Area, Production and Yield analysis for Shrimp and Seaweed farming

Dr.(Cdr.) Arnab Das
Director
Maritime Research Center
Pune, India

Shlok Nemani
Research Intern
Maritime Research Center
Pune, India

***Abstract*—The first step towards the introduction of technological interventions would be to compile and study the growth pattern and trends in the domain of associated aquaculture species. This is formally termed as the Area, Production, and Yield (abbreviated as APY) analysis. The development of area, Production, and yield analysis tools to assist in the conventional APY analysis of shrimps and seaweeds is becoming necessary with the increasing prospects associated with aquaculture. The expansion of marine related activities to cope with increasing demand has led to the trade-off between area under cultivation and the land available for sustaining biodiversity. The opportunities and challenges in conducting the APY analysis for marine species in the Indian ocean region (abbreviated as IOR) have been discussed. The future advancements by employing frontier technologies in the aquaculture development are mentioned in the paper.**

***Index Terms*—Shrimps, Seaweeds, Indian Ocean region, APY analysis, APY Tool, Django**

I. Introduction

Shrimps and seaweeds are aquatic species. Shrimps are a major as well as a delicious source of food, popular in most of the country. Shrimps have numerous species out of which many are even marked as commercially important species in India. The species *White leg shrimp and Tiger shrimp* having the scientific name *L.vannamei and P.monodon* are the two widely cultivated for the commercial purposes.

With an increasing demand for the shrimps and seaweeds as a source of food and an important raw material for manufacturing value added products, the need for sophisticated technological interventions is becoming more and more necessary. India has a substantial potential in terms of geographical biodiversity and human capital, if harnessed properly, can lead India in becoming mega consumer and global exporter in the world.

In the year 2020-21, 1.08 Lakh ha. area was under the white leg shrimp cultivation and 58,196 ha. the area was under tiger shrimp cultivation. (src: MPEDA [1]). The estimated brackish water area in Indian region which is considered suitable for undertaking shrimp cultivation is 11 lakh hectares. This shows the vast disparity between the available potential and harnessed potential. The factors behind this disparity need to be studied and issues must be resolved to enhance the production. Considering about the seaweeds, not much importance to increase their production is given, which is clearly visible from the fact that India's share in the global seaweed production is 0.01% despite the well-known fact that India has more than 8000 km coastline, and approximately 2.17 million sq. Km, economic exclusive zone (EEZ) [2]. India needs to import seaweeds to meet its required demands despite having rich geography and climatic favour.

The aquaculture farmers currently lack in having advanced technology at their disposal which can help not only to guide them to maximise their returns by analysing and suggesting the optimal parameters but also have the added benefit to digitally link them.

II. The Broader Perspective on Underwater Domain Awareness Framework

The results and the research benefits the three key stakeholders of the Underwater Domain Awareness (abbreviated as UDA) framework and accompanies them for figuring out the sustainable pathway for the development of aquaculture in IOR. These stakeholders are

- Science and Technology
- Blue Economy
- Marine Environment and Disaster Management

Sustainability is becoming the key challenge in the development of every technology. As the masses are becoming more aware about the risks of climate change and impacts of anthropogenic activities on the global scale, governments and organizations are now more inclined towards developing a sustainable economy, where the step is to minimise the negative impacts and finding pathways to eliminate them.

Every action have an associated consequence. Same goes true in the context of the expansion of shrimp aquaculture. The following cause-effect list related to the environmental impacts of expansion of shrimp aquaculture [3].

- Establishment of shrimp ponds - Wetland destruction: Biodiversity loss, reduction in mangrove cover, reduced yields of commercially important species, and alteration of water drainage patterns
- Conversion of agricultural land: The land under rice fields may be affected with increasing demand of land under aquaculture, this can lead to disputed between the agricultural and aquaculture farmers
- Discharge of shrimp pond effluents: The shrimp pond effluent is highly acidic because of chemicals which, if not

properly treated before discharge can lead to discharge of toxic chemicals into the adjacent water bodies.
- Salt water intrusion: The seeping of chemicals into the ground water will increase the salinity and toxicity of the ground water, leading to the fresh water crisis and fresh water availability related disputes.
- Soil Treatment: The bedding of shrimp ponds requires the chemicals to treat the soil in order to make it suitable for the growth of the shrimps.
- Post-industrial Processing Waste: Not only the cultivation, but also after the shrimps are being processed or sold as a food, the non-edible parts needs to be disposed. If these wastes are thrown directly in the river, it may lead to eutrophication due to biological decomposition.

While the negative impacts of the Shrimps are so prominent, the positives of seaweeds make them highly desirable for their increased production, which is naturally assisted by the sustainable nature of the seaweeds [4]. The seaweeds as *a pioneer of sustainable aquaculture*, because of their versatile uses [2], can be understood from its following properties:
- Carbon Sequesters: Seaweeds act as natural water purifiers as they absorb carbon dioxide from deep waters. The carbon absorbed is needed by the seaweed species to support their life, growth, and metabolism.
- Ocean de-acidification: Seaweed metabolism for growth requires the nitrates and phosphates compounds for NP-Kinetics, which they absorb from the surroundings, and thus optimally maintains the overall concentration of these minerals in the water.
- Nutritious Source: They are the source of various nutritious elements having vital importance in our health. Therefore, they can be seen as a food source rich in vitamins and minerals, and have huge scope to become an integral part of our plate.
- Cattle feed: Rich in nutrients, they can be primarily used as a feed for cattles. It has an added benefit that the manure generated from cattle waste and cow dung manure will be highly rich in the amino acid nutrients required in the soil for better plant growth and has the potential to enhance crop yields.
- Oxygen level restoration: Being a phytoplankton species, they acts as oxygen generators which is a byproduct of the process of photosynthesis. The depleting oxygen levels in natural water reservoirs because of anthropogenic activities can be countered by promoting the growth of seaweeds.
- Coastal ecosystem engineers: The Floating Bamboo Raft Technology and seaweeds planted on the bamboo raft, are found to attenuate the ocean waves and thus can act as water shock wave dampers [5].
- Wastewater Treatment: Having the ability to accumulate the heavy metals present in the water, they can be employed in water treatment plants to eradicate the traces of metallic elements, iron, copper, and zinc which get accumulated due to flow of toxins, chemicals by industries or human-related activities to the water bodies.

