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Aerial view of the seaweed farm at Thondi, Tamil Nadu.

(Photo Credit: Johnson, B.)

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.

MFIS
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Technical & Extension Series

From the Editorial Board

Warm greetings to all our esteemed readers

Marine fisheries in India are typically multi-species, multi-gear with open access. Under the Marine Fisheries Regulation Act(s) of the various maritime states, certain legislations with aim of protecting the fish stocks and also provide sustainable yield are in place. Among these, the Seasonal Fishing Ban (SFB) is one implemented consistently across all maritime states for more than two to three decades since its inception in Kerala in 1988. The lead article highlights various intricacies of data collection and analysis required for basing a SFB. Another important communication is on seaweeds which are rich and renewable source of food and high value bio-molecules and chemicals. Products like agar, alginates and carrageenan have much demand in the food and bio-medical industries. Scientific seaweed farming is required to build up seaweed based industries in India which has the potential to generate employment and valuable export opportunities. Also their capacity for carbon sequestration and reducing coastal pollution are positive factors to promote seaweed farming in the country. The articles presented in this issue of MFIS deal with these topics in detail.

Marine Fisheries Information Service
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Lead Paper

Seasonal Fishing Ban: Need for collecting and applying right type of scientific information

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Introduction

Increasing fishing intensity and consequent decline in fish stocks has led to considerable investment to manage the fisheries and arrest the declining trend. Globally, several input and output control measures are adopted for management of fisheries and it has been reported that better assessed and managed fisheries are recovering. With improved management practices, the stock biomass relative to MSY target has increased up to 2.0 off Alaska, US west coast, EU Atlantic, Australia and New Zealand (Hilborn, 2019). This is an encouraging trend that gives hope to the fisheries fraternity that all will be well if proper approaches are adopted and implemented. The fisheries that are winning the battle against overfishing have adopted output control measures such as catch quotas and total allowable catch, supplemented by input control measures such as closure of fishing season and area, restriction on number of boats, etc. In India, mainly input control measures are followed for management of marine fisheries. Among the several input control measures in the Marine Fishing Regulation Act, seasonal fishing ban (SFB) is being followed diligently in all the maritime States and Union Territories (UTs). While Kerala started implementing SFB in 1988 other States and UTs followed to implement it in different years from 1989 to 2001. Thus, the SFB is being followed every year across the maritime states of India for the last 18 to 30 years. All mechanised boats (with a fixed engine and a wheelhouse) are covered by the SFB. Motorised boats (with outboard motor and open deck), are covered by the SFB based on the engine horsepower of the fishing vessels. In certain States, boats operating with horsepower 10 and above and in others, those above 25 hp only, are covered by the SFB. When SFB was introduced it was observed for 45 to 47 days, during the southwest monsoon period of June to August by the States and Union Territories (UTs) on the west coast and during April and May on the east coast. In 2015, based on the recommendations of an appointed Technical Committee, the Union Ministry of Agriculture (MoA), raised the fishing ban period to 61 days along both the west and east coasts. Since then, the SFB is followed for 61 days during southwest monsoon months from June 1 to July 31 along the west coast (including Lakshadweep Islands) and during summer months from April 15 to June 14 along the east coast (including Andaman & Nicobar Islands).

For fixing the timing and duration and achieving the objectives of SFB, we require right type of accurate scientific information. For example, if protecting the spawners is the prime objective of SFB, information on the spawning seasonality of important species are required as input and data on the improvement in spawning stock biomass (SSB) as the result of the SFB is needed. These data should be collected accurately by adopting rigorous and time-tested methods. Achieving the objectives of SFB is a good example of a strong science-policy nexus. If the scientists supply quality information by following suitable, reliable methodologies the SFB will deliver the intended outcomes.

Objectives of SFB

SFB has the potential to address a bouquet of intended and incidental objectives (Table 1). It may not be possible to achieve all the objectives simultaneously, but the result could be a bunch of 2 or 3 outcomes. Based on the intended objectives, the specific management measures will differ. Hence, we should be clear about the key issues, intended objectives and expected outcomes for enforcing SFB. It may be noted that the outcomes are often a combination of management measures other than SFB, such as mesh size regulation, Minimum Legal Size, etc.

Table 1. Potential objectives of a seasonal fishing ban

#	Objectives	Specific measures required	Other measures required	Indicator	Expected outcome
1	Protecting fish spawners	Ban fishing during peak spawning period	Ban fishing in intense spawning areas	Increase in fish recruitment	Enhanced fish regeneration; increase in spawning stock biomass
2	Reducing annual fishing effort/capacity	Ban fishing for adequate number of days	Overseeing (i) fishing effort not spilling over to non-ban period; (ii) fishing capacity does not increase	Reduction in annual fishing effort/capacity	Reduced fishing mortality; Increased stock size
3	Giving respite to seafloor from bottom trawling	Seasonal ban on bottom-contact gears	Restrict use of bottom contact gear in all months	Recovery of bottom flora and fauna	Ecosystem function maintained
4	Reducing low-value bycatch	Seasonal ban on gear generating low-value bycatch	Prescribe Minimum Legal Size and mesh size regulation	Reduction in the amount of annual bycatch	Reduced growth overfishing
5	Protecting the endangered, threatened species	Seasonal ban on fishing during abundance of the identified species	Restrict fishing in 'hotspot' areas; promote use of Bycatch Reduction Devices	Reduction in the bycatch of endangered, threatened species	Ecosystem structure and function restored
6	Reducing carbon footprint	Seasonal ban on boat types with high carbon emission	Introduce fishing technologies to reduce carbon emission	Reduction in (i) carbon emission; (ii) expenditure on fuel	Green fishing systems put in place
7	Reducing fishermen fatality at sea	Ban fishing during seasons of unfavourable weather conditions	Cyclone forewarning, better communication, use of sea safety appliances	Reduction in human fatalities and boat damage	Risk reduction measures in place.

While protecting spawners (fish, crustaceans and molluscs) has been projected as the major objective of SFB in the marine fisheries in India, another important objective is reducing the annual fishing effort. To address these two prime objectives, we need right type of high quality and validated data. The data required to meet these two objectives are (i) accurate spawning seasonality/months of major species; and (ii) monthly/annual fishing effort and capacity of major craft/gear types. For evaluating the performance of SFB against the stated objectives, we need validated data on (i) Spawning Stock Biomass (SSB); (ii) fishing mortality; and if possible, (iii) yield-per-recruit. In the absence of the above-mentioned science-based evidences, the underlying assumptions and the resultant conclusions on SFB can be seriously wrong. For example, visual observation of gonadal condition without validation, would lead to serious misunderstanding on the spawning seasonality of fishes. Similarly, measuring fishing effort alone, without considering fishing capacity, will not provide the required information for control of fishing activity.

The present review is an attempt to examine the data that are available to address and evaluate the output for the two key objectives, i.e., protecting fish spawners and reducing fishing effort/capacity indicated in Table 1. For this, answers to the following questions were attempted:

I. What are the conclusions of the previous studies/reports on the effectiveness of SFB in marine fisheries in India as well as elsewhere?
II. Are right type of data available to meet the objectives as well as assess the performance of SFB in India?
III. If not, what could be the right approach?

To find answers to Question 1, the available publications/reports on the subject were reviewed. For Questions 2 and 3, the conventional and time-tested methods of (i) analysing the spawning characteristics of fishes such as maturity stages, fecundity, spawning frequency, SSB, etc; and (ii) estimating the fishing effort/capacity were reviewed. This exercise re-visits the conventional methodologies that may be adopted for collection of reliable scientific data.

Review of studies/reports in India

The purpose of SFB is to ensure that a large number of fish will breed and spawn, enhancing the recruitment of young ones into the fishery. Hence protection of fish occurs during the times and at places where the fish are reproductively active, *i.e*. when they are most vulnerable. The SFB could be easily enforced as it is often accepted by fishers because of its simplicity. However, in the last three decades, the SFB has drawn mixed reaction from different sections of stakeholders on its timing and duration as well as its effectiveness. In addition, (i) the fishermen complain about loss of livelihood and demand higher compensation; (ii) mechanised boat owners demand all the motorised boats to be brought under the ban; (iii) motorised boat owners want total exemption from the ban. Thus, in a situation of many types of fisheries and target species, the difficulties of the various stakeholders to adjust to the SFB are evident. Consequently, the Department of Animal Husbandry, Dairying & Fisheries periodically constituted technical committees to take an informed position on the SFB. In 2014, the technical committee to review the duration of fishing ban reported the following important observations (DAHDF, 2014):

I. SFB has been found to be an ideal tool from implementation angle as well as wider acceptability in India.

II. Biological studies have indicated that there is an improvement in the recruitment of some demersal species into the fishery immediately after the ban, which lasts for a short duration of one to two months. While no significant difference in catch and catch per unit effort (CPUE) trends was observed before and after introduction of fishing ban for different fish species/groups along the west coast, there was marginal improvement in the same for different fish species/groups along the east coast.

III. Increase in catches along the Indian coast in the last two decades is essentially due to increase in efficiency of craft and gear and spatial extension of fishing to offshore regions (and not due to SFB).

IV. Almost all tropical species have a prolonged spawning season lasting for 6 to 7 months, with one or two peak spawning in a year. As these spawning peaks occur during different months for a variety of species, a common time period covering spawning period of most species could not be identified. Studies showed no indication that fishing ban alone has helped recovery of stocks. Seasonal closure of mechanised fishing has certainly helped to keep in check the increasing annual fishing effort apart from giving respite to different habitats. Perhaps, a combination of several other regulatory measures would be needed for achieving replenishment of fish stocks.

V. Consultations with stakeholders revealed diverse views of fishers on different issues but a near consensus prevailed on the need for a SFB. In general, while there were concerns about the adverse impact of loss of jobs and livelihoods, majority opinion converged on the benefits of ban.

Twenty five years after inception of SFB along the Kerala coast, detailed analysis showed that the positive impact on fishery yields continued for 9 years and the yield declined thereafter, indicating that the positive impact on fishery yields was not sustainable. The economic analysis also indicated that in value terms the benefit of SFB was prevalent for 12 years, after which there was a decline in the value of the fisheries in Kerala (Mohamed *et al.*, 2014). In a study on economic valuation of net social benefit of SFB in five maritime states in India, Narayanakumar *et al.* (2017) reported that the value of enhanced annual catch estimated at ex-dock centre price ranged from ₹13 crores in Andhra Pradesh to ₹ 28 crores in Tamil Nadu and indicated that continuation of SFB will be beneficial.Using semi-structured interviews with randomly selected participants before, during and after SFB in Tamil Nadu and Puducherry, Colwell *et al.* (2019) reported unintended consequences of fisheries regulations. Some fishers shifted their fishing effort to unrestricted fishing when the fishery opened after the ban and though this post-ban race for fish was exemplified by all gear types, an illegal, unregulated gear type, locally termed *surukku valai* (ringseine) exhibited the largest increase in effort. According to the authors, lack of fishing-related employment options during the ban period led to high levels of unemployment and food security concerns. Thus the previous studies have reported conflicting results on the performance of SFB. The recent annual reports of Central Marine Fisheries Research Institute that show that the stocks of many fish species are declining over the years due to overfishing which need to be taken into consideration while evaluating the effectiveness of SFB.

