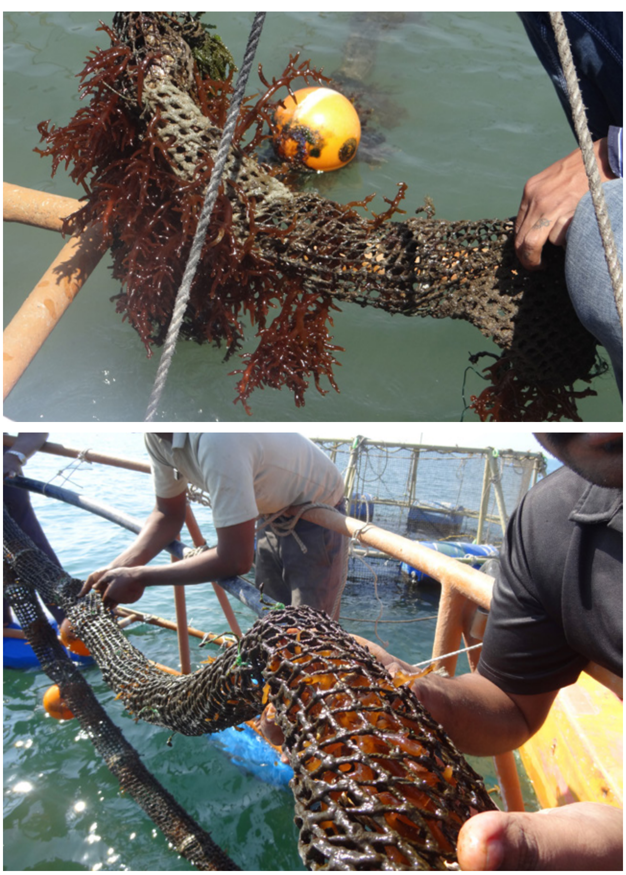
Net-tube integrated seaweed farming at sea cage sites

The cultivation of seaweed has increased in popularity in recent years, which has led to the development of innovative and cutting-edge farming methods. Among several traditional methods of seaweed farming, the net-tube method is the most advanced technique and can be successfully carried out even under extreme weather conditions involving high wind speeds and water currents. It functions effectively in harsh environmental conditions because of its tube-like structure and superior exchange to conventional seaweed techniques, giving it an edge. When the net tube technique is combined with open sea cage farming, such as in Integrated Multi-trophic Aquaculture (IMTA), seaweed grows faster than in a net tube monoculture. Bamboo rafts and the monoline method for seaweed farming are being adopted predominantly along the Tamil Nadu coast. The tube-net method is ideal for coastal states such as Andhra Pradesh and Gujarat.

Net-tube seaweed farming has overwhelmingly favourable socioeconomic advantages, as it involves resource integration and maximum utilization, benefitting fisher folks. Many community-based coastal resource management programmes and fisheries management initiatives have also included this farming technique as an alternate subsistence for fishermen in tropical developing countries. In light of this, it is rational to advocate for seaweed net-tube farming inside sea cages. Net tubes can be further promoted under the Pradhan Mantri Matsya Sampada Yojana (PMMSY)–a scheme to bring about the Blue Revolution via sustainable and responsible development of India's fisheries industry, which can improve resource utilization and help generate more revenue.

Seaweed, *Kappaphycus alvarezii* cultivation using High Density Poly Ethylene (HDPE) raft-based tube net culture method for unprotected sea

Seaweed culture in exposed unprotected sea with dynamic coastal system is not popular like calm and nearshore waters in India due to unavailability of suitable and sturdy faming