III. Discussions

A. Area Production Yield analysis

The APY analysis should include two broad domains for the outcomes to be practically understandable:

1) **Growth patterns in Area, Yield and Production**: This is required for the instability and risk assessment, by highlighting the regions having the negative growth pattern or high variability of production. The more the risk, higher is the danger associated with investments made.
Advantage: The regions can now be scaled on the basis of growth rate, the higher returns associated with regions of high and positive growth rate will attract huge investments.
Disadvantage: It has a limitation that it does not directly give the reasons as to why such trends are occurring. It is the job of the researcher to accumulate the data about the economy and willingness of the farmers by conducting onsite research and relate the two.

2) **Yield parameter relationship**: It involves establishment and verification of relations relating the obtained Yield with the parameters affecting the yield. It is important to figure out the optimum value of these parameters to maximise the Yield. Maximising the yield is the first step to make the production sustainable in terms of land cover under cultivation.
Advantage: The modelling of the variation of the Yield with the parameters can be incorporated within further advancements for development of a fully-fledged working software as all-time farm observation system.
Disadvantages: Huge amount of real-time survival and growth data is required for the modelling purposes. The farmers should be made techno-friendly to make this research plausible in reality.

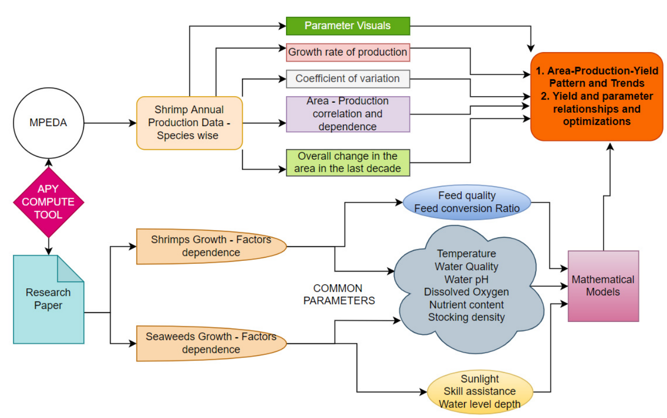

Fig. 1. The working architecture and modelling of the developed APY tool

B. Development of the APY Tool

1) Aim of the Tool: The APY compute tool is designed to have two unique functionalities:

1) Available Data Analysis: It assists the researcher by providing the relevant parameters and visualisations required for analysing the growth trends, based on the provided input data. The further conclusions can be easily made by the
2) Parameter Based Analysis: From the established probabilistic model, where every parameter acts as a random variable, it extracts the effect of the parameter on the yield. Through this analysis, one can obtain the probability of survival.

2) Technalities of the tool: The tool is developed in the *python* coding language. The computations and webpage rendering are done by the Python's open source web framework *django* [6]. The plotting of graphs is done using the *Matplotlib* library and their image rendering on the webpage is handled by the *StringIO* package. The regression study of the data is done using the python's mathematical library *numpy* and the statistical library *scipy*. The Front end of the tool is written in *html* and designed in *css*, and site-user interactions are handled in *javascript*.

3) Working: The sole motivation to use a Python framework for this compute tool is that in future, the advancement of the compute tool to the monitoring tool and the subsequent availability of real time data may require the use of neural net models famously written in Python libraries, which can be easily interfaced in the django as it is solely written in python. The development of the APY compute tool in the django framework which is based on the model-template-view pattern, is shown in the following flowchart.

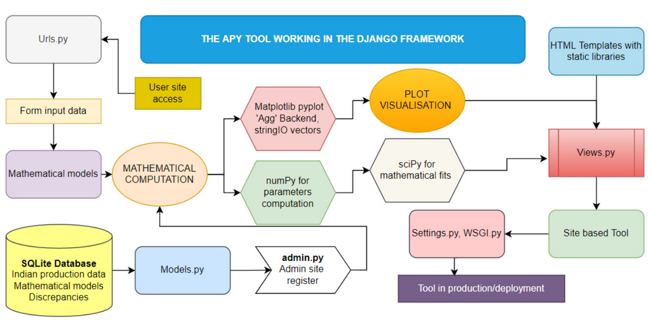

Fig. 2. The flow of the django-based APY tool

C. Selection of the species

1) Shrimps: The following species are the widely cultivated shrimp species (src. [1]) in the IOR region in recent decades:

- L.Vannamei: The Litopenaeus vannamei specie is the largely cultivated species in the last decade. The growth rates of the production in all the coastal areas are very large. This shrimp species have the advantage of higher survival rates even with fluctuating parameters. It also benefited the farmers in monetary terms as they can achieve the Feed conversion ratio (FCR) of 1.2. The optimal parameters for this specie are the salinity range of $0.45 - 0.55^oC$, the stocking density of $150 units/m^2$ are achievable, and even survives at low salinity levels of 10-15 ppt, whereas the optimal is 35 ppt. It is also called the 'White leg' shrimp based on its characteristics [7].
- P.monodon: Also known as the 'Tiger' shrimp, the most significant advantage of Penaeus monodon over the L.vannamei is its high weight and relatively smaller cultivation cycle. This specie can also tolerate the salinity levels of 0.2 to 70 ppt. The temperatures of about 37.5^oC are tolerable while some species even die at such temperatures [7].