Lessons from international experience

The performance of SFB has been documented for a number of fisheries in different countries. In general, the SFB is adopted for specific fisheries such as shrimp fishery or lobster fishery in designated locations and it is intended to meet specific management goal(s) for each fishery. Similar to India, the conclusions on the performance of SFB are mixed. While seasonal closures have been evaluated by managers as useful and beneficial management strategies for some fisheries have emerged, there are also some reservations (Table 2), particularly when SFB is used as the sole management strategy for a particular fishery. It also has been suggested that seasonal

Table 2. Effectiveness of SFB in different countries

Fishery	Result
Gulf of Mexico shrimp fishery	Increase in overall yield and values in the first year, but no benefits in the second year
Florida lobster fishery	Beneficial to the fishery
Taiwan and East China Sea fisheries	Right spawning season should be identified for effectiveness
Southern coast of England	Increased abundance and biomass of benthic fauna
Browns and Georges Banks, north-eastern US	Recovery of heavily depleted barndoor skate
Bangladesh	Effective for successful spawning of Hilsa
Shrimp trawl fishery in Saudi Arabia	Effective in sustaining the fishery
Snapper-grouper fishery in the South Atlantic	Did not reduce overfishing
Pacific Halibut fishery	Failed to reduce fishing effort and was considered to be of limited conservation value
New England groundfish fishery	No impact on the decline of groundfish stocks
Hawaiian longline swordfish fishery	Not effective in conservation of sea turtles

ban will be effective for those species that aggregate for spawning during specific seasons. In many fisheries, seasonal closures are the initial management strategy employed and subsequently they have been supplemented or replaced with more effective measures.

Approaches to assess the effectiveness of SFB to protect the spawners

To find an answer to the question whether the SFB is actually protecting the spawners and improving the reproductive output, we have to make incisive scientific analysis of the subject based on the following questions.

Are there enough spawners in the sea?

The hypothesis that fishing during the spawning period reduces production of fertilized eggs per spawning female cannot be disputed. However, before we talk about protecting the spawners, we have to ascertain whether enough number of spawners are available for spawning. In other words, the emphasis is to reduce the exploitation rate and allow more fish to survive and participate in the reproduction process. It is intuitively obvious that, if there are only a few mature fish available to spawn, relatively fewer eggs are produced, whether or not spawning act is disrupted by fishing. Hence, the overriding importance is to be given for estimating the spawning stock biomass (SSB) and whether it is sufficient to support the fish harvest in a sustainable way. SSB is the combined weight of all individuals in a fish stock that has already spawned at least once, or that is ready to spawn during the reference year. It is an important Biological Reference Point (BRP) that has to be estimated regularly on a stock-by-stock basis. The assessment of SSB helps in detecting "recruitment overfishing" that happens when the parental biomass is reduced by fishing, resulting in a reduction in the production of new individuals, which in turn leads to reduced number of reproductively active mature fish. SSB and its associated reference point, the SSB at Maximum Sustainable Yield (SSB_{MSY}) (the level capable of producing the MSY) need to be estimated from appropriate quantitative assessments based on the analysis of catch-at-length (including discards). Achieving or maintaining a healthy stock status requires that SSB values are equal to or above SSB_{MSY}. Generating time-series data on SSB and SSB_{MSY} is an important step to understand the availability of spawners as well as evaluate the performance of SFB.

It is reported that the contribution of SSB ranges from 18% to 80% to the total standing stock biomass for different species in commercial fish landings (CMFRI, 2018). These estimates, in most instances, are simply the estimated biomass of individuals in length groups above length-at-first-maturity of the respective species. To determine the SSB, it is necessary to have estimates on the number of fish by length group, average weight of the fish in each length group and the number of mature fish in each length group. The SSB could be better expressed as a relative measure, i.e., from catch-per-unit effort (CPUE). Yield-per Recruit analysis expanded to include maturity and fecundity would provide SSB per recruit, or SSB_R that gives the data on the stock to replace itself.

Do we have accurate information on spawning season and spawning frequency?

Tropical fishes are known to spawn for prolonged duration. Extended spawning seasons provide a number of reproductive opportunities, which have the potential to increase recruitment. While SFB has the potential to maintain or increase the reproductive output and may provide a cost-effective enforcement option, protection of spawners needs accurate information on the season, strength and variability of spawning within and among locations and species. This information is an important requirement for developing meaningful temporal management protocols. It is also important to collect information on the major fishing grounds from where the fish are captured.

The ovaries of tropical fishes have several batches of eggs destined to mature and shed periodically. In tropical species, the population consists of fishes of variable stages of maturity and hence utmost care should be exercised to determine the spawning season accurately. During the spawning season, oocyte development is a continuous process involving all stages of oocytes, with a new spawning batch maturing every week to 10 days in peak spawning months. Fishes from the temperate waters, on the contrary, have a definite spawning season, either short or long. Environmental conditions in temperate waters, particularly during winter are adverse for prolonged spawning and hence each individual puts all its reserves into a single spawning. In temperate water species, the gonads show clear seasonal change and at any particular time of the year, the stages of maturity are fairly uniform throughout the population, and hence, it is easier to collect accurate information on spawning season of these fishes.

Information available on spawning season of the marine fishes of India

Consolidated information on the spawning months of 98 species based on reports and publications during 1980-2010 of ICAR-CMFRI (Vivekanandan *et al*., 2010), indicated that on an annual basis, majority of fishes spawn for 4 to 6 months, 22.5% spawn for 3 months or less and 20.4% spawn for 10 months or more (Fig.1). Moreover, of the 43 and 55 species analysed from the west and east coasts respectively, every month witnesses spawning by more than 20 species (Fig. 2).

Information on the spawning season of 63 species collected by Qasim (1973) also showed prolonged spawning of marine fishes in Indian seas, but the average duration of spawning calculated from the data gathered was 4.8 months compared to 6.1 months by Vivekanandan *et al.* (2010). While many species overlap between the two publications, large differences in the number of months of spawning of the same and related species reported by the two publications underline the uncertainties in generalising the spawning seasonality of fishes. To determine and generalise the months and duration of spawning in multiple spawning fishes with prolonged spawning periods , is a huge challenge for researchers. Hence, it is important to painstakingly follow time-tested

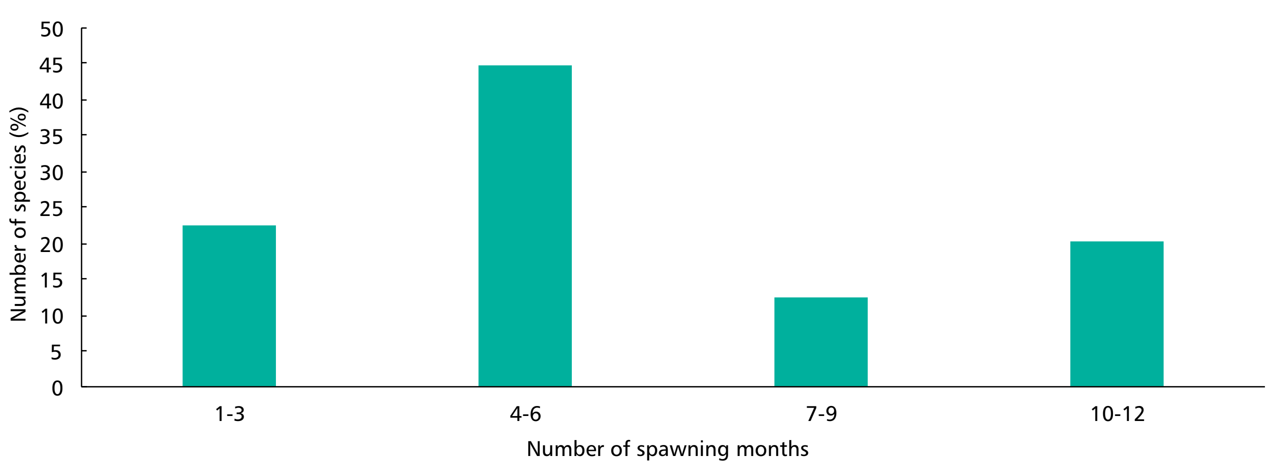

Fig. 1. Number of spawning months for marine fish species in India (n = 98; Data source: Vivekanandan *et al.*, 2010)

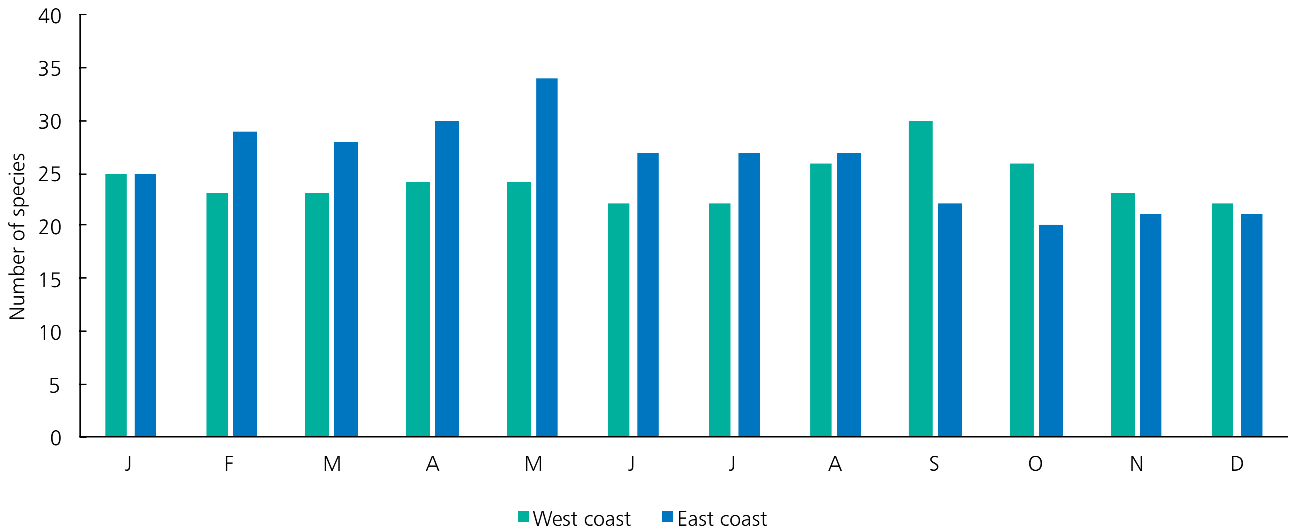

Fig. 2. Number of species spawning in different months along west (n = 43) and east coasts (n = 55) of India (Data source: Vivekanandan *et al.*, 2010)

and reliable methods to find out spawning months. Determining spawning seasonality of marine fishes in India is problematic with the following "drawbacks". The fish samples analysed are collected from landing sites without related information on the fishing grounds from where these fishes were caught. In recent years, particularly, the last ten years, in a single voyage, fishes are caught from different fishing grounds which are at varying distances from the landing sites. These are pooled on the deck of the boat and are landed, masking any site-specific spawning seasonality assessment difficult. In such situations, by the use of information originating only from the landings, the accuracy of information on spatial-seasonal pattern of spawning will be influenced by improper definition of the fishing area. A critical analysis of the two compilations mentioned above indicates that the results on the spawning seasonality were not validated by the authors who originally generated the data. Though the method(s) used by different authors to determine the spawning months has not been stated in the compilation of Vivekanandan *et al.* (2010), it is evident that majority of the studies had determined spawning periodicity based on a visual examination of gonads and classifying it into maturity stages using colour, shape and size of gonads in relation to body cavity. Visual examination lacks precision as it relies upon subjective judgement and very often, visual distinction of stages is not easy. Moreover, in a majority of species, visual classification of maturity stages is confusing as there are vast differences between species. Prior to 1970, most of the studies in India used ova diameter frequency method (Qasim, 1973). As eggs of many sizes and in various stages of development will be present in a single ovary, classifying them into distinct stages from ova diameter measurements may become biased. Visual observation of gonads as well as ova diameter studies were developed for fishes with a definite spawning season as observed in the temperate waters. On the contrary, identifying the spawning timing for tropical fishes has always remained an enigma.

Conventional methods of assessment of gonadal condition

In this challenging background, it is worth re-visiting the traditional methods of assessment of gonadal condition so that appropriate method(s) could be selected to determine the spawning seasonality. The performance of four conventional methods are given in Table 3.