Net tube seaweed farming

technology. The floating bamboo raft and monoline methods commonly practiced in India are well adopted and suitable for calm and shallow areas with minimum tidal influences, and these bamboo rafts generally cannot withstand high wave action. Also, seaweeds seeded in monolines are directly exposed to the rough waters, and can get easily damaged. Thus, keeping in hindsight the physical forces existing in tropical marine waters, an innovative High Density Poly Ethylene (HDPE) raft-based tube-net method supported by grid mooring is designed for culturing of *Kappaphycus alvarezii* in adverse climatic conditions prevailing in mainly North East and North West coast of India. This method was tested in the North East coast, off Visakhapatnam and was found suitable to withstand rough weather conditions. High Density Poly Ethylene (HDPE) pipes of 90 mm outer diameter is used to prepare the square shaped (3 x 3 m) floating raft. Short length tube-net (3.0 m in length) is prepared by using HDPE net material for holding growing seaweed. Seeds of 5.0 kg/tube net is seeded separately in each tube net, and 10 different tube nets were attached in one raft structure. Cluster of rafts (25 nos.) were anchored by multi point mooring system with the help of dead-weight permanent anchors made of concrete cement blocks. The five concrete blocks in each corner of the grid are inter-connected with the help of long-link alloy steel mooring chain (13 mm diameter, 80 grade quality). The mooring chain is connected at the top, to the floating HDPE raft with the help of D-shackles. Prior to connection with the raft, fibre reinforced plastic (FRP) cans are attached to the mooring chain at every corner to facilitate chain floatation. It has been observed that the seaweed seeded with approximately 5 kg/tube net helps to yield a production of approximately 30 kg. A total of 300 kg /raft consisting of 10 tube nets could be obtained. Therefore, *K. alvarezii* can be cultured for six cycles in a year with 45 days of culture period/crop. This culture method yields approximately 45,000 kg of seaweed/year/cluster of 25 raft with a net profit of 1.53 lakhs/year/cluster of 25 rafts.

Carbon sequestration potential of farmed seaweed

An experiment involving the culture of seaweed (*K. alvarezii*) from three bamboo rafts was conducted to estimate its carbon sequestration potential in Munaikadu, Ramanathapuram district, Tamil Nadu. For each of the rafts (12 ft × 12 ft), three pre-weighed bunches of seaweed were tagged, and their weights were periodically (once in 15 days) measured. Furthermore, subsamples from each bunch were collected, dried and preserved. The samples were analysed for their

HDPE raft-based tube net culture method for *Kappaphycus alvarezii*

carbon content using a CHN- elemental analyser. The average carbon and nitrogen content was 19.92% and 0.99%. The specific growth rate of the seaweed was multiplied by the percent composition of carbon (C) and 3.667 (mass of CO_2= 44/mass of C= 12), which provided an estimate of the specific rate of sequestration (per unit mass of seaweed per unit time) of carbon dioxide by the seaweed. The specific rate of sequestration of CO_2 per gram dry weight of seaweed was 0.018673 g day^{-1} (0.02557 x 0.19915 x 3.667). The specific rate of sequestration (per unit mass of seaweed per unit time) of CO_2 by the seaweed was estimated as 19 kg CO_2/day/tonne dry weight of *K. alvarezii* (= 760 kg CO_2/day/tonne dry weight/ha). The total amount of carbon sequestered in one tonne of dry seaweed can be estimated by multiplying the quantity of dried seaweed by the percent composition of carbon (C). Hence, the total amount of carbon sequestered in one tonne of dry seaweed is 199.2 kg (1000 x 0.1992).

Integrated Multi-Trophic Aquaculture (IMTA)

Intense fishing pressure along coastal waters, coupled with the negative impacts of climate change, has recently started impacting the livelihoods of fishers. While harvests are dwindling, the demand for marine fish is increasing steadily owing to the crucial role of marine fish in ensuring food and nutritional security. This necessitates augmenting marine fish production through the farming of promising commercial species of fish in the sea. Realizing this important priority, ICAR-CMFRI has developed and standardized technologies for the seed production and farming of marine finfishes and shellfishes in open sea cages. One of the anticipated issues while expanding sea cage farming is the possible increase in organic and inorganic loads in water and consequent disease problems. In this context, the idea of bio-mitigation along with increased biomass production can be achieved by integrating different groups of commercially important aquatic species that have varied feeding habits. This concept is known as Integrated Multi-Trophic Aquaculture (IMTA), which has recently gained global importance. ICAR-CMFRI has successfully conducted trials and demonstrated IMTA under the NICRA project by integrating seaweed with sea cage farming of marine finfishes/shellfishes in Tamil Nadu, Gujarat and Andhra Pradesh. This has resulted in an increased production of seaweed, which has improved the livelihood of farmers and contributed to the increase in carbon availability in the country.