D. Seaweeds

The following species are widely cultivated seaweeds in the Indian Ocean region [2]:

- Kappaphycus alvarezii: The production of the red algae/seaweed *kappaphycus* have good prospects associated with it because of the demand of this species in the manufacturing of various value-added products like pharmaceutical products, agar, alginate, carrageenan extracts, which have huge international demand.
- Gracilaria edulis: The Gracilaria species is also a kind of red algae and is mainly used in the production of food products and commercial food grade agar. Additionally, it has been used in the production of binding materials for lime used in wall paintings. There are wide variety of species under the Gracilaria family which shows different variations with different parameters.

E. Identification of Parameters

1) Shrimps: The following important parameters (natural/artificial) have been identified that have a significant effect on the growth of shrimps, and are being listed in the order of their influence on the growth:

- Temperature [8], [25]
- Stocking Density [9], [10], [25]
- Water Quality [11], [12], [27]
- Dissolved oxygen level [13], [27]
- Feed Conversion Ratio [14], [25]
- Soil Quality [15], [27]
- Feed Quality [16]

2) Seaweeds: The following important parameters (natural/artificial) have been identified that have a significant effect on the growth of seaweeds:

- Temperature [17], [18]
- Light Intensity (Sunlight) [19] and Effect of UV rays [30]
- Water Salinity and Nutrient content [17], [20], Water motion [31]
- Stocking Density [21], [22]
- Water level Depth and clarity [19], [23]
- Skill Assistance [24]

IV. Modelling

The model for APY analysis can be seen as a mapper or function, which maps the input parameters to the output (in our case, is the final weight of the species). It can be mathematically represented as

$$W = \alpha(r_1, r_2, ..., r_k) * f(p_1, p_2, p_3, ..., p_n) \quad (1)$$

Where,
$r_1, r_2, r_3, ...r_k$ denotes the qualitative parameters
$p_1, p_2, p_3, ...p_k$ denotes the quantitative parameters
The former function α will be considered as a weighing constant as the qualitative parameters will be computed as probability factor. The probabilistic intersection bound gives

$$P(A_1)+P(A_2)+.....+P(A_k)-(k-1) \leq P(A_1 \cap A_2......\cap A_k) \quad (2)$$

$$\leq min(P(A_1), P(A_2), ..., P(A_k)) \quad (3)$$

The latter function f will be modelled on the basis of the data available under researches.

A. Shrimps

1) Temperature: The temperature not only effects the growth rate but also alters the feeding rate and feed conversion ratio of the shrimps. These variations show the high dependence of the shrimps growth on the temperature fluctuations. The studies [8] show that the growth rates of shrimps also vary with the size (the body mass), which may occur due to metabolic changes. The table data showed the contrast

TABLE I
GROWTH(GRAMS/WEEK) OF THE SHRIMPS WITH TEMPERATURE AND SIZE

Size	**Temp=**23^oC	**Temp=**27^oC	**Temp=**30^oC
Small	0.8	1.78	2.1
Medium	0.42	1.1	1.25
Large	0.37	0.62	0.5

of variation of growth rate with temperature and size. The temperature range considered can achieve 100% survival rate if other parameters are within the limits. The study depicted that the temperatures less than 23^oC and much larger than 30^oC are not optimal and survival rate will be very low.
Linear weighted sum model The overall growth can be modelled as a linear weighted sum of growth rates over the period of days of cultivation of the shrimps as follows

$$W = a * GR_S + b * GR_M + c * GR_L \quad (4)$$

Where,
GR_S = Growth rate for small shrimps
GR_M = Growth rate for medium shrimps
GR_L = Growth rate for large shrimps
W = Final Weight
and a,b,c is the number of weeks for small, medium and large shrimps respectively.
The cultivation times were taken to be 20 weeks and the temperature under study was kept at $27-29^oC$. Therefore, the growth rates at the temperature 28^oC are taken into consideration. The standard final weight for the species is 21 grams which is considered here for formulation [25]. The equation to be solved becomes

$$W = a * 1.94 + b * 1.17 + c * 0.56$$

under the constraints,

$$a + b + c = 20$$

The solution is $a = 4$, $b = 7$, $c = 9$.
Thus, the equation can be considered as

$$Weight = (0.2 * GR_S + 0.35 * GR_M + 0.45 * GR_L) * t$$

Where,
t = Time of cultivation in weeks
In order to make the model general, the second step will be to generalise the growth rates GR_S, GR_M and GR_L. The quadratic exponential piecewise model for the GR_S can be given by

$$\begin{cases} 0.456e^{(x-22)} & x \leq 22 \\ -0.01976x^2 + 1.2330x - 17.1071 & 22 \leq x \leq 35 \\ 1.843e^{-(x-35)} & 35 \leq x \end{cases}$$

Where, x denotes the temperature in degrees centigrade
The decay rates are decided on the basis of the chance of species of survival, and the *L.vannamei*, which is the one of the abundant species has also shown the sign of tolerance of up to 37 degrees centigrade, this is kept in mind to decide the appreciable decay rate for all the three growth rates outside the region of optimality.