Like visual observation of gonads, determination of gonado-somatic index (GSI) is another way of finding the spawning season with minimum effort and in conjunction with other methods like the standardized histological methods will give accurate information on spawning season. Use of histological techniques to study gonadal maturation has proven to have greater precision than the other methods listed above. Valuable information on spawning fraction, i.e., the proportion of gonads in spawning condition becomes available but the method is laborious, time consuming and may not be possible to adopt on a routine, species-by-species basis. Hence, a reasonable number of intense analysis using histology

Table 3. Conventional methods of assessment of gonadal condition

Method	Description	Performance	Confidence level of assessment
Visual examination of gonad	Gives a cost-effective, rapid assessment of maturity stages	Judgement is subjective, accuracy is uncertain; vast differences in the character of maturity stages between species; cannot be considered as a stand-alone method to determine spawning season.	Low
Ova diameter measurement	Allows frequency distribution of ova diameter; may be used if the diameter ranges of various stages for the species are already known.	Eggs of many sizes in various stages of development will be present in a single ovary, and classifying them into distinct batches may be biased.	Medium
Gonado-somatic Index	Simple means of assessing reproductive cycles. Classification could be successful on dry-weight basis. Necessary to sample individuals of discrete size ranges	Atresia of oocytes and resorption of eggs will not be accounted. If discrete size ranges are not considered, the method assumes that the allometric relationship between gonad and total tissue does not change over the size range, which is not correct.	Medium
Histological examination	Maturation can be assessed a few weeks before or after the spawning season accurately. Arguably the most accurate method to assess the gonadal condition.	Laborious, expensive, and limited to providing data on germ cell development.	High

techniques and covering the whole range of maturity cycle for selected major species can be used to accurately identify the spawning season periodically in conjunction with any two of the first three methods listed in Table 3.

Measuring spawning frequency

In batch spawning fishes, it is necessary to determine the spawning frequency because the standing stock of advanced oocytes or one-time egg count gives no indication of seasonal/monthly fecundity. New spawning batches are continuously recruited from small unyolked oocytes during the spawning season in batch spawners. In the context of SFB, spawning frequency can be defined as the number of spawning events within a spawning season for the species. Several methods have been suggested for measuring spawning frequency. Histological examination of ovaries with incidence one-day old post-ovulatory follicles in *Engraulis mordax* led to the conclusion that it spawns at least 20 times in one year (Hunter and Leong, 1981). While some attempts have been made to study the frequency of spawning in marine fishes in India (for example, Devaraj, 1986), the classification of maturity stages itself is confusing as it differs from species to species, even closely related.

Estimating fecundity

For determining the spawning season, it is crucial to estimate the fecundity of fishes in different months and is decisively important in determining the spawning strength and recruitment. In this context, it is worthwhile to consider three terms related to fecundity, namely, Potential Fecundity (PF), Realised Fecundity (RdF) and Relative Fecundity (RF). Potential Fecundity is the term used to describe the maximum number of oocytes commencing to differentiate and develop into mature eggs. However, due to one or other environmental factor like food supply or physiological state of the fish, a fraction of these developing oocytes is resorbed through a phenomenon called atresia. The number of remaining viable oocytes is termed as Realised Fecundity (RdF). The proportion of RdF to the PF changes temporally and from species to species. Relative Fecundity (RF) refers to the number of oocytes in relation to the body size of fish. In general, the RF, estimated as RdF divided by the body size of the fish (in terms of length or weight) differs between months and locations, and increases with the body size of the fish. It has been reported by Devaraj (1986) that the fecundity increases by 65,998 eggs for every 10 mm increase in length in the streaked seerfish *Scomberomorus lineolatus*. Hence, to determine the spawning months, it is important to estimate the RdF of the species during different months considering the size composition prevalent in different months and RF. An understanding of the relationships between reproductive parameters, such as spawning frequency, batch fecundity and spawning duration, with fish length are required to estimate seasonal absolute fecundity for multiple-spawning species with indeterminate fecundity (Fig. 3).

Fishes exhibiting multiple spawning have either of the three types of oocyte development in the ovary, which need to be considered for determining the spawning strength (Table 4). Among these, indeterminate seasonal fecundity is the most common among tropical fishes.

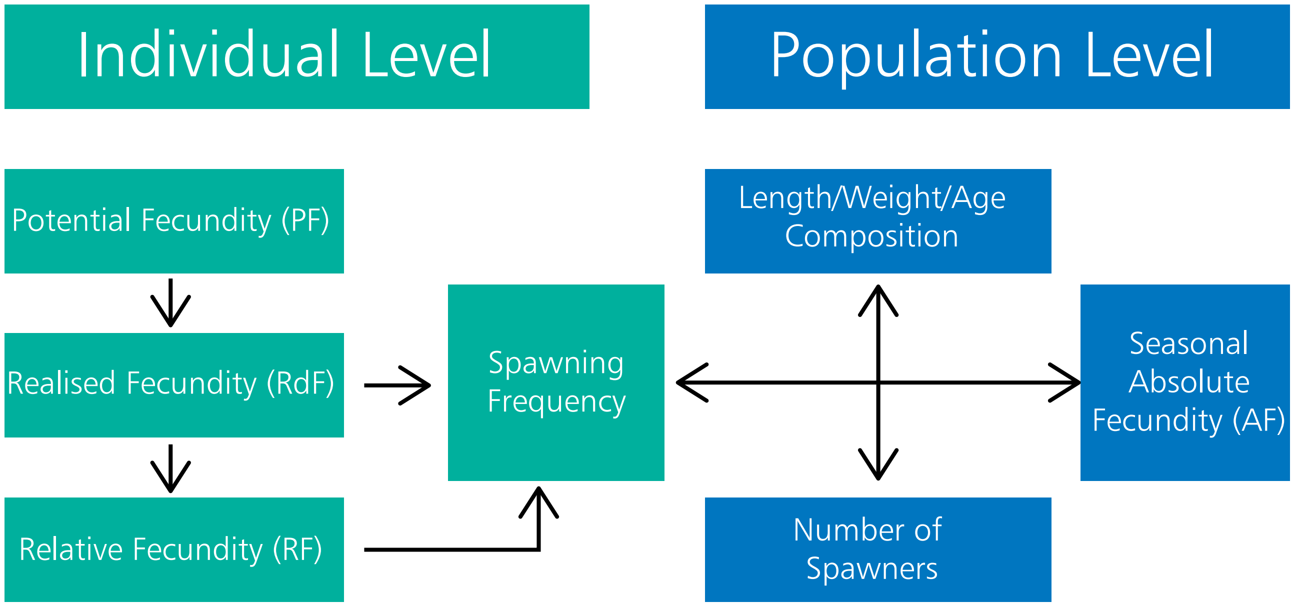

Fig. 3. Flow chart for determining seasonal spawning strength of fish species

Egg Production Model

Assessment of the spawning biomass of marine fishes based on ichthyoplankton data and annual egg production method was described by Saville (1964), and later a model was developed by Lo (1985). By downscaling this annual model to monthly fish landings data and incorporating the proportion of mature spawning female, the following equation could be adopted for estimating the SSB on a monthly basis:

$$P = B*R*F (E/W)$$

Where, P = Egg production at a given month; B = Spawning biomass; R = Proportion of female; F = Proportion of mature spawning female; E = Average monthly fecundity; W = Average monthly female weight.

While modern egg production models demand on-board fishing and ichthyoplankton surveys which are expensive, the modified method narrated above is simple to follow and can be applied to data collected from the commercial catches. It is an extension of the estimates on gonadal maturity, fecundity and spawning frequency.

Data required for identifying spawning season

The data required for finding out the spawning season of fishes, as mentioned above is indicated as a flow chart (Fig. 4). Until right type of accurate information are available, there will be uncertainty in identifying the spawning season. However, in multispecies fisheries, it is not possible to collect the entire set of data for all the species. Hence, species may be selected for the analysis

Table 4. Different types of multiple spawning in fishes

Type	Description	Prescribed analysis
Indeterminate seasonal fecundity	New spawning batches of oocytes are recruited from small unyolked oocytes continuously during the spawning season. Presence of unsynchronised, unlimited number of developing oocytes.	Rate of egg production to be determined from spawning frequency and batch fecundity.
Determinate seasonal fecundity	Oocytes destined for spawning in a season are identifiable at the beginning of the season. Presence of synchronous development of a fixed number of oocytes.	Fecundity to be estimated for the entire spawning season until all the oocytes spawn; spawning frequency need not be determined.
Determinate fecundity, but all oocytes do not spawn in a season	Un-utilised oocytes exist at the end of season	Fecundity to be estimated for the entire spawning season and the unspawned oocytes to be determined at the end of season; spawning frequency need not be determined.

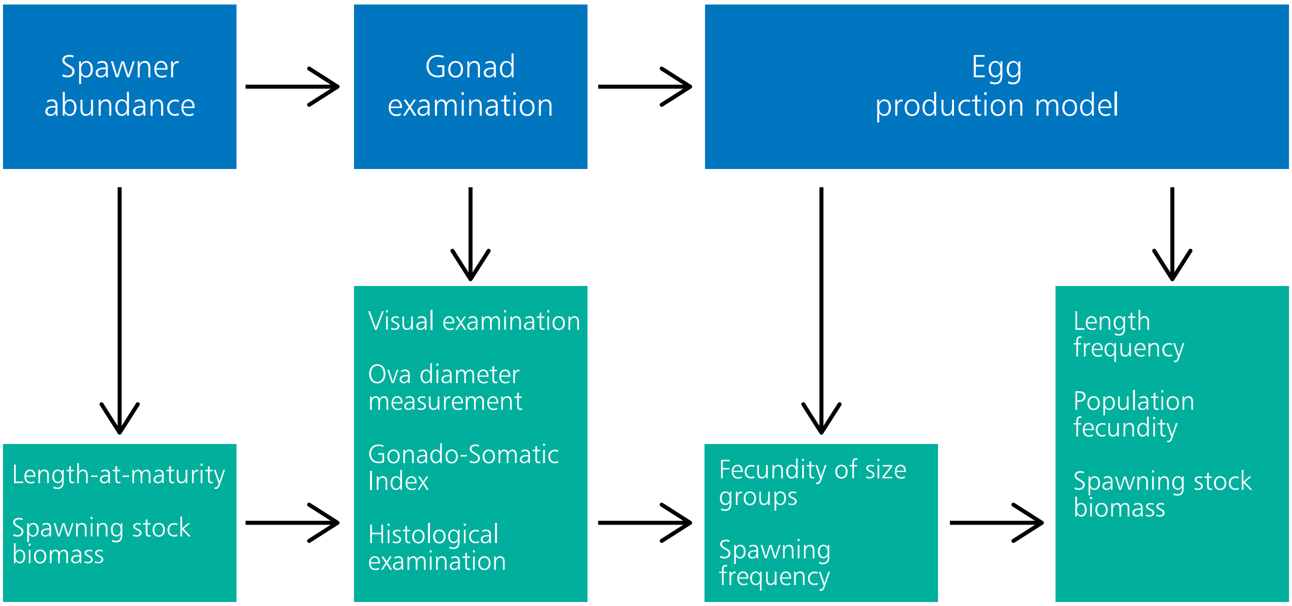

Fig. 4. Sequential flow of data required for determining the spawning season of multiple spawners

based on their abundance levels as per landings data and economic value. This is a time-consuming and expensive exercise, but would provide strong scientific insights with certainty, on the spawning seasonality of fishes that is essential for creating/improving effective strategies to link scientific advice to management decisions on timing and duration of SFB.

Fishing effort and capacity control

Another important objective of SFB is control of fishing effort. Reduction of the fishing duration and fishing mortality by limiting the amount of fishing, would supposedly increase stock size. However, it is difficult to predict the response of fishing mortality based on the amount of effort control since it depends on how fishers respond to the specific regulations set forth. For example, if fishing mortality and effort are high in a fishery and a closed season is established, fishers may respond with greater effort by using more gear and/or boats when the season is open. When opened after the closure, the fishery provides the communities with an opportunity to boost fish catch to meet elevated social and economic demands.

In India, the number of fishing boats and efficiency are consistently increasing, with smaller non-motorised boats being replaced by motorised and mechanised boats. The census carried out by ICAR-CMFRI during different periods shows that not only the number of fishing boats has increased, but the composition of fishing fleet has changed over the years, from 15.0% mechanised boats in 1992-93 to 36.5% in 2010 (Table 5). The gross tonnage of fishing fleet and the summed up horsepower of engines in the fleet would have increased substantially, for which data are not available. It is overwhelmingly important to estimate the capacity of fishing fleet and complement the data with fishing effort.