Table 3. Economics of IMTA (comparison of integrated and non-integrated seaweed farming)

Particulars	With IMTA	Without IMTA	Gain
Average yield per raft on fresh weight basis (45 days/cycle)	390 kg	250 kg	+ 140 kg
Fresh seaweed production excluding the seed material–60 kg per raft (for 4 cycles, 16 rafts)	21,120 kg (330 X 16 X 4)	12,160 kg (190 X 16 X 4)	+ 8,960 kg
Dried seaweed production (for 4 cycles, 16 rafts) (Dry weight = 10%)	2,112 kg (33 X 16 X 4)	1,216 kg (19 X 16 X 4)	+ 896 kg
Price of dried seaweed (₹ per kg)	96.00	96.00	-
Revenue (₹)	2,02,752	1,16,736	+ 86,016
Costs (₹2,000 /raft)	32,000	32,000	-
Net Profit (₹)	1,70,752	84,736	+ 86,016

Aerial view of IMTA farm at Mandapam

ICAR-CMFRI has promoted cage farming of cobia, a high-value marine fish, since 2010. To achieve environmental sustainability and economic stability, the innovative idea of integrating seaweed with sea cage farming of cobia was demonstrated during 2014-17 at Munaikadu, Palk Bay, Tamil Nadu. A total of 16 bamboo rafts (12×12 feet) with 60 kg of seaweed per raft were integrated for a span of 4 cycles (45 days/cycle) i.e., 180 days along with one of the cobia farming cages (culture period 7 months i.e., 210 days). The rafts were placed 15 feet away from the cage in a semicircular manner to enable the seaweed to absorb the dissolved inorganic and organic nutrient waste that moves along the water current from the cage.

Currently, through IMTA, seaweed rafts integrated with cobia farming cages have a better average yield of 390 kg per raft, while in non-integrated rafts, the yield is 250 kg per raft. An additional yield of 140 kg of seaweed per raft (56% additional yield) was achieved through integration with the cage farming of cobia. Under traditional methods, 1 kg of seaweed grows to 4.1 kg in 45 days. However, the application of IMTA substantially enhanced this growth rate, with seaweed reaching an impressive ~6.4 kg in the same timeframe. An additional net income of ₹86,016/- was generated through the integration of seaweed rafts with cobia cages (Table 3). Carbon dioxide sequestration (per unit mass of seaweed/day/16 rafts/4 crops) into the cultivated seaweed in the integrated and non-integrated rafts was calculated as 47.4 kg CO_2/day/tonne dry weight of *K. alvarezii* vs 30.4 kg CO_2/day/tonne dry weight. Hence, an additional 17.0 kg of CO_2/day/tonne dry weight credit was obtained through the integration of 16 seaweed rafts (4 cycles) with one cobia farming cage (per crop) (Table 4). Thus, in one hectare area, a total of 20 cages of 6 m in diameter can be integrated with 320 bamboo rafts (12× 12 feet) @ 16 bamboo rafts per cage. IMTA is an eco-friendly option ensuring sustainable income for coastal fishers. It is also one of the significant mitigating measures for reducing the adverse impacts of climate change and earning carbon credit in our country.

Table 4. CO_2 sequestration into the cultivated seaweed in the integrated and non-integrated rafts

Particulars	With IMTA	Without IMTA
Fresh seaweed production in tonnes (for 4 cycles of 45 days each, 16 rafts)	24.96 (390 X 16 X 4)	16.00 (250 X 16 X 4)
Dried seaweed production in tonnes (10% of fresh weight)	2.496	1.6
Specific rate of sequestration of CO_2 by the seaweed in kg CO_2/day/tonne dry weight	19.00	19.00
Total amount of CO_2/day/tonne dry weight of *K. alvarezii* sequestered (per unit mass of seaweed /day/16 rafts/4 crops) (2) × (3)	47.4 kg	30.4 kg

Nitrogenous waste removal by seaweeds

The nitrogenous waste removal amounts from the integrated and non-integrated seaweed were 2.49 kg and 1.59 kg, respectively. Hence, an additional 0.9 kg of nitrogen removal was achieved by integrating one cobia farming cage (per crop) with 16 seaweed rafts (4 cycles) (Table 5).