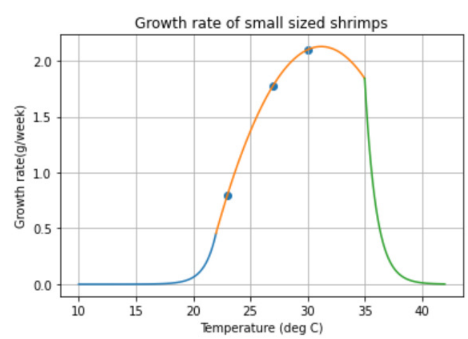

Fig. 3. The GR_S variation curve plotted on the basis of the derived piecewise model for GR_S

Applying the similar procedure for calculation of the growth rate of medium-sized shrimps with the available data can yield the following quadratic exponential piecewise formulation:

$$\begin{cases} 0.1643e^{(x-22)} & x \leq 22 \\ -0.01714x^2 + 1.0271x - 14.1357 & 22 \leq x \leq 35 \\ 0.8143e^{-(x-35)} & 35 \leq x \end{cases}$$

Where, x denotes the temperature in degrees centigrade

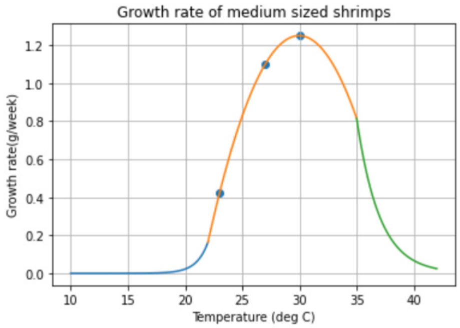

Fig. 4. The GR_M variation curve depicting temperature dependence on the growth of medium sized shrimps

The growth rate model of the large shrimp can be given by

$$\begin{cases} 0.234e^{(x-22)} & x \leq 22 \\ -0.0146x^2 + 0.7946x - 10.16 & 22 \leq x \leq 35 \\ -0.285e^{-(x-35)} & 35 \leq x \end{cases}$$

Where, x denotes the temperature in degrees centigrade
One thing to note in this case is the curve goes negative for temperatures greater than 32^oC, which also agrees theoretically that the growth is affected at higher temperatures.

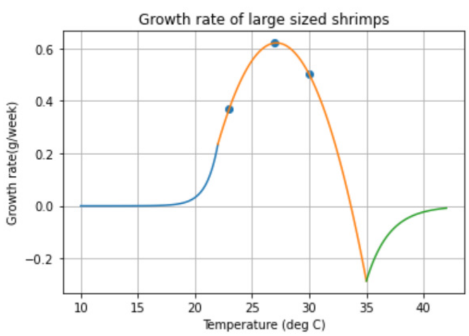

Fig. 5. The GR_L variation curve shows the temperature dependence on the growth of large sized shrimps

On the basis of the formulated results for the GR_S, GR_M and GR_L and combining all three results, to obtain the temperature dependence on the growth (g/week) of the shrimp as shown in Fig. 6.

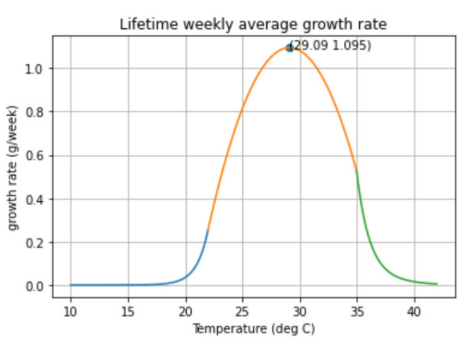

Fig. 6. The overall averaged growth rate curve of shrimps with varying temperature. The marked point shows the maxima of growth rate.

Observations: The APY tool suggested that the farmers should make efforts to keep temperature in the close proximity of about 29 degrees. Many regions of the coastal area naturally possess such temperatures for most of the periods of the cultivation year. Hence, our climate intrinsically favours the growth of these shrimps.

2) Stocking Density: Stocking density refers to the number of species cultivated/grown on a given amount of area. This area is called as the area of cultivation.
For shrimps, mathematically,

$$S.D = \frac{\text{Number of Shrimps}}{\text{Area of pond}}$$

Higher stocking density is desirable for the farmers as they can use the available land to maximise their overall yield of shrimp, but very high stocking density takes toll on the biological and metabolism development of the shrimps, leading to lower survival rates [9]. Therefore, roughly, with increasing stocking density, the overall biomass increases, then it attains the peak and thereafter, the correlation is negative. The growth rates with stocking density [10] are tabulated as follows:

TABLE II
GROWTH RATE (G/WEEK) OF THE SHRIMPS WITH STOCKING DENSITY

Stocking density ($/m^2$)	Growth rate
30	1.5248
40	1.394
50	1.167
60	1.0675
70	0.9905
80	0.856