Moreover, the number of existing boats, particularly the mechanised and motorised boats is double the number

Table 5. Change in the composition of fishing fleet over the years in India

Year	Non-motorised	Motorised	Mechanised
1992-93	74.0	11.0	15.0
1994-95	70.9	11.8	17.4
2003	64.8	15.9	19.2
2005	44.0	31.5	24.5
2010	26.6	36.9	36.5

(Source: Census Reports, ICAR-CMFRI)

of the estimated optimum fishing fleet (DAHDF, 2011), indicating overcapacity of the fleet. Excess capacity is, in general, associated with open access fisheries. These factors have the potential to jeopardise the objective of SFB. Hence, it is important to realise that SFB will not be effective as a stand-alone management measure to reduce fishing effort and thereby fishing mortality. The problems in using input controls alone to regulate fisheries are associated with problems of determining how much effort is actually represented by each fishing unit. Even discrete fleets within a fishery are characterized by considerable variation in the size of vessel, nature of gear and technical and technological aids used. However, SFB could complement other stronger measures to control fishing effort such as cap on the number of boats, and gear and catch restrictions. Otherwise, SFB amounts to just postponing fish capture by two months. Unless effective measures for capacity controls are concurrently implemented, the period of closed season for building the stock size could become longer. Gulland (1974) stated that there is little theoretical justification for seasonal closures unless the fishing effort is controlled by other effective methods. If the fishing effort or capacity is not restricted, achieving the targets such as reduced fishing mortality and increased stock size becomes redundant.

Conclusion

Authoritative scientific input and monitoring is required to fix the period and duration of seasonal fishing ban and to assess its performance. Considering that protecting fish spawners is the major objective of enforcing seasonal fish ban in marine fisheries in India, this overview emphasises the need for generating accurate data on a monthly basis on the gonadal condition, spawning frequency and egg production of important species to enable identification of right months and duration of fishing closure. To assess whether the ban has addressed the intended objectives, continuous monitoring of recruitment and spawning stock biomass is required.Closure of fishing for a specific duration every year is expected to reduce/control pressure on fish stocks. This would be reflected in the form of reduction in annual fishing effort, but the right type of data required is time-series on changes in annual fishing capacity, if any. The positive outcome of ban, that needs to be assessed, is reduction in fishing mortality and improvement in yield-per-recruit. To generate the above-mentioned data, conventional methods that are being used by fishery biologists for the past many years have been suggested in this overview. However, painstaking effort has to be made to collect the data to gain a firm grasp of the dynamics of fisheries and the bases underlying the importance and problems of their management.

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Research Communications

Perspective plan of ICAR-CMFRI for promoting seaweed mariculture in India

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Abstract

Seaweed mariculture is a green and climate smart technology to assure steady and continuous supply of raw materials for the production of algal polysaccharides, fodder, biofuels, manure, nutraceuticals etc. The perspective plan of ICAR- Central Marine Fisheries Research Institute on seaweed cultivation and utilization observes that (a) raw materials for value added products from seaweeds should be sourced from large scale mariculture and not from wild habitats.; (b) mariculture of species of *Gracilaria* and *Gelidiella* for agar, *Kappaphycus alvarezii* for *k*-carrageenan and *Sargassum*, *Ulva* and *Caulerpa* for their nutraceuticals and other secondary metabolites should be widely promoted; (c) seaweed mariculture can be undertaken in integrated mode with finfish or shellfish (IMTA) to double the farmers' income and (d) large scale mariculture of seaweeds should be encouraged as it can help mitigate major greenhouse gas and thereby check ocean acidification, while the farmers achieve livelihood security simultaneously.

***Key words**: Seaweed mariculture, Agar shortage, Kappaphycus alvarezii, IMTA*

Introduction

Seaweeds are marine macrophytic thallophytes belonging to the groups of green (Chlorophyta), brown (Phaeophyta) and red (Rhodophyta) seaweeds. They grow best in the tidal and inter-tidal waters and the Andaman-Nicobar and Laccadive Archipelagoes of India. With a coastline exceeding 8000 km , India has more than 0.26 million tonnes wet harvestable biomass of seaweeds belonging to 700 species. Of these, nearly 60 species accounting for about 30 % of the harvestable biomass are economically important for their polysaccharides and secondary metabolites and hence exploited commercially for agar, algin, carrageenan, bioactive metabolites, cattle fodder and plant manure. World seaweed production in 2016 was 30.1 million tonnes wet weight with first sale value estimated at 11.7 billion USD (FAO 2018). Approximately 20,000 tonnes of seaweed resources from the wild are harvested annually in India (Fig.1).

ICAR-CMFRI under the Indian Council of Agricultural Research (ICAR) an autonomous body in the Department of Agricultural Research and Education, Ministry of Agriculture & Farmers' Welfare has been working on seaweed mariculture and utilization in India since 1964. Under its Trainers' Training Centre, it had imparted more than 20 hands on training to 119 trainers from erstwhile Andhra Pradesh, Gujarat, Maharashtra, Kerala, Tamil Nadu and West Bengal. The Mandapam Regional Station of the institute developed the technology for commercial scale cultivation of *Gracilaria edulis*, an agar yielding red algae, using raft, coir-rope nets/spore method. A cottage industry method for the manufacture of agar from *Gracilaria* spp. and Alginic acid from *Sargassum* spp. during 1980s was demonstrated to many farmers and entrepreneurs which paved the way for development of many small scale agar industries in Madurai, Tamil Nadu. Providing technical inputs for the meetings and discussions on seaweed culture and commercialization

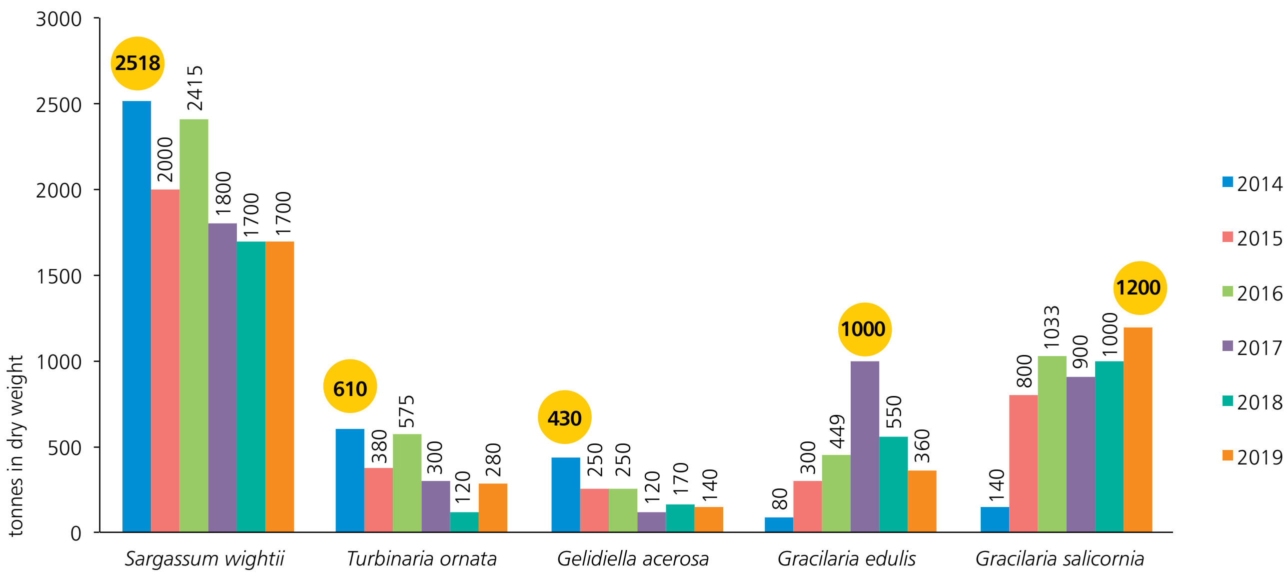

Fig.1 Production of seaweed through wild collection during the year 2014-2019 in Tamil Nadu, India

of seaweed products to the Ministry of Agriculture and Farmers Welfare, participation in preparing a policy-support document on 'Seaweed Cultivation and Utilisation (NAAS, 2003) and Action Plan on seaweed research and utilization have been significant contributions of the institute. Estimates of Annual seaweed harvest (wild collection) from India as well as mariculture production along the east coast is done by the ICAR-CMFRI with which Potential Yield of seaweeds from India was estimated. Though started in 1964, seaweed mariculture (*Gracilaria edulis* and *Gelidiella acerosa*) remained in experimental trials in India until recently. Large scale sea farming of *Kappaphycus alvarezii,* a *k*-carrageenan yielding seaweed started in 2000 with a back up by Pepsico India Holdings Ltd., in the coastal waters of Tamil Nadu, Odisha and Gujarat including Daman & Diu with technical support from the Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar. Contract farming of *Kappaphycus alvarezii* by the fisherfolk on the east coast of India touched maximum of 1500 tonnes dry weight during the year 2012 and more than 70,000 tonnes wet biomass of *Kappaphycus* in the decade between 2005 to 2015. Its concomitant purchase value per kilogram (dry) was ₹4.5 to 35 with an annual turnover of around ₹2.0 billion. However, after 2013 the production sharply declined due to mass mortality and the average production in recent years is only around 200 t dry weight per year (Fig.2). At present, commercial farming is carried out

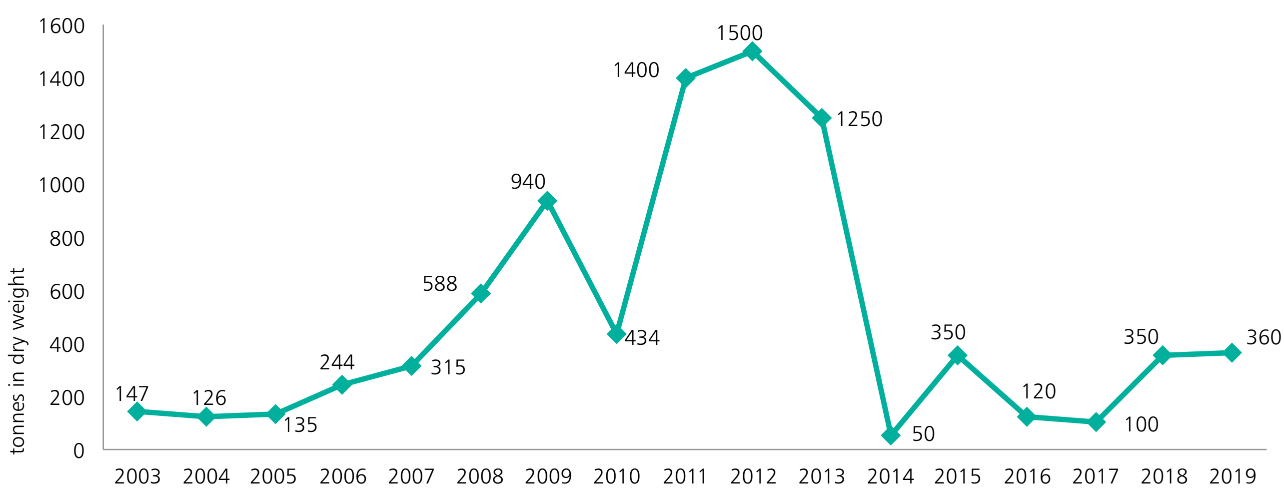

Fig. 2 *K.alvarezii* production (dry weight in tonnes) from Tamil Nadu Coast (2003-2019)

following three techniques, namely floating bamboo raft, tube net (net sleeves),and long lines, of which, the former two are widely popular. Seaweeds are renewable resources, but indiscriminate exploitation affects their resilience and standing stock. Globally the production of seaweeds through mariculture lags far behind the demand for raw seaweed materials to produce the traditional and emerging products. This communication highlights the need for large scale sustainable mariculture of seaweeds in India for various uses.