Table 5. Nitrogenous waste removal by seaweeds

Particulars (180 days)	With IMTA	Without IMTA
Fresh seaweed production in tonnes (for 4 cycles, 16 rafts)	24.96 (390 X 16 X 4)	16.00 (250 X 16 X 4)
Dried seaweed production in tonnes (10% of fresh weight)	2.496	1.6
Percentage nitrogen content in dry seaweed	0.996	0.996
Total amount of nitrogen removed during the culture period (2) × (3)	2.49	1.59

Fish carbon

The carbon biomass in the integrated and non-integrated cobia cages were 729.56 kgs= 2675.7 kg CO_2 and 583.11 kgs= 2138.1 kg CO_2 respectively. Hence, an additional 147 kg of carbon credit was generated by integrating one cobia farming cage (per crop) with 16 seaweed rafts (4 cycles). Comparatively, the fish biomass increased 14 per cent in cobia cultured with IMTA compared with those cultured without IMTA (Table 6).

Table 6. Fish carbon in the IMTA system

Particulars (210 days)	With IMTA	Without IMTA
Cobia production in kgs	3,316	2,651
Cobia production in kgs dry weight (Average moisture content of fish is 60%)	1,326.48	1,060.2
Carbon content	729.56	583.11
(Average carbon content of fish is 55% of dry weight)	(55% of 1,326.48)	(55% of 1,060.2)
Carbon content (in kg CO_2 equivalent)	2,675.7	2,138.1

Nitrogenous waste removal by fish

The nitrogenous waste removal amounts from the integrated and non-integrated seaweed were 26.53 kgs and 21.20 kgs, respectively. Hence, an additional 5.30 kg of nitrogen was removed by integrating seaweed with cobia (Table 7).

Table 7. Nitrogenous waste removal by fish

Particulars (210 days)	With IMTA	Without IMTA
Cobia production in kg	3,316	2,651
Cobia production in kgs dry weight (Average moisture content of fish is 60%)	1,326.48 (2% of 1,326.48)	1,060.2 (2% of 1,060.2)
Total amount of nitrogen released during the culture period	26.53	21.20

Water quality parameters of the non-integrated and integrated systems

The water quality parameters of the integrated systems are better than those of the non-integrated farming system.

Table 8. Average water quality parameters of the IMTA system

Parameters (210 days)	Non-integrated		Integrated
	Cobia-Control	Seaweed-Control	Cobia+ Seaweed
Water temperature (^{o}C)	30.6 ± 2.7	29.8 ± 2.5	29.0 ± 2.1
pH	8.2 ± 0.1	8.1 ± 0.1	8.1 ± 0.1
Salinity (ppt)	34.4 ± 0.5	34.6 ± 0.5	34.6 ± 0.5
Dissolved oxygen (ml/l)	5.2 ± 0.2	5.7 ± 0.3	5.8 ± 0.5
Nitrite (mg-at- NO_2-N/l)	0.00313 ± 0.001	0.00272 ± 0.001	0.00161 ± 0.0007
Nitrate (mg-at-NO_3-N/l)	0.724 ± 0.115	0.580 ± 0.223	0.265 ± 0.100
Phosphate (mg-at-PO_4-P/l)	0.024 ± 0.014	0.012 ± 0.012	0.018 ± 0.013
Silicate (mg-at- Si/l)	0.0160 ± 0.009	0.002 ± 0.001	0.005 ± 0.001
Ammonia (mg-at- NH_3-N/l)	0.046 ± 0.012	0.044 ± 0.008	0.018 ± 0.006

Doubling farmers income

Integrating seaweeds into cage farming systems has proven to enhance fish farmers income as detailed here. In a regular cage culture system with cages of 6 m in dia. x 5 m depth and with either Indian pompano, silver pompano, grouper, cobia, snapper, or rabbit fish as farmed species for a duration of 7-8 months, the annual gross revenue for 2 cages was estimated as ₹17.5 lakhs and the net revenue was estimated as ₹7.0 lakhs. Integrating this cage culture system with seaweeds *i.e.,* 32 seaweed rafts along with 2 cages of fish results in an additional gross revenue of ₹4.79 lakhs from the seaweeds alone. The net revenue after reducing the cost of production (0.64 lakhs) was ₹4.15 lakhs. Thus, integrating seaweeds resulted in enhancement of farmer's income by 60 per cent.