Using the *numpy polyfit command in python* to fit the curve with the available research data, the relation between growth rate and the stocking density can be formulated as

$$GR = 9.44 * 10^{-5}x^2 - 2.47 * 10^{-2}x + 1.98 \quad 20 \leq x \leq 100$$

Where, x denotes the stocking density
GR denotes the growth rate in grams/week

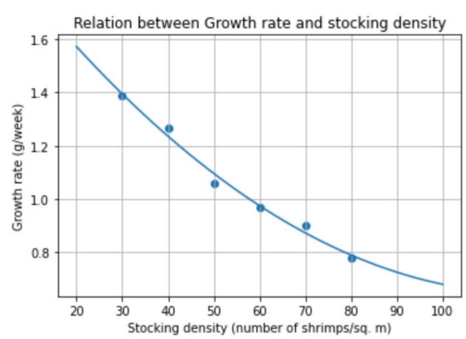

Fig. 7. The overall averaged growth rate curve of shrimps with varying stocking density, with scatter points showing the available data and line plot is the best fit curve

The obtained relation and curve is a normalised curve with respect to the temperature model. All these values are *normalised so as to take the product of dependence of growth on both temperature and stocking density.*

Incorporating survival probability/rate: *(Assuming that all other parameters are optimised to their best)* The study of survival rate is important because the net productivity also depends on the factor that *the alive shrimps are the only useful ones to be sold in the market*. The thing to note is as the survival rate is necessarily a probability, it is also intrinsically normalised on the scale of 1.

$$\text{Survival rate} = \frac{\text{Live Shrimps after full cultivation}}{\text{Shrimps cultivated}}$$

$$\text{Useful shrimps} = \text{Shrimp cultivated} * \text{Survival rate}$$

Conceptually, as per the biological understanding, higher stocking densities leads to lower survival because of congestion, crowding, and nonavailability of enough nutrients. The curve fit on the survival rate and the stocking density data as tabulated in the following table [10] also confirms the same theory.

TABLE III
SURVIVAL PROBABILITY OF THE SHRIMPS WITH STOCKING DENSITY

Stocking density ($/m^2$)	survival rate
30	0.95
40	0.925
50	0.91
60	0.90
70	0.85
80	0.82

The relation can be mathematically formulated as

$$S.P = -2.94 * 10^{-5}x^2 + 0.0007x + 0.951 \;\; 20 \leq x \leq 100$$

Where,
$S.P$ is the survival probability
x denotes the stocking density
Without the available data for the extreme cases, the model is assumed to be capable to give the acceptable results for the usual stocking densities till $100/sq.m$.

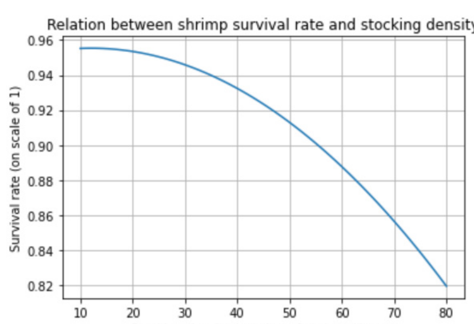

Fig. 8. Survival rate of the shrimp with varying stocking density

3) Water Quality: Water quality is a broader term encompassing various parameters within itself. The main parameters constituting the overall quality of the water are [27]:

- Nutrient content (Nitrogen compounds, zinc traces, hydrogen sulphide, copper phosphates, and Iron) [11]
- Dissolved oxygen level of water [13]
- pH level of the water [12]

To incorporate the whole effect of the water quality, the relationship has to be established by taking one parameter into the consideration, keeping others constant. The theoretical cultivation criteria for L.vannamei for soil and water quality management can be thoroughly found in [25].

Water salinity

Salinity of water plays the most important role in determining the growth and survival of the shrimps. Shrimps cannot grow in fresh or saline-free water. The salinity determines the content of certain minerals which are important for the bio-kinetics of the metabolism of growth of the shrimps. Similar to the behavior at low salinity levels, at very high salinity levels, the growth rate is diminished. Consistent monitoring of the pond is required for maintaining the optimal salinity level. [11]

TABLE IV
GROWTH(GRAMS/WEEK) OF THE SHRIMPS WITH SALINITY

Growth rate (g/week)	salinity(ppt)
2.146	5
2.120	15
1.834	25
1.864	35
1.632	49

On fitting the curve with the quadratic model, there is no such significant second order effect seen in the curve. Thus, the curve fit to the data is taken to be linear, and the relation is as follows,

$$GR_{salinity} = -0.0056x + 1.04 \;\; 3 \leq x \leq 60$$

and the plot for the same is,

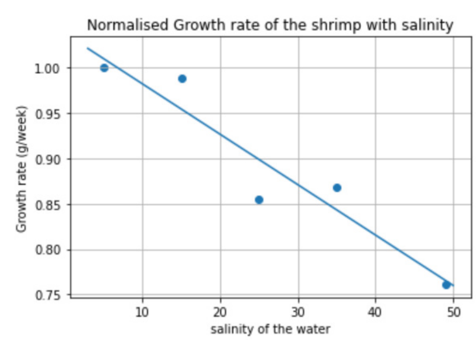

Fig. 9. Growth rate of shrimps with varying salinity (in ppt)

Water pH

In theory, the shrimp growth is affected in the acidic water and this is the main reason as to why their ponds needs to be limed before being prepared for the cultivation of the shrimps. The pH scale is a defined scale to determine the acidity of the substance. Lower the pH, higher is the acidity.

In general, water having pH below 7.0 is said to be dominated by acidic components and above 7.0 is said to be having higher basic components. Highly acidic and highly basic both tend to virtually stop the shrimp growth. The optimal range is experimentally seen to lie in the proximity neutral range. [12] From the available experimental data, the theory can be confirmed and a model relating the growth to the varying pH of water can be devised.