Agar production: Acute shortage of agar yielding red seaweeds all over the world can jeopardize the research programmes in biology and medicine for want of agar and agarose. In India, reduction in the quantity of wild collected seaweeds like species of *Gracilaria* and *Gelidiella* is observed. Red seaweeds are now imported from Sri Lanka, Morocco and SAARC countries with import duty varying between 4-37% and hence, most of the agar producing units in India remains shut due to lack of raw material and high costs of operation. This acute shortage in raw material supply is mainly due to indiscriminate exploitation over the years from Tamil Nadu coast (3,700- 4,500 tonnes dry weight per year) coupled with habitat destruction. The crustose red alga *Gelidiella acerosa* is the most important agarophyte that can yield pharmaceutical grade agar with gel strength above 650 g/cm^2. Standing crop estimation of *G. acerosa* in the Gulf of Mannar region over a decade revealed that the wet biomass of 1400 g / m^2 recorded during 1996- 1998 has drastically reduced to 600 g / m^2 during 2004- 2005 and recently during 2009- 2010, shrunken to just 450 g / m ^{2} (Ganesan *et al*., 2015). The farming of *G. acerosa* will ensure consistent production of quality and pure raw materials that can fetch alternative livelihood to the coastal fishers (@₹ 80,000/tonne dry weight). The CSIR-CSMCRI has already developed successful technology for the mariculture of *G. acerosa*, *G. dura* and *G. debilis* (Gracilariaceae, Rhodophyta) and their large scale culture of agarophytes and value addition is very much essential.

Fodder use: In rural India, domestic animals are engines that drive the economy. Farmers are increasingly shifting to crops that do not yield fodder and also as the country moves towards rearing animals with higher milk yields, better quality fodder and stall feeding becomes a necessity. An investigation under the AP Cess fund of ICAR to produce better quality feed / fodder for animals found saturated fatty acids predominant in *Kappaphycus, Hypnea* and *Gracilaria.* Monounsaturated fatty acids were predominant in brown seaweed *Sargassum* and the green seaweed *Ulva.* While *Sargassum wightii* contained maximum amount of omega-3 fatty acids, *Hypnea* and *Gracilaria* species had higher levels of omega-6 fatty acids.

Biofuel: In view of the increasing demand for fossil fuels and the environmental hazards caused by its use, alternatives from renewable sources (biofuels) are to be considered. Government of India initiated several programmes to promote production and use of biofuels blended with fossil fuels. Compared to crop based biofuels marine algae are regarded superior for quality biofuel production due to their rapid multiplication and growth rate (8-10 times faster) compared to terrestrial and aquatic higher plants.

Agriculture and allied business: Farmers often use chemical fertilizers and pesticides in agricultural lands to enhance the crop yield which has several undesirable effects on soil and environment. As an alternative, biofertilizers from seaweed extracts which contain many growth promoting substances like auxins, gibberllins, trace elements, vitamins and amino acids that are not found in terrestrial plants and which promote growth, flowering and better yield are being explored. As more firms, individuals and farmer cooperatives are coming forward to produce seaweed based manures and fertilizers, the demand for seaweed biomass is increasing. Regulatory mechanisms for commercial production of seaweed based fertilizers and biostimulants as it involves exploitation of wild stock and quality assurance to check addition of inorganic nitrates and micro elements have been proposed by ICAR-CMFRI and ICAR-CIFT respectively. To conserve the natural wild stock, the raw material required for producing seaweed based manures and fertilizers should be essentially sourced from large scale mariculture and not from wild habitats.

Combating climate change impacts: Seaweeds are reported to be excellent bio-remediating agents capable of improving water quality by uptake of dissolved minerals, nitrates, ammonia and phosphates. Large scale seaweed mariculture has been recognized as one of the climate resilient aquaculture techniques to mitigate ocean acidification. It is estimated that the seaweed biomass alone along the Indian coast is capable of utilizing 3,017 t CO_2/d against emission of 122t CO_2 /d indicating a net carbon credit of 2895 t/d (Kaladharan *et al*., 2009)

An experimental culture of seaweed (*Kappaphycus alvarezii*) to estimate its carbon sequestration potential was conducted at Munaikadu, Ramanathapuram district, Tamil Nadu. In each of the three bamboo rafts (12 ft × 12 ft), 3 pre-weighed bunches of seaweed were tagged and their weights were periodically (once in 15 days) measured. Sub-samples from each bunch were dried and analyzed for its carbon content using CHN elemental analyser which indicated average dry weight percentage of the harvested sea-weed was 8.75 % and the average carbon content was 19.92%. The specific growth rate of the seaweed multiplied with % composition of carbon (C) and 3.667 (mass of CO_2/ mass of C) gave an estimate of specific rate of sequestration (per unit mass of seaweed per unit time) of carbon dioxide by the seaweed as 0.018673 g per day per g dry weight. Hence, large scale mariculture of seaweeds, preferably red seaweeds, to check ocean acidification is a green technology by not being labour intensive and without the involvement of energy, fertilizers and chemical inputs.

Drugs and nutraceuticals: The research work at the Marine Bioprospecting laboratory of ICAR-CMFRI has focused on developing bioactive leads and nutraceutical products from seaweeds with pluralities of bioactive properties for use against various diseases viz., inflammation, dyslipidemia, hypercholesterolemic disorders, thyroid disorders, osteoporosis, type-II diabetes, cardiovascular, pathogenic infection, and oxidative stress. Nutraceutical formulation(s) (Cadalmin^{TM}Antidiabetic extract and Cadalmin^{TM} Green Algal extract from seaweeds) are effective green alternatives to the synthetic drugs available in the market to combat type-II diabetes and rheumatic arthritic pains, respectively. Cadalmin^{TM}GAe, Indian patent Appl. No. 2064/CHE/2010) has been out-licensed to a Biopharmaceutical company for commercial production and marketing in India and abroad. Cadalmin^{TM} Antihypercholesterolemic extract (Cadalmin^{TM}ACe, Indian patent Appl. No. 201711013741) and Cadalmin^{TM} Antihypothyroidism extract (Cadalmin^{TM}ATe, Indian patent Appl. no. 202011011490) from marine macroalgae to combat dyslipidemia and hypothyroid disorders, respectively, and these products were out-licensed to a pharmaceutical company. Cadalmin^{TM} Antihypertensive extract (Cadalmin^{TM}AHe, Indian patent Appl. No. 202011011489) and Cadalmin^{TM} Antiosteoporotic extract (Cadalmin^{TM}AOe, Indian patent Appl. no. 202011009121) for use against hypertension and osteoporosis, respectively are being commercialized.

Semi synthetic C-4/C-6 methylene-polycarboxylate cross-linked hybrid drug delivery system and a topical antibacterial formulation developed from marine macroalgae were found to be comparable with commercially available products. This pioneering research work at ICAR-CMFRI envisages a systematic approach involving chemical profiling of major species of seaweeds for lead pharmacophores coupled with evaluation of target biological activities against different disease models, for example, 3-hydroxy-3-methylglutaryl coenzyme A reductase, type-2 diabetes modulators (dipeptidyl peptidase-4, protein tyrosine phosphatase 1B), angiotensin-I, inflammatory cyclooxygenases, lipoxygenases, alkaline phosphatase and bone morphogenic protein. Optimized physical/ chromatographic procedures have been developed by this institute to isolate and purify the molecules with target bioactivities (Table 1). As the percentage recovery of such

Table 1. Various nutraceuticals produced from seaweeds by ICAR-CMFRI

Nutraceuticals from seaweeds

Cadalmin^{TM}	Mode of Action
ADe	DPP4 & Tyrosine Phosphatase inhibitor; Nullifies insulin resistance at cellular level
ATe	Activates selenodeiodinase that converts T4 to T3 (Thyroxine)
AHe	Inhibits angiotensin converting enzyme (ACE) and inhibits production of hypertension causing Angiotensin II from I
ACe	Activates lipoprotein lipase, inhibiting the production of triglycerides
GAe	Inhibits cyclooxygenase II (that causes production of inflammatory prostaglandins) and 5-lipoxygenase, thus reducing inflammation.
AOe	Stimulate alkaline phosphatase and bone morphogenic protein, along with lower serum osteocalcin levels and prominent mineralization, and effective for controlling osteoporesis and bone health development.

active principles is around 10%, large scale mariculture of seaweeds is urgently required for the steady supply of raw materials for the production of value added products and nutraceuticals from seaweeds in India.

Seaweed mariculture through Integrated Multitrophic Aquaculture (IMTA)

Seaweeds such as *Kappaphycus alvarezii, Gracilaria edulis*, *Gracilaria verrucosa* and *Gelidiella acerosa* are farmed/ being experimented under IMTA, in India. The recycling of waste nutrients by seaweed and filter-feeding shellfish is the best way to economically improve mariculture activities. Trials on seaweed *Kappaphycus* with finfish cobia (*Rachycentron canadum*) in floating cages in coastal Tamil Nadu indicated that though there were many challenges, the shift from monoculture to the IMTA resulted in increased production. Seaweed rafts integrated with cobia cage had a better average yield of 320 kg per raft while the same was 144 kg per raft which were not integrated. An addition of 176 kg of seaweed per raft was achieved due to the integration with the cobia cage farming. The total amount of carbon sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 357 kg and 161 kg respectively -an addition of 196 kg carbon credit. The presence of inorganic extractive components contribute to the periphytons to the aquaculture area as well as offer habitat for planktons to settle. Seaweeds are known to release 30-39% of their gross primary production as dissolved organic carbon (DOC) to the ambient water. Trials on IMTA with bivalves and finfish (seabass) in inshore waters of Karnataka demonstrated reduced risk of crop failure through diversification. Mortality loss of finfish (seabass) in the cages was compensated to a certain extent by bivalve production. Gross revenue realized was ₹5.34 lakhs of which 30% was contributed by mussel (₹1.6 lakhs).

Future projections of *Kappaphycus* mariculture

During 2012-13, maximum 27,000 rafts produced 15,000 tonnes of *Kappaphycus* (wet weight) from 5 coastal districts of Tamil Nadu in a 45 days culture period per crop. If an additional 73,000 rafts are deployed for cultivation in 6 states–Gujarat (15,000 rafts), Andhra Pradesh (15,000 rafts), Odisha (15,000 rafts), Kerala (10,000 rafts), Karnataka (10,000 rafts) and Maharashtra (8,000 rafts) by 2030, a total of 1,00,000 rafts can be utilized for seaweed production of the country. It is estimated that by 2030, with 4 crops of 45 days duration in a year, these 1,00,000 rafts [@ 250kg/raft] can yield a total of 1,00,000 tonnes (wet weight) of seaweeds harvest per year.

Economics

Total cost of production	₹ 3000/raft/year (including cost of seed material for 4 crops)
Seaweed production	1,000 kg/raft/year
Price of seaweed	₹ 6.50/kg (wet weight)/ raft
Total revenue generated	₹6500/year/ raft
Net profit	₹3500/raft/year (₹6500 minus ₹3000)
Additional net income (from 45 raft unit)	₹157,500/year/fisher

The perspective plan of ICAR- Central Marine Fisheries Research Institute on seaweed cultivation and utilization lists the following priorities.

a. Raw materials for processing and value added products development from seaweeds should be sourced from large scale mariculture and not from wild habitats.
b. Mariculture of species of *Gracilaria, Gelidiella* for agar, *Kappaphycus alvarezii* for *k*-carrageenan and *Sargassum*, *Ulva* and *Caulerpa* for their nutraceuticals and other secondary metabolites should be widely promoted.
c. Seaweed mariculture can be undertaken under integrated mode (IMTA) with finfish or shellfish to double the farmers' income.
d. Large scale mariculture of seaweeds should be encouraged as this can help mitigate major greenhouse gas and thus check ocean acidification, while the farmers achieve livelihood security from the seaweed harvest.
e. Seed stock/seed bank for commercially important seaweed species in controlled onshore facilities at strategic locations should be established to ensure uninterrupted supply of seed materials.
f. It is essential to bring seaweed cultivation under insurance coverage to compensate crop losses during natural calamities.
g. Cultivation of seaweeds is like Agriculture in Sea and hence the harvested seaweeds (wet/ dry) should be

treated as agricultural produce for the purpose of fiscal levies.

h. A minimum price for the farmed seaweeds and opening of marketing channels for seaweeds also should be considered before taking up large scale farming of seaweeds in the country.
i. Seaweed based bio-stimulants for use in agriculture should be duly notified as agricultural inputs by the Ministry of Agriculture and Farmers' Welfare.
j. In brackishwater areas, seaweed *Gracilaria tenuistipitata* can be cultivated integrated with fish or shrimp for improving the water quality and for doubling the farmers' income.