Similarly integrating marine ornamental fish rearing with seaweed culture has also proven to be more beneficial to farmers in terms of economic returns as detailed here. For *Kappaphycus alvarezii* farming in 45 rafts of 12 x12 feet dimension for a culture period of 45 days (4 cycles of culture of 45 days each) the annual gross revenue was estimated as ₹3.28 lakhs and the net revenue was 2.38 lakhs. Integrating ornamental fish rearing along with this seaweed farming system resulted in an additional gross revenue of ₹4.6 lakhs. The ornamental fish rearing system details are as follows: 8 glass tanks of 150 litre each stocked with clown fish at 50 numbers (fish of half inch size) per tank for a rearing period of 60 days for a total of 6 rearing cycles in a year. The annual gross revenue from the ornamental fish was ₹4.6 lakhs and after reducing cost of production (₹2.0 lakhs) the annual net revenue was ₹2.6 lakhs.

Thus, in this integrated system of seaweed and ornamental fish, the economic returns to farmers were enhanced by 109%. Hence, both these types of integrated seaweed farming systems can be promoted as approaches for doubling farmers' income in the coastal regions of the country.

Awareness and outreach programme on the PMMSY

Owing to the importance of seaweed farming, the Government of India is promoting seaweed farming through Pradhan Mantri Matsya Sampada Yojana (PMMSY) by providing financial, marketing and logistical support to ensure income and welfare gains for small fisher populations, especially women- and fisherwomen-headed households. To reach the fishing community at the village level, ICAR-CMFRI has been conducting a series of awareness-cum training programmes on Pradhan Mantri Matsya Sampada Yojana (PMMSY) and seaweed farming. This has created interest among many farmers/entrepreneurs in adopting seaweed farming. Since 2021, a total of 94 training programs involving 8,896 participants have been organized on seaweed farming for the promotion of seaweed cultivation.

Fishermen being sensitised on seaweed and IMTA farming

Promoting seaweed farming

ICAR-CMFRI, which has implemented the Scheduled Caste Sub-Plan (SCSP), NICRA-SCSP, AINP-SCSP and other programmes, provides inputs and technical assistance for seaweed farming activities. A total of 207 families (414 fishers) have directly benefited from this programme and were undertaking seaweed farming on 2,520 rafts along the Tamil Nadu coast.

Promoting seaweed farming activity through Scheduled Caste Sub-Plan (SCSP) Programme

The way forward

Need for large-scale seaweed farming

The domestic requirements for agar and alginate are approximately 400 tonnes per annum and 1,000 tonnes per annum, respectively, whereas only 30% and less than 40%, respectively, of these materials are produced indigenously. The domestic requirement for carrageenan is 1,500-2,000 tonnes/year. Considering the demand for agar, alginate and carrageenan, the total annual seaweed requirement on a dry weight basis is 4,000 tonnes of agar yielding algae, 5,000 tonnes of alginate yielding algae and 4,500–6,000 tonnes of carrageenan yielding algae (Johnson *et al.,* 2023). Hence, to attain self-sufficiency in seaweed-based products, large-scale farming needs to be promoted.

Marine spatial plans

In view of the emerging importance of seaweed mariculture, an all-India preliminary survey for the selection of sites suitable for seaweed farming was conducted by ICAR-CMFRI using approximately 15 parameters across all the maritime states of India. ICAR-CMFRI identified 24,251.9 hectares of potential seaweed farming area (a spatial map of 333 locations with geo-coordinates along the Indian coast within a 1000 m distance from the lowest low tide line) through coastal surveys and remote sensing data analysis (Johnson *et al.*, 2020: Johnson *et al.*, 2023). Out of the 333 sites, trial farming activities were carried out at 78 sites. These sites can yield a maximum of 9.7 million metric tons of seaweed (wet weight) annually, facilitating the country's imminent expansion and effective adoption of seaweed farming. ICAR-CMFRI has also provided a "decision support spatial suitability map for Seaweed Farming in India" (Divu *et al.,* 2021). In line with such studies, a detailed spatial suitability map of seaweed farming sites along the Indian subcontinent along with island systems is essential, and the first step is to cater to the targets anticipated by the nation through commercial farming activities. Hence, prioritization of marine space usage through marine spatial planning is highly essential for creating an investor-friendly atmosphere for seaweed farming augmentation through joint collaboration with maritime state governments since fisheries are a state subject according to the Indian constitution. Apart from these, the most critical factor that must be considered before concluding must be the stakeholder perspective, which in turn must be obtained through various consultation meetings along the country's coastal villages.