TABLE V
GROWTH RATE OF SHRIMPS (G/WEEK) WITH THE PH OF THE POND WATER

pH level	Growth rate (g/week)
5.1	0.28
5.9	0.5
6.5	0.52
7	0.55
8	0.67

The growth rate is being normalised to scale the effect of pH in the range 0 to 1. The normalisation is done by taking the ratio of the parameter and the maximum value of the same parameter over the whole data set. The same normalised curve can be seen in the following graph. The normalised relation between the growth rate and pH of water can be given by the following piece-wise quadratic-exponential model,

$$GR_{pH} = \begin{cases} 0.79e^{2(x-6.5)}, & 0 \leq x \leq 6.5 \\ -0.04x^2 + 0.721x - 2.16, & 6.5 \leq x \leq 9.5 \\ 0.98e^{-2(x-9.5)}, & 9.5 \leq x \leq 14 \end{cases}$$

Where, GR_{pH} denotes the normalised growth rate in grams/week with pH variations

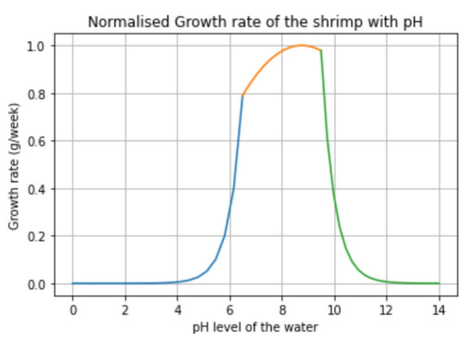

Fig. 10. Growth rate of shrimps with varying pH

Dissolved Oxygen

The oxygen is a vital element in the growth of shrimps. Adequate amount of oxygen is needed to be dissolved in the pond water, otherwise the effects in shrimps are adverse. From the available research data, the intuition is clear that low levels of oxygen concentration are lethal for the shrimps growth. The oxygen concentration also affects the immune response of the shrimps, which plays a critical role in case of any disease outbreaks [13].

TABLE VI
GROWTH RATE OF SHRIMPS (G/WEEK) WITH THE DO OF THE POND WATER

DO (ppm)	Growth rate (g/week)
< 2	1.98
2-4	2
> 4	2.52

As not much data about the variation of dissolved oxygen is available, this parameter cannot be completely fitted for the analysis. The data points may introduce significant errors because of the lack of data set.

4) Feed Quality: The quality of the feed used in the farms can vary the metabolism and healthy growth of the shrimps. [16] The major species White legged shrimp, which requires comparatively less protein than the others. The protein requirement for the shrimp varies between the quarter to 40% based on the density conditions. The optimal feeding frequency for this species lies around 2-6 times a day. The amount of feed distributed to the shrimps is highest in the evening conditions. The lipid requirements should be maintained along with the fatty acids and cholesterol contents. Certain kinds of foods being used for feeding the shrimps are:

- Natural Feed dependence
- Local feed meals made of clams, fishmeal, and Oilcake
- Imported pellets are used along with the local feeds
- Extensive use of high-quality imported pellets

For analysis purposes, the requirement is to scale these feed categorise according to an order, which is considered as follows:

TABLE VII
FEED QUALITY VALUES AND THE CORRESPONDING FEED

Feed	Quality
Natural feed	0.75
Clams, Oilcake, and fishmeal	0.85
Imported pellets+local feeds	0.95
High quality Imported pellets	1

Note that this scaling is purely intuitive based on the tool based results.

5) Feed conversion ratio: This term is defined as the ratio of the amount of feed taken or consumed by the animal or organism and the subsequent weight gained by the organism. Higher the feed conversion ratio, less profitable is the farming for the owner because the production costs or feeding costs will be high and the subsequent gains by selling the shrimp would be low. Hence, there has been the effort to reduce the feed conversion ratio as much as possible. The feed conversion ratio which is seen in L.vannamei cultivation is about 1:1.4. [14]

6) Combining all the relations: Finally, after modelling the dependence of the growth rate on all these significant factors, using the probabilistic approach to combine all obtained solutions.

Let, $GR(.)$ denotes the complete growth function of the shrimp. Then according to obtained relations, let

$$A(.) = GR_{temp} * GR_{stock\_den}$$

The required growth rate after using the probabilistic model,

$$GR(.) = p(r_1, r_2, r_3) * A(.)$$

Where,
$p(r_1)$ denotes the normalised pH dependence,
$p(r_2)$ denotes the normalised salinity dependence,
$p(r_3)$ denotes the normalised Feed Quality
From equation (iii), We have;

$$p(r_1, r_2, r_3) \leq p(r_1) * p(r_2) * p(r_3)$$

Therefore, the final expression is,

$$GR(.)\text{per week} = p(r_1) * p(r_2) * p(r_3) * A(.)$$

Final Weight of the shrimp is given by

$$W(\text{shrimp}) = GR(.)(\text{per week}) * \text{Weeks of cultivation}$$

Hence, the total biomass obtained from the farm in per sq. meters can be found by,

$$\text{Biomass}\frac{g}{m^2} = \text{Survived shrimps} * \text{Final weight}$$

Which can be formulated as,

$$\text{Biomass}\frac{g}{m^2} = \text{survival rate} * \text{stocking density} * \text{Final weight}$$

The land productivity in terms of monetary returns is given by,

$$\text{Productivity}(\frac{Rupees}{m^2}) = \frac{\text{Price (Per Kg)} * \text{Biomass}\frac{g}{m^2}}{1000}$$

This completes the overall estimated productivity analysis of the shrimp farm, if the data about the monetary gains of the shrimps are known.