The Way forward

Expansion of seaweed farming in the country will improve the socioeconomic status of coastal fishermen/farmers and will be helpful in mitigating the negative effects of climate change by protecting the marine ecosystems from ocean acidification and de-oxygenation. The seaweed cultivation procedure does not requires land, fresh water, fertilizers or pesticides. The large scale cultivation can enhance rural employment opportunities and improve rural economy. Seaweed mariculture is an economically viable livelihood option for the coastal fishing community, especially fisherwomen. The Benefit Cost Ratio (BCR) is estimated above 2.0, which signifies the profitability of the activity and it can double the fisher's income.

Currently, the growth of seaweed farming is primarily constrained by lack of proper marine spatial plans, appropriate financing and insurance cover against crop losses due to natural calamities. Other challenges include difficulty in obtaining quality seed materials of native species such as *Gracilaria dura*, especially after monsoon rains, natural hazards such as cyclonic weather and grazing by herbivorous fishes. To improve production of *Kappaphycus* in India, developing *in vitro* cell culture techniques is crucial as it facilitates year-round mass supply of seed materials maintained under controlled conditions. Development of new and improved strains of *Kappaphycus* through strain development and hybridization and through protoplast fusion techniques are to be attempted. Surveys conducted by ICAR-CMFRI all along the Indian coasts could not find any settlement of *Kappaphycus* in seaweed/coral beds as well as in the beaches as drifted mass. From the impact assessment of *Kappaphycus* cultivation on the environment being attempted since 1983 from Hawaii Islands to the recent studies by CSIR-CSMCRI in Indian waters also could not observe the occurrence/establishment of non-farmed populations of *Kappaphycus*.

Seaweed cultivation can be taken up by fishermen/ fisherwomen co-operatives and self-help groups (SHGs) of the coastal areas as IMTA. A minimum price for the farmed seaweeds and opening of marketing channels for seaweeds also should be considered before taking up large scale farming of seaweeds in the country. Promotion of seaweeds as healthy food for human consumption apart from its use as raw materials for the extraction of bioactive compounds and phycochemicals may also be attempted. Development agencies like National Fisheries Development Board (NFDB) can promote seaweed consumption through awareness campaigns and seaweed based food festivals organised throughout the country. Large scale mariculture of seaweeds which is a green technology can thus fuel the growth of blue economy.

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Design of low-cost indigenous recirculating aquaculture systems (RAS) for broodstock maturation of marine fishes

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Maturation of most coastal fishes may well be achieved if the animals are maintained in good quality seawater, provided they are well fed and reared without the stress of overcrowding and disturbances. RAS provides perfect opportunity to manipulate environmental conditions that are critical in maturation processes such as temperature, photoperiod, nutrition and other water quality parameters in addition to facilitating observation of the behaviour of fishes and do various husbandry steps. There is a need for the development of cost-effective, economically viable systems that minimize the environmental impact while at the same time ensuring optimal rearing conditions. Present article describes design and operation of low-cost RAS systems developed by ICAR-CMFRI for broodstock development of marine fishes, which include 30000 to 2000 l FRP systems with mechanical, biological filtration sub systems including disinfection, temperature control and photoperiod manipulation, using equipment such as, proteins skimmer, UV filters, chillers, biological filter cabinets and LED lighting with timer control.

A typical 10 t system with a dual-drain recirculatory aquaculture system (RAS) is described here (Fig. 1). RAS tank has a central drain (CD) of 4-inch diameter depending on the capacity of the broodstock tank and a side overflow opening (overflow

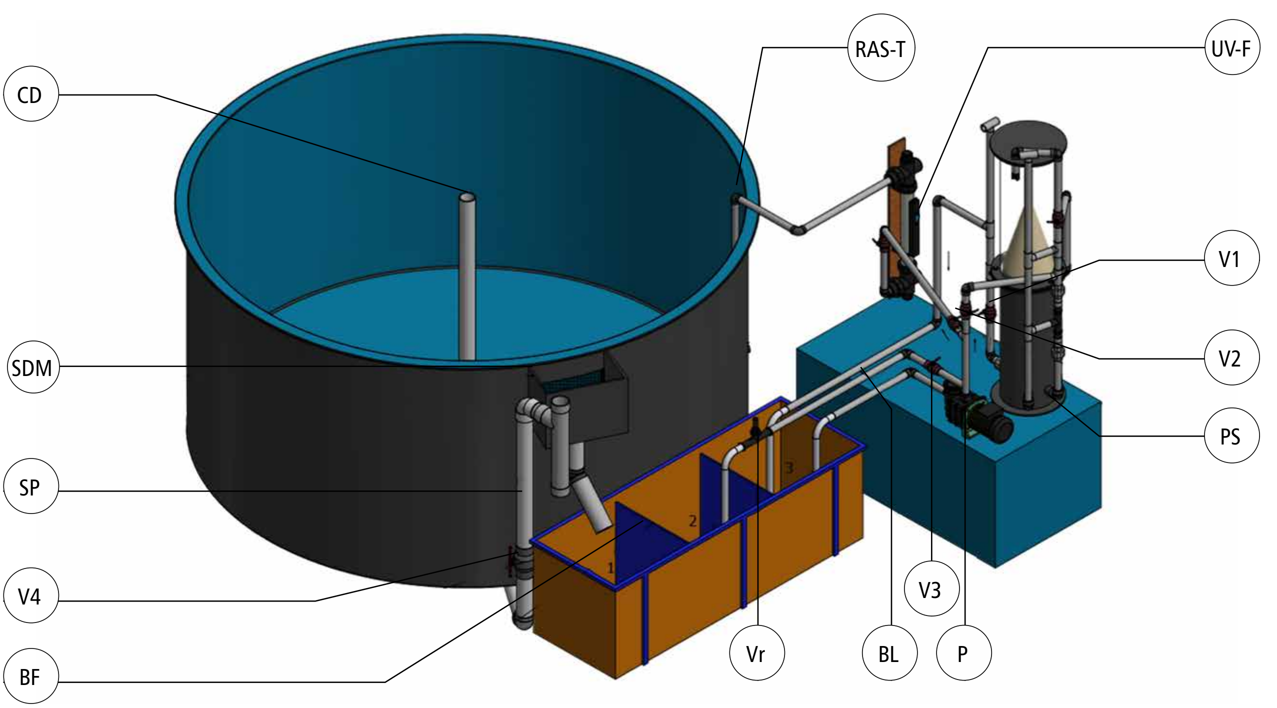

Fig. 1. Dual-drain single pump recirculation aquaculture system (RAS)
RAS-T-tank; CD-central drain; SP-standpipe with valve; OD- overflow drain; BF-biological filter; P-pump; PS-protein skimmer; BL-bypass line; UV-F- Ultraviolet filtration unit; V-valve, Vr- venturi, SDM- side drain mesh

drain-OD) made by cutting off a strip of 20 cm length and 5 cm height from the sidewall of the tank. This opening is protected with a 3 mm mesh screen to prevent brood fishes from escaping. The water flowing out from the side drain of the tank falls into a box-shaped chamber and further into a 4-inch diameter tube or conduit fixed to the bottom plank of the box, which also facilitates the collection of floating eggs for incubation and hatching. A 3-inch diameter standpipe (of length more than 4 cm of the required water depth in the tank) is fixed in the central drain hole inside the tank which has holes drilled on its lower one-foot length, to selectively remove waste from the bottom of the tank. The central drain is connected to the standpipe (SP) fixed outside the tank close to the side drain via a 3inch diameter pipe running underneath the tanks using a 3-inch elbow. This standpipe has a height slightly lower than that of side drain level (which is essential for regulating the percentage flow via overflow/ central drain) and is provided with a valve (V4) to regulate the water flowing out through the central drain. This helped to direct the full outflow through the central drain when the valve was kept fully open. Thus, by regulating the water flowing through the standpipe valve (V4), the percentage of water that goes out through the central drain and side drain could be controlled. Water (depth) in the tank will remain at the side overflow level. It is maintained at 1.0 m depth with the recirculation flow rate in the RAS at 9000 l h^{-1} in the case of the 10 t system.

Filtration system

The outflow from the tank, drained through the central drain and side drain fell into a bio-filtration system (BF) of size 180 x 70 x 60cm with three compartments, with partitions facilitating the flow of water from one compartment to the other serially. The first compartment was packed with

Fig. 2. RAS tanks in operation at marine fish hatchery of Vizhinjam Research Centre

a sponge filter, bio-balls, and coral rubbles in such a way that incoming water gets first filtered by the sponge. Filter sponge has to be cleaned with seawater twice a week. The next two compartments are packed with moving bed biofilm reactor (MBBR) media which is aerated and kept fluidised for efficient bio-filtration. Foot valve of the suction pipe of the pump (P) is kept in the last chamber (3rd) which pumps water out of the biological filter. The delivery was divided into three pipelines and seawater to each was controlled by three valves namely V1, V2 and V3. The valve V1 delivered water to a protein skimmer (PS) with a capacity of 250 l $min^{-1}$and from there the skimmed-aerated seawater was pumped back into the third chamber of the biological filter through outflow line of the skimmer. This kept the MBBR media in the third chamber in suspension. Valve V2 regulated the water flow into the RAS tank via UV system (Emaux Nano Tech Series UV System with timer–maximum flow rate of 15 m^3 per hr). Aeration is provided in the second chamber of biological filter by a venturi (Vr) connected in the bypass line (BL-the third branching line from the delivery line of the pump) and water flow was controlled by valve V3. This line brought the remaining water and air sucked in by the venturi into the second chamber and delivered the same below the MBBR media filled in the chamber through a bubble maker grid/disc. High-density systems of more than 30 t may require a drum filter for physical removal of particles before the water passed into the biological filter. Physico-chemical parameters such as salinity, pH, dissolved oxygen, water temperature, NH3-N of the seawater in the system has to be checked at regular intervals.

An average flow rate of 30 t, 10 t and 5 t RAS was 15000, 7000-9000 and 1500-2000 litre/hour respectively. Normally 12 h L:12 h D photoperiod is maintained during the culture period but 14 h L:10 h D speeds up the oocyte maturation and light intensity of more than 2000 lux also has to be provided. Temperature control, if needed, is achieved by passing the seawater through a chiller-heater combination taking a bypass line from the main delivery line and releasing back in the second or third compartment of the filter. These systems were successfully used in the maturation and spawning of serranid fish Marcia's anthias *Pseudanthias marcia*, Pink ear emperor *Lethrinus lentjan*, Silver pompano *Trachinotus blochii* and Banded grunter *Pomadasys furcatus* in the finfish hatchery of Vizhinjam Research Centre of ICAR-CMFRI. Adult sized fishes (*L. lentjan*) usually takes 4-6 months on an average to start volitional spawning while *T. blochii* requires 6-12 months to reach the oocyte maturity (500 to 600 μ) stage when hormone induced spawning can be done.

Argulus quadristriatus infestation in cage cultured Asian seabass

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Forty six numbes of Asian seabass *Lates calcarifer* (length:21.5 ±35.9cm; weight: 161.6±2.36g) collected from fish culture cages in three locations (Naganathwada, Sunkeri and Kumta) of Uttara kannada district, Karnataka were found infected with ectoparasites identified as *Argulus quadristriatus*. Major external symptoms of infected Asian seabass was the erratic swimming, behavior of fish of rubbing against net of the cage, hemorrhages and lesions of epithelial tissues in the infected regions. This is a first report of *A. quadristriatus* infection on seabass in cage culture ecosystem.