Improvement in the quality and quantity of seaweed seed material

The scarcity of quality seed material for *Kappaphycus* cultivation in coastal areas and quality seed materials of native species such as *Gracilaria edulis, Gracilaria dura* and *Gracilaria debilis,* especially after monsoon rains, are the major bottlenecks for the development of seaweed farming in our country. To address this issue, importing high-yielding species/varieties and establishing seedbanks to improve the availability of quality seed material to support farming activities are needed. As a national interest, ICAR-CMFRI has planned to convert four RCC tanks, each with a 1000 tonnes water holding capacity, at the Mandapam Regional Centre for quality seaweed seed production. The dimensions of the three tanks are 30 m×14 m×2.3 m, and one tank is 35 m×15 m×2.3 m. A total of 200 tonnes of *Kappaphycus* seeds per year can be produced and supplied from this facility.

Quality seaweed seed materials

Vegetative cuttings obtained from earlier harvests or from seedlings in natural beds have been extensively utilized in modern seaweed farming. However, there are significant drawbacks to this farming technique, including diminished genetic variability and physiological variance in the seed stock, which lowers the seaweed growth rate, carrageenan yield, and gel strength. Seaweed aquaculture requires more innovative methods than ever before to meet growing worldwide market needs. Large-scale seaweed production continues to face substantial challenges, primarily related to the availability of seedlings for year-round marine farming. As a result, high-quality seedling materials are required for continuous biomass production throughout the year.

Seedlings from natural beds and vegetative propagation

In this method, fragments from plants are used as seeding material and are collected by leaving the basal portion for regeneration.

- The seedlings that need to be harvested should not have any grazing or a whitened thallus (which might indicate disease), and they should be brittle, shiny, and have young branches with sharp pointed tips.

- After sowing, similar to *K. alvarezii* plants, which are farmed through vegetative propagation, healthy seedlings should be collected, preferably from the young portion of the plant, which has more apical portions. If seedlings are taken from other districts/states, they should be placed in a clean net bag and kept at the bottom (1-2 m depth) of the sea for a few days before planting.

- A scalpel was used to collect small, wiry plants, such as *Gelidiella acerosa,* that were firmly connected to the substrate.

- Lengthy plants such as those of the *Sargassum* and *Turbinaria* can be easily collected by hand alone. Handpicking is an effective method for gathering the intertidal and shallow water plants such as *Caulerpa racemosa*, *Ulva lactuca* and *Enteromorpha compressa*, *Acanthophora spicifera* and *Hypnea valentiae* are also handpicked.

- *Gracilaria edulis* grows up to 1-2 m below the surface. It grows as epiphytes on seagrasses, pebbles, and small stones. It is thin and simple to remove from the substrate.

- The seed materials are gathered in seawater-filled plastic buckets, polythene bags, or gunny sacks. For long-distance transit by road, the water conditions would constantly change.

- In the case of seaweed farming unit, if the field conditions are favourable for further cultivation, the remnants of the first harvest are allowed to grow further, or a portion of the harvested material is used as seed material for succeeding crops after the material is brought to the shore and transferred to a plastic bin or FRP tank containing clean seawater.

- The seed materials were collected in gunny bags, polythene bags or plastic buckets containing seawater. Frequent change of water is required on the way for long-distance transportation.

Seedlings through spore production

Spores are typically cultured on an artificial substrate and maintained in a land-based seedling-rearing facility until they reach the appropriate plantlet size for transplantation. The plantlets were attached to ropes and released into the open sea for field cultivation. This method can provide a reliable supply of seedlings for seaweed farming. The reproductive ability of seaweed species largely determines their efficacy. Reproductive cells (spores or gametes) have been used to propagate species with high reproductive potentials, such as the *Pyropia, Ulva, Saccharina, Undaria* etc. Using spores to produce seed is one possible way to increase production and improve cultivation techniques.

- Researchers may develop a combination of various abiotic factors to induce reproductive maturity and eventual sporulation independent of the natural life cycle based on their understanding of the reproductive biology of seaweed.

- Carpospores are easier to use as a seed source because the naked eye can observe their spore sacs (cystocarp). The use of spores as a source of seedlings has been successful in several countries. However, rigorous, long-term experimentation is needed to optimize the conditions that can trigger maturity and sporulation in a given species.

- Thus, for industrial seedling production, it is critical to use optimum culture conditions to manage the development and reproduction of species-specific conchocelis cultures.