Prevalence of *A. quadristriatus* infestation was more on the head and operculum (Fig.1) and was high in the month of March,2019. Prevalence (%), severity of infection, gender status, mean intensity and abundance of *A. quadristriatus* was noted during study period. Parasitic Frequency Index (PFI %) was scored as : a=rare (0-9.9%); b=occasional (10-29.9%); c = common (30-69.9%); d = abundant (70-100%) and Severity score as: 0 = Absent, 0.5 = Present, low grade, 1=present, High grade, 2= present, Very high grade. The prevalence of infection was high in Naganathwada (PFI:50%) followed by Sunkeri (PFI:30%) and Kumta (PFI:7%). However, severity of infection was found to be more in Kumta (2) and low (0.5) in the other two sites. It was also observed that there was no variation in occurrence and abundance between male and female fishes in all the three locations. There was no record of mortality of cage cultured Asian seabass in any of the farms from where sampling was done. This parasite can induce lot of stress to the host when water quality is poor. Hence care should be taken with management protocols in order to prevent occurrence of these parasites.

Fig.1. Asian seabass infested with *Argulus quadristriatus*

Fig.2. *A.quadristriatus* (40X) isolated

Taxonomic note on the Indian species of genus *Netuma*

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In Indian waters, genus *Netuma* is represented by two species namely *N. bilineata* and *N. thalassina* (Order: Siluriformes, Family: Ariidae). Rounded shout, thin lips, inconspicuous median longitudinal groove, and higher anal fin ray count (16-19) are characters of *N. bilineata* while *N. thalassina* has conical snout, clearly visible median longitudinal groove and lower anal fin ray count (13-15). Prior to the erection of *N. bilineata (*earlier considered as synonym of *N. thalassina*) as valid species, Indian workers had difference of opinion regarding the representation of species under this genus from Indian waters. Jayaram and Dhanze (1978) were of opinion that only *Tachysurus thalassinus (N. thalassina)* is present in Indian waters and a similar looking species reported from India is the juvenile of the *Tachysurus thalassinus*. On the other hand, Menon *et al.* (1982) were of the opinion that there are two species namely *T. serratus and T. thalassinus.*

In present investigation, the two species were found to be significantly different in several morphometric aspects. *N. thalassina* is found to have longer pre-dorsal, snout and head length whereas longer adipose fin and barbels length were recorded in case of *N. bilineata.* Palatine teeth pattern of *N. thalassina* have longer and relatively narrowly separated posterior patch of teeth compared to *N. bilineata.* The inner vomerine teeth in the later case are joined along the mesial

Fig. 1. *Netuma bilineata* with round snout (a) and vomerine teeth attached along mesial line (b) with wider gap between posterior patches (c) indicated.

Fig. 2. *Netuma thalassina* with conical snout (a) vomerine teeth separated along mesial line (b) with narrow gap between posterior patches (c) indicated.

Table 1. Differentiating characters for the two species of genus *Netuma* from Indian waters

Characters	N. bilineata	N. thalassina
Snout	Round	Conical (prominent in adult)
Lips	Relatively thin	Relatively thin
Median longitudinal groove	Inconspicuous	Prominent
Anal fin rays	Mostly higher count (modal count 17/18)	Mostly lower (modal count 15)
Inner vomerine teeth patch	Joined along mesial line	Never joined along mesial line
Posterior teeth patch	Relatively widely separated	Relatively closer to each other

line, whereas in former case they are clearly separated. To help the field enumerators and surveyors in easy identification and correct reporting of the species from commercial landings the Figures (1&2) and Table 1 are presented.

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Kaleidoscope

Cobia culture in low volume cages in coastal waters of Uttara Kannada, Karnataka

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Cobia, *Rachycentron canadum* is a marine finfish globally favoured for aquaculture. In India, cage culture of cobia was first reported by ICAR-CMFRI in 2013 with better growth rate recorded under conditions of higher salinities (Philipose *et al*.2013). The present report is on the growth and production of cobia, *Rachycentron canadum* in Gangavali estuary (14º 61’ 225’’ N and 74 º35’726’’E) of coastal Karnataka during the period 2018-19. Cage culture of cobia by a local fisherwomen of Shiroor village of Ankola taluk in Uttarakannada district of Karnataka under ICAR-CMFRI-NFDB (National Fisheries Development Board) project on “Open Water cage culture in selected Districts in Kerala and Karnataka” was successfully completed. 1724 numbers of hatchery produced cobia seeds with an average initial weight of 15 gm were stocked in square galvanized iron (GI) cage (4m x 4m x 3 m) during December 2018 and were fed with low value fishes during the culture period. Culture

Fig.1. Cobia harvest from cage site at Shiroor village, Uttara Kannada, Karnataka

was for a period of 180 days and recorded an average final weight of 475 g each. The specific growth rate and average daily growth rate of fish were recorded as 1.46 % weight gain/day and 2.51 g/day respectively. The water quality parameters were recorded during the culture period and the salinity ranged between 24-28 ppt. The harvested biomass of 460 kg after 180 days of culture generated an income of 1,0,1200. The study indicated that cobia is a potential candidate species for coastal water cage culture but growth rate was low compared to marine waters. The present study indicated the prospects of cobia cage farming in coastal Karnataka to meet the future demand for food fish from aquaculture sector in India.

Kaleidoscope

Installation of fishing net tracking buoys in deep sea multiday tuna drift gillnetters at Chennai

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The deep sea multiday tuna drift gillnetters face many risks while they engage in fishing. The cutting and stealing of nets by fishermen of other boats or damage of the nets by the ships is common. As the total length of a net when set is around 5 to 6 nautical miles (nmi) and the fishing is carried out during night, quite often the fishermen come to know about the loss only at the time of hauling the net. Another serious issue is the possibility of collision with an approaching ship as sometimes the fishing ground can be on the same track of a ship and fishermen notice it only when the ship is too near to them. Installation of fishing net tracking buoy can effectively avoid these risks and enable a hassle free fishing trip.

The deep sea multiday day tuna drift-gillnetters in Chennai have fitted the fishing net tracking buoy in their boats in April-May 2019. This consisted of a transmitter (model SH-098 AIS buoy) fitted on the net, a receiver and a screen chart plotter fitted on the boat. The transmit distance is about 15 nmi. In a boat generally, two transmitters, one receiver and one screen are used and the total cost of these is ₹ 75000. Now most of the drift gillnetters are fitted with this they have mostly procured this without any incentives from the government. With this installation, there is slight modification in the operation of net also. Earlier, one net consisted of 60 net pieces joined together during the setting of the net. One end of the net was free and the other end was tied to the boat. Now, the tying of the net to the boat is done away with and instead the net is divided into two, with each one consisting of 30 pieces. After fitting one transmitter to each net, these are set in one beside the other in any desired position. This enables the fishermen to haul the net at different times. The nets are monitored from the boats throughout the period of operation. The advantage with this system is that the fishermen can always track the position of the net, the presence of any other boats near the net and also other approaching ships or boats. Similar tracking system was installed much earlier in the boats based in Tuticorin Fisheries Harbour.

Stranding of the Risso's dolphin in the Gulf of Mannar

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A dead female dolphin identified as Risso's dolphin, *Grampus griseus* (Fig.1) was found on the shore at Vedhalai, Gulf of Mannar near Mandapam, Ramanathapuram district, Tamil Nadu on 5th May 2019. 26 morphometric parameters recorded are given below (Table 1).

The specimen was relatively robust with unique body, head was blunt without distinct beak. Compared to other dolphins the forehead was bulging with relatively more squarish profile than the rounded melon. A prominent vertical crease on the front side of the melon was noticed. The dorsal fin was relatively tall and slender with a pointed tip. The flippers were relatively long. The upper jaw had only one pair of worn teeth and the lower jaw had six pairs of worn-down teeth. With the available morphometric information including the absence of beak, blunt-head and its overall size, with its bulk ahead of the dorsal fin, it was identified as *Grampus griseus*. The carcass was in an advanced stage of decomposition and necropsy findings did not reveal any abnormalities.

Fig. 1. Carcass of Risso's dolphin in Gulf of Mannar

Table 1: Morphometric measurements of the Risso's dolphin

Morphometric parameters		Measurement (cm)
Length, tip of forehead to angle of mouth	:	15
Length, tip of forehead to blowhole	:	25
Length, tip of forehead to center of eye	:	22
Length, tip of forehead to anterior insertion of dorsal fin	:	115
Length, tip of forehead to tip of dorsal fin	:	127
Length, tip of forehead to fluke notch (total length)	:	232
Length, tip of forehead to anterior insertion of flipper	:	43
Length, tip of forehead to center of umbilicus	:	101
Length, tip of forehead to center of genital aperture	:	148
Length, tip of forehead to center of anus	:	157
Length, notch of flukes to center of anus	:	60
Length of flipper: anterior insertion to tip	:	44
Length of flipper: axilla to tip	:	29
Width of flipper: Maximum	:	16
Fluke span	:	58
Width of flukes	:	28
Depth of fluke notch	:	5
Height of dorsal fin	:	31
Width of dorsal fin	:	20
Base of dorsal fin	:	37
Girth: axillary	:	94
Girth: maximum (at anterior insertion of dorsal fin)	:	136
Girth: at the level of anus	:	51
Blubber thickness: ventral	:	2
Total number of teeth on one side of upper jaw	:	1
Total number of teeth on one side of lower jaw	:	6

Record of the Trident cuttlefish from Maharashtra coast

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Cuttlefish are important fishery resources landed mostly by mechanized trawlers operating along Maharashtra coast. Many new records of cuttlefishes have been reported from Maharashtra over the years. Trident cuttlefish, *Sepia trygonina* (Rochebrune, 1884) was observed in trawl (reported depth of trawl operation was about 30-40 m at 70-80 km southwest of Mumbai coast) landings at New Ferry Wharf, Mumbai on 10.11.2017. The. The dorsal mantle length (DML) of the species landed ranged from 66.12 to 85.04 mm with corresponding weight ranging from 17.87 to 35.35 g.Identification was based on following characters: mantle oblong, acuminate posteriorly, fins narrow. Tentacular clubs short, with a well-developed swimming keel extending proximally beyond the base of the club; 5 suckers in transverse rows; 4 greatly enlarged suckers in longitudinal series towards posterior end of club dorsal protective membrane broad and separated at base from the ventral membrane. Cuttlebone outline lanceolate, strongly recurved ventrally and anterior striae on cuttle bone inverted U-shaped (Figs. 1& .2).

Fig. 1. Trident cuttlefish *Sepia trygonina* landed in New Ferry Wharf, Mumbai

Fig. 2. Cuttlebone of Trident cuttlefish

Record size Gizzard Shad and Titan Cardinalfish landed

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Nematalosa nasus (Bloch, 1795) a small pelagic fish and locally known as 'Kundadi Mathi' (Malayalam). are mainly caught in ring seines, gill nets and occasionally found in pelagic trawl and shore seine landings of Malabar region. During a field visit on 30th Aug. 2018, four specimens of unusually large *N. nasus* were procured from the gill net landings at Chaliyam fish landing centre,Kozhikode. The specimens measured from 230 mm to the largest 280 mm in total length (TL) & weighed 127 g to 248 g (Fig. 1 & 2). Three out of four were females (252 mm, 263 mm & 280 mm TL) with late matured to partially spent stage and a single male measured 230 mm TL was at late mature stage and weighed 127 g to 248 g each. The maximum TL reported for *N. nasus* reported in FishBase is 255 mm (Froese & Pauly, 2018. *FishBase*, version (06/2018). In India the largest record of *N. nasus* reported from the East coast was 252 mm TL caught in Chilka Lagoon, Odisha, (Panda *et al.,* 2016. *J. Appl. Ichthyol.,* 32 (6): 1286-1289) and on the West coast was 241 mm TL landed at Fort Kochi, Kerala (Roul *et al.,* 2017. *Mar. Fish. Infor. Serv*., 231: 27-28.) Other morphometric measurements of the largest specimen (280 mm TL) were as follows: Head length, 54 mm; Snout to insertion of pectoral fin, 52 mm; Snout to insertion of pelvic fin, 95 mm; Snout to insertion of dorsal fin, 98 mm; Snout to insertion of anal fin, 151 mm; Maximum body depth, 91 mm; Inter-orbital width, 18 mm; Standard length, 212 mm and Fork length, 230 mm.

The Indo-Pacific genus *Holapogon* universally known as titan cardinalfish is represented by a single species *Holapogon maximus* (Boulenger, 1888) which are purely marine, mostly found in 38 to 100 m depths. In recent years particularly during post monsoon

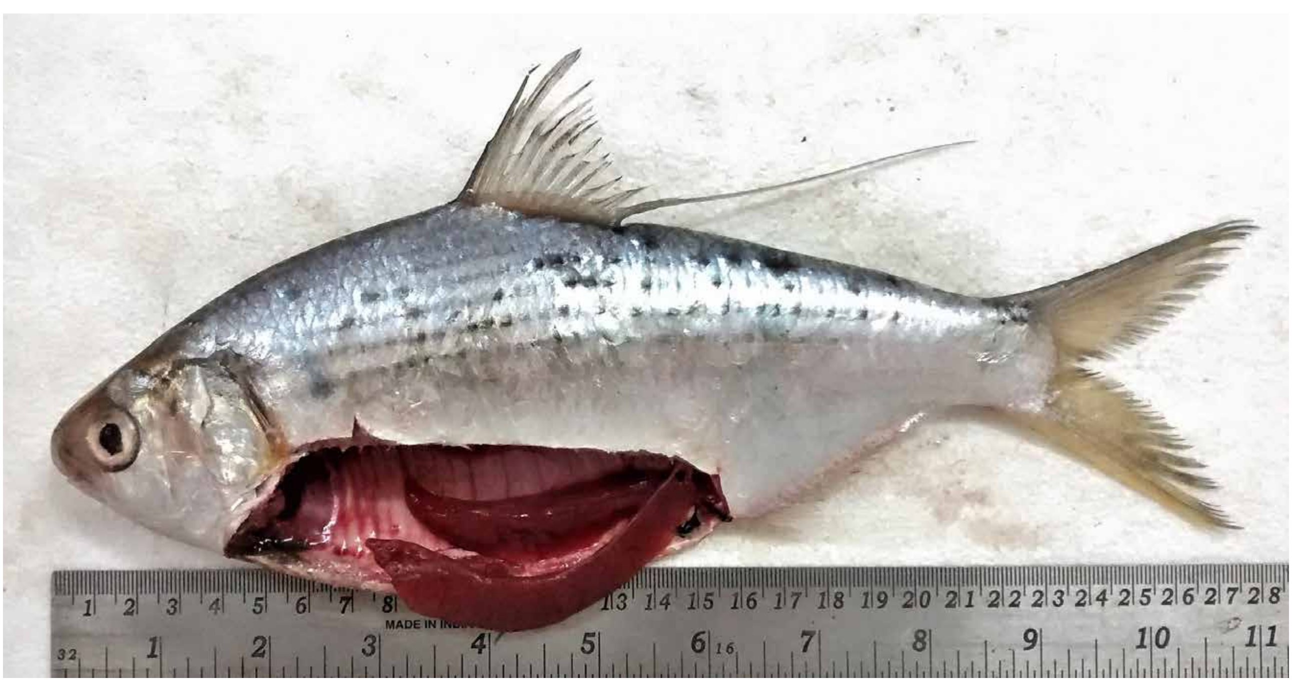

Fig. 1. *Nematalosa nasus* (Female, 280 mm TL, with partially spent gonads)

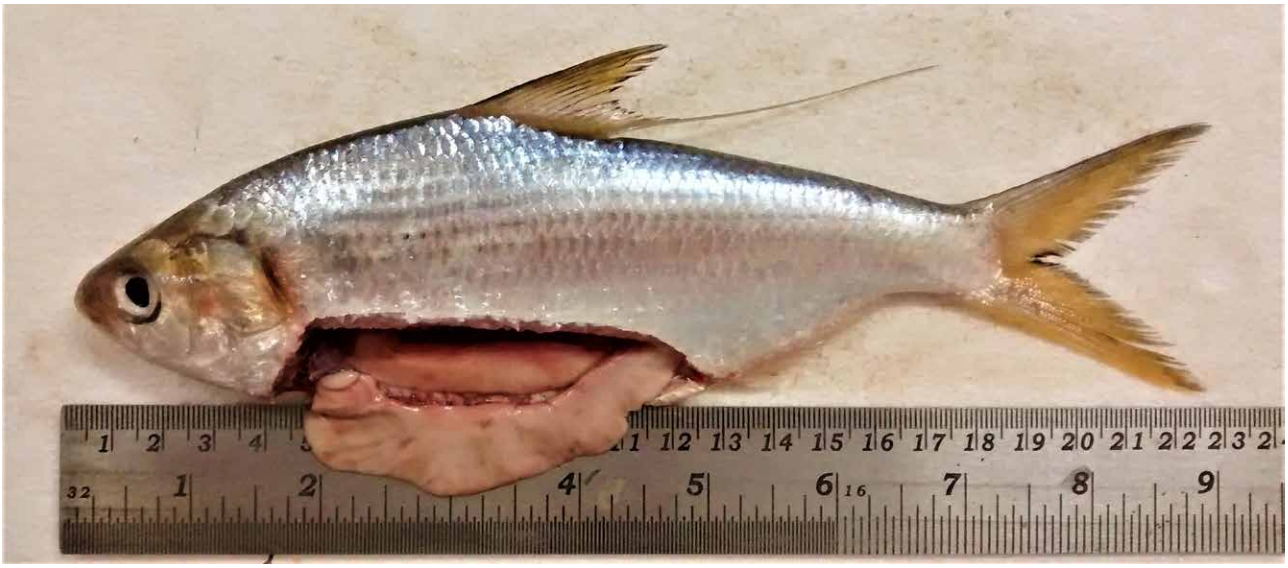

Fig. 2. *Nematalosa nasus* (Male, 230 mm TL, with mature gonads)

months, specimens of various sizes are frequently encountered in the multiday trawl catches in Kerala. During a regular field visit on 22nd October 2018, an unusually large specimen of *H. maximus* was collected from the multiday trawl landings at Puthiyappa Fisheries Harbour, Kozhikode, Kerala. The specimen measured 273 mm total length (TL) and weighed 258.5 g (Fig. 3) and was deposited to the Marine Biodiversity Museum of Calicut Research Centre of ICAR-CMFRI. The largest *H. maximus* so far recorded from its distribution is 250 mm TL (Froese and Pauly. 2018, *http://www.fishbase.org*).

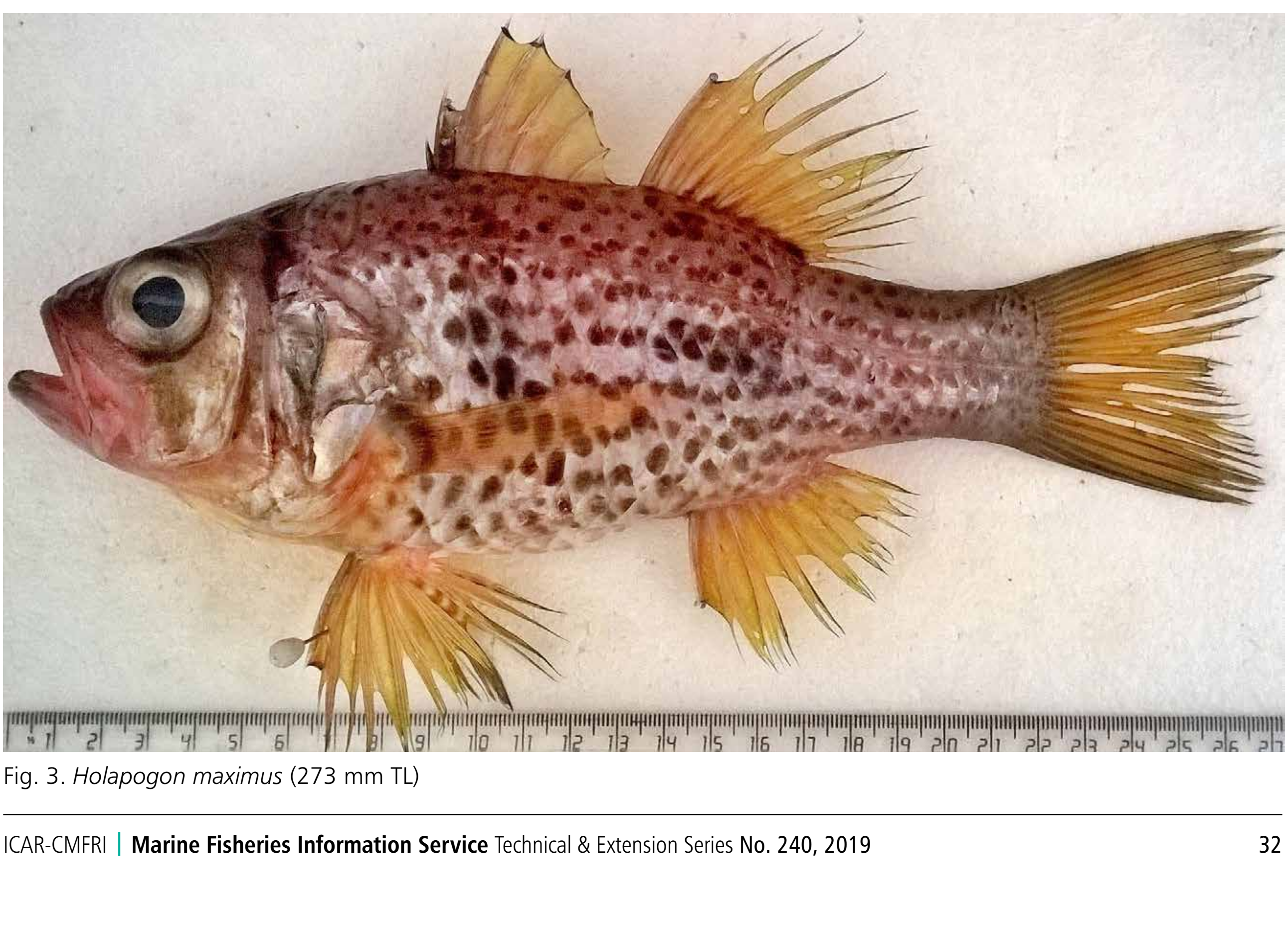

Fig. 3. *Holapogon maximus* (273 mm TL)

Albinism in Engraved catfish from Northeast Arabian Sea

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In Maharashtra, catfishes form 2.3% of fishery landings and is dominated by ariid catfishes. The major species supporting the fishery include *Osteogeneiosus militaris, Plicofolis tenuispinis, P. dussumieri, Nemapteryx caelata* and *Netuma thalassina*. In October 2018, two albino specimens of the Engraved cattfish *Nemapteryx caelata* (measuring 37 and 40 cm in Total Length, TL) was collected from the landings of a commercial trawler operated off Mumbai at 50 m depths (Fig.1). Though an estimated 2.7 tonnes of catfishes were landed in the same week, additional albino specimens were not observed. Albinism or lack of pigmentation is caused by a disorder in an enzyme that controls melanin metabolism. Albinism in marine fishes has been sparsely reported and documented and reports from India indicate most of them are from the northern Arabian Sea. Both albino specimens of the Engraved catfish *N.caelata* mentioned in the current report are retained in the museum collections of ICAR-CMFRI at Mumbai.

Fig.1. Albino *Nemapteryx caelata* (40 cm TL, fresh condition) caught off Mumbai

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Friedman and Bell. 1996. *J. shellfish Res*., 15: 535-541. (Reference with two authors)

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