- However, the environmental cues that induce fertility and spore/gamete release in this species are difficult to detect, necessitating a fundamental understanding of the underlying biological mechanisms that control the rate of embryo formation and reproductive cycles for successful cultivation. Indeed, an alternative seedling production system that does not rely on vegetative fragments or reproductive cells is expected to address these issues.

Vegetative fragments or reproductive cells (spores or gametes) are principally employed in seaweed farming as a source of propagation in plants (propagules). For such types of seaweed, vegetative reproduction has been successful, especially when vegetative pieces have a greater propensity to increase, as in the cases of *Kappaphycus*, *Gracilaria*, *Gelidiella*, *Gelidium*, etc. Nevertheless, a sizable crop product (one-fourth of the total) is used as a seed for further farming activities. Additionally, using seedlings with the same genotype repeatedly causes vigour loss, a decrease in production, and susceptibility to diseases and pests. The potential loss of all crops owing to sudden changes in climatic conditions is a significant risk factor for seaweed farming in open waters. To support the seaweed farming industry, a novel scalable seedling production technique that generates a large number of high-quality plantlets in a sustainable manner is needed.

Seed production through micropropagation

The use of tissue culture and micropropagation techniques has recently increased the supply of seeds and produced uniform seedlings in considerable numbers in a shorter time, showing promise for the future of seaweed production. Several seaweed species have been successfully cultivated and transformed into new plantlets in laboratory settings through direct regeneration, callus culture, and protoplast culture. Seedling quality is further improved by the addition of bio-stimulants and plant growth regulators to culture media. Micropropagated plants grew more quickly than conventionally cultured plants and exhibited superior biochemical characteristics. To improve their chances of survival, tissue-cultured plants were advised to go through an acclimatization phase before being moved to a land-based grow-out system or ocean nets for farming. Preventing disease, pest infestations, and grazing by herbivorous fish and turtles during construction requires routine monitoring.

Offshore seaweed farming

- Future societal demands for renewable energy and biobased products, such as sources for biodegradable packaging materials, biofuels, and sustainable fertilizers, can be satisfied by offshore seaweed farming, and seaweeds represent an untapped biomass potential. The following are crucial considerations for offshore farming:

- Suitable species of seaweed is to be chosen for offshore cultivation. The seaweed species that are available naturally in the wild in that particular region would be ideal.

- Optimized growth properties suitable with growing in offshore conditions are demonstrated under simulated onshore circumstances.

- The appropriate cultivar need be used for the environment and for mechanical planting and harvesting on sophisticated, extensive textile cultivation substrates.

- Studies on bioprocessing to maximize the production of desired products, such as animal feed from digester waste, should be launched, and butanol production for renewable biofuels should be concentrated.

- An updated economic analysis need be conducted considering the economics of seaweed-related products and offshore seaweed farms.

- By minimizing ship movement, a largely automated and very reliable seaweed farm can be constructed to reduce expenses, risks to people and property, and global warming. This is accomplished by using an Autonomous Underwater Vehicle (AUV) to monitor the growth of the macroalgae and the state of the substrates and anchoring.

- Since production zones serve as nurseries for smaller fish in places off-limits to ships and fishermen, offshore seaweed cultivation also benefits fish populations.

Biotechnological interventions

Advances in plant biotechnology, such as mass propagation, genetic engineering and the production of bioactive compounds, were mainly due to the development of tissue culture techniques. The methods adopted for higher plant tissue culture were modified and used for seaweed tissue culture. The process commonly involves the preparation of axenic explants and their culture on solid agar media enriched with a range of macro- and micronutrients, vitamins and sugars. Even regeneration and callus formation could be achieved. However, for more complex biotechnological applications in seaweeds, absolute control of growth and development, as is achieved through higher plant tissue culture, is required (Baweja *et al.,* 2009). Micropropagation, or *in vitro* clonal propagation, is an effective tool for providing a greater quantity of plants for commercial cultivation in a shorter duration (Yong *et al.,* 2011). This approach will also pave the way for sustainable utilization and conservation of natural seaweed resources (Nair and Yocie, 2011). With the development of a tissue culture system, *in vitro* mass propagation and the production of genetically modified good-quality seedlings can be achieved. Developing *in vitro* cell culture techniques for selected seaweeds is crucial because it will facilitate a year-round mass supply of seed materials maintained under controlled conditions. Strain development and hybridization of *Kappaphycus* and *Gracilaria* through protoplast fusion techniques are envisaged to produce fast-growing, productive and high-temperature-tolerant seaweed seed materials.

Policies and institutional support

The formation of seaweed-based Fish Farmers Producers Organizations (FFPOs) is needed to economically empower seaweed farmers and enhance their bargaining power. The financial support provided under the PMMSY to each FFPO primarily includes the cost of formation and incubation, management, equity grants, training and skill development. Appropriate financing and insurance coverage for crop losses due to natural calamities are essential for further promoting seaweed farming in Indian waters. Currently, Indian seaweed cultivation occurs in nearshore waters. To experiment with offshore farming techniques, policy interventions and their technoeconomic viability are essential. The integration of seaweed and cage farms can be promoted wherever possible for bio-mitigation. As a healthy food for human consumption, seaweed must be promoted through awareness campaigns and festivals.The large-scale mariculture of seaweeds is a green technology that will improve the livelihood of coastal fishers, mitigate major greenhouse gases and prevent ocean acidification.

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Landing of *Exhippolysmata ensirostris* at Azheekkal Harbour

Exhippolysmata ensirostris (Kemp, 1914), commonly known as Hunter shrimp (Family-Lysmatidae) were observed in landings at Azheekkal Fisheries Harbour, Kollam on 2nd March 2023. They were caught in trawlers. Twenty-two single-day trawlers operating at 10 to 15 m depth off Azheekal Kollam, caught approximately 1kg each of the species among other shrimps such as *Parapenaeopsis stylifera, Metapenaeus dobsoni* and *Penaeus indicus*. The specimens measured on an average 65 mm in total length and most of them were berried. The species is hermaphrodite and hence sexes are not separate (Kagwade, 1984). Kunju (1967) reported commercial fishery of *E. ensirostris* from Maharashtra and Ganapathy and Subramaniam (1966) from Godavari Delta. Its early larval stages were studied by Bensam and Kartha (1967), and Pillai (1974) described the complete larval stages reared in the laboratory. The species occurs only rarely in the landings.

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Huge Giant manta ray landed

A Giant manta ray, *Mobula birostris* locally known as "*Aana Thirandi*" weighing around 900 kg was landed at Neendakara Fishing Harbour on 14th April 2023. It was caught in *Ozhukkuvala,* a drift gill net with 80 mm mesh size operated by a 12 m outboard plywood boat at about 75 m depth. The *Mobula* was auctioned for ₹28,000. The species is listed as Endangered by the International Union for Conservation of Nature (IUCN). Mobulids are widely used for their meat, skin, liver oil, and gill plates which fetch high prices in Asian markets especially China. The meat from mobulids is often consumed locally and the skin is sometimes used for making leather products. The Oceanic manta ray was listed in Appendix I and II of the Bonn Convention for the Conservation of Migratory Species of Wild Animals (CMS) in 2011. In India, the species is listed under Wild Life Protection Act under Appendix I and therefore benefits from conservation rules.

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Report on *Acentrogobius cyanomos* from the south-west coast of India

The fishes belonging to the genus *Acentrogobius* (Bleeker 1874) are considered true gobies, with 25 valid species described worldwide. A specimen of *Acentrogobius cyanomos* was collected from the Chinese dip net on 30th May 2023, operating at Munambam sea mouth at a depth of 3 m. The specimen was of a total length of 115 mm. The major identifying characters observed in this species were black triangular spot present just above the dorsal of the gill opening and numerous pale blue-green spots were present on the body. *Acentrogobius cyanomos* had been previously recorded from North Eastern part of River Krishna estuary.

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Accidental catch of Bull shark at Munambam Fisheries Harbour

The Bull shark *Carcharhinus leucas* is a large, predatory shark that occurs in warm-temperate, tropical and subtropical coastal and estuarine systems worldwide. Most of the Bull sharks are commonly caught by the hook and lines, long lines, and drift gill net in India but on 10th January 2023, a female Bull shark was landed by a multiday trawler at Munambam Fisheries Harbour. It was reportedly caught at 60 metres depth and measured 272 cm in length and weighed 262 kg. Sharks caught accidently in the trawl net is quite rare, as was observed here.

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