Important Conclusions and observations

- The temperature is optimal around 30 degrees centigrade. The growth rate is much higher around 30 degrees than 25 degrees. The growth of the shrimps virtually stops below 18 degrees centigrade.
- The lower stocking density favours the growth of the shrimps. With increasing stocking density, the growth rate decreases. Similar relation holds for the survival rate behaviour.
- Salinity dependence is normally constant with no large variations. The salinity of brackish waters are preferable for the shrimps growth.
- The optimal pH is slightly above neutral and lies in the range of 8.0 to 9.0 pH for optimal growth performance.
- Higher DO levels are required for the survival of the shrimps. DO levels below 2 ppm are lethal for growth.
- The variations and dependence of growth rate and biomass accumulation on these external factors changes with the species under the cultivation. No two species have the same days of cultivation, neither have the same growth rate statistics, which is evident from the subtle disparities regarding cultivation between species as mentioned in [26].

Optimisation of the Inputs can led to higher Yields

The following different farming architecture confirms the fact that with better conditions and optimal growth environment, the yields can be significantly enhanced. On the basis of these conditions and parameters, the following categorisation has been proposed in [28]

- *Traditional*: In these systems, small amounts of shrimps are cultivated with large components of fish. There is no control over the water quality and stocking because the ponds are filled with tidal water. As evident, the production is low with average values hovering around 200 to 500 kg/ha. Such practice does not employ any technological intervention and is practiced in the Bheries systems of West-Bengal and Paddy-cum-aquaculture systems of Kerala, Goa, and Karnataka.
- *Improved traditional*: Improvising of the stocking of shrimp seeds. No improvements in the technology for water quality and waste management. No emphasis on the use of quality feed and there is full dependence on natural food in the ponds. Overall production saw a minor increment to some 300 to 600 kg/ha from the traditional system.
- *Extensive*: Square ponds with 2 m deep walls and freshwater supplied from canals. Stocking density is determined and kept to be 2-5/ sq. meter. The feed is prepared from clams, oilseeds, and fishmeal. The improved work shows improved yields of the order of 300 to 700 Kg/ha.
- *Modified extensive*: Higher stocking density of 5 – 10/ sq. meter with better construction of pond using liming, tiling, and fertilization. Local feed is mixed with imported pellet feeds to make quality feed. Resultant yields of 600 to 1100 kg/ha are possible.
- *Semi-intensive*: The farms of 0.25 to 1 ha size are constructed with a regular water supply and drainage canals for waste discharge. Imported pellet feeds and quality feed check is done. Much use of chemicals is involved to enhance efficiency. High stocking density of 15 – 30 /sq. meter is done and the average yield in India lies around 2200 kg/ha.
- *Intensive*: Similar to semi-intensive with an improvised central drainage system for sludge discharge. Very High stocking density of 30 to 80/sq. meter is used. The average yield theoretically can go up to 8000 kg/ha but in India lies about only 4500 kg/ha/year and the reason for lower production can be credited to various other factors. It is the most common practice in Taiwan and Thailand.

B. Seaweeds

To determine the influence of the parameters on the growth rate of the seaweeds, it is important to first understand the concept that the literature have various definitions regarding the growth rate of seaweed adapted in different researches.

- The daily growth rate formulae (adapted in [29])

$$GR = 100\frac{ln\frac{W_t}{W_0}}{t}\%day^{-1}$$

- The daily growth rate formulae (adapted in [17])

$$GR = 100\left[\left(\frac{W_t}{W_0}\right)^t - 1\right]\%day^{-1}$$

- The daily growth rate formulae (adapted in [30])

$$GR = \frac{100}{t}\left[\left(\frac{W_t}{W_0}\right) - 1\right]\%day^{-1}$$

- The relative daily growth rate formulae (adapted in [31])

$$GR = \frac{ln\frac{W_t}{W_0}}{t}day^{-1}$$

- The specific daily growth rate formulae (adapted in [32])

$$GR = 100\frac{ln(W_t) - ln(W_0)}{t}\%day^{-1}$$

Where,
W_t is the weight after time t units W_0 is the initial or reference weight t units is the study duration Of these all determined relations, the [33] showed that the second relation gives the least amount of error between the theoretical and experimental results and suggested that it should be used for quoting the growth rate results. Therefore, we are proposing the following formulation for the final growth rate, after obtaining the daily growth rate, in our analysis.

$$\text{Final weight} = W_0\left(\frac{GR}{100} + 1\right)^{doc}$$

Where,
doc denotes the days of cultivation,

1) Temperature: The influence of temperature on the growth, and reproduction of the various forms seaweeds has been studied. Studies and experiments confirm the fact that the temperatures do have a effect on the growth rate of the seaweeds [18]. The synthesis of essential molecules and chemicals within the organism requires a certain temperature to keep this life mechanism running. The following tabulated data shows the dependency on temperature and salinity keeping other parameters almost constant [17]:

TABLE VIII
GROWTH RATE OF SEAWEEDS (%/DAY) WITH THE TEMPERATURE AND SALINITY

Temperature	Salinity (ppt)	Growth rate (%/day)
27.5	32.5	5.5
26.5	32.5	6
24.5	32	7
25	34	6
22.5	35	5
20	34	3
22.5	30	3
25	32.5	4

Assuming that the salinity is constant for analysis and is at the optimal level, bringing out the closest approximation to the *Normal distribution* for the seaweed-Temperature relation as depicted below:

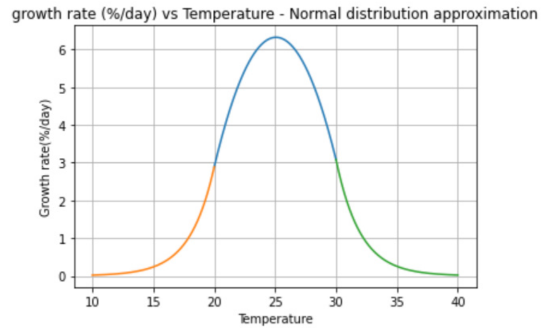

Fig. 11. Growth rate(%/day) of seaweeds with the Temperature

The growth rate model is given mathematically by;

$$\begin{cases} 2.9e^{0.5(x-20)} & x \leq 20 \\ -0.133x^2 + 6.7x - 77.6 & 20 \leq x \leq 30 \\ 3.08e^{-0.5(x-30)} & 30 \leq x \end{cases}$$

2) Light Intensity: Sunlight is essential for the process of photosynthesis in the phytoplankton species. For algaes and seaweeds, it is an important catalyst to support their metabolism governing chemical equations. The energy globule compound Adenosine Triphostphate (ATP) is generated from chemical equation which requires the presence of sunlight to occur [19]. Therefore, the presence of sunlight is a necessity for their growth. The amount of sunlight or sunlight intensity is important for seaweeds to accumulate certain proteins and gain overall weight. From the experiments involving different light intensities while keeping other factors approximately constant, the following data can be tabulated for the dependence of growth rate and light intensity:

TABLE IX
GROWTH RATE OF SEAWEEDS (%/DAY) WITH THE ALLOWED SOLAR INTENSITY

Light intensity(W/m2)	Growth rate (%/day)
113	0.363
84.786	0.318
56.524	0.276
28.262	0.166

From this data, we can obtain the best fit variation,

$$GR_{Norm} = -5.6*10^{-5}x^2 + 1.4*10^{-3}*x + 0.11, \;\; 10 \leq x \leq 250$$

which shows that the growth is inhibited at very low intensities of the light and with increasing intensity of the light, the growth rate rate, attains a maximum, and then again decreases. The decrease at very high intensities can be attributed to the loss of the thallus tissue in the seaweed leading to biomass loss [19].

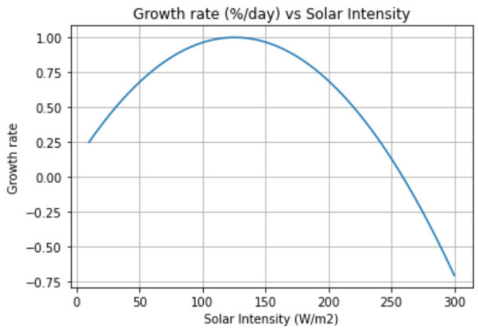

Fig. 12. Normalised Growth rate of seaweeds with the light intensity

According to [34] and [35], even the colouring of the light also plays a considerable role for certain species. The presence of lower wavelength blue and white content in the light affects the mechanisms which support the higher growth rate.

3) stocking density: The stocking density is defined as the biomass of seaweed cultivated per area at the beginning of the cultivation cycle.

$$\text{Stocking density} = \frac{\text{Seaweeds biomass cultivated}}{\text{Area}}$$

For the computations, the area will be taken to be per square meter. The units of biomass is the standard weight scale grams or kilograms. The relation of growth rate and the stocking density is that both are negatively correlated [21]. The lower stocking densities prefer the higher growth rate and with increasing stocking density, the growth rate decreases because of increasing stress on the seaweed with increasing congestion [22].

4) Water Quality: The quality of water affecting the seaweed can be seen in terms of

- water depth
- Nutrient content - accumulation of amino acids in terms of salinity
- oxygen level
- Water turbidity - secchi disc measurement
- Water flow rate

Water Salinity

Salinity of water is a measure of minerals, salts, soil residues, and essential elements mixed in the water. Higher salinity of water provides the phytoplanktons with the vital minerals required for the optimum growth of these organisms. The lipid production within the seaweeds/algae which is important raw input for the manufacture of value added products, is also affects by the salinity. Hence, maintaining an optimum salinity is a crucial criteria.

Water level Depth

For seaweed to have sufficient exposure to the sunlight, it is important that the seaweeds are not submerged deep inside the water where the sunlight cannot penetrate enough to be absorbed by the seaweed. Thus, the growth rate diminishes with the increasing depth and the reason can be accounted to the decreasing exposure to the sunlight. [23]

TABLE X
GROWTH RATE OF SEAWEEDS (%/DAY) WITH THE WATER LEVEL DEPTH

Depth (m)	Growth rate (%/day)
0.2	5.8
1	4
2	3.5
3	3
4	2.7
5	2.4

The continuous variation of the clear water depth and the growth rate:

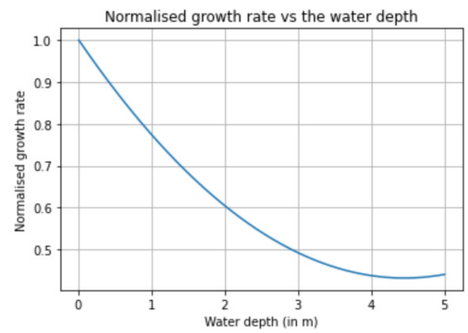

Fig. 13. The monotonically decreasing relation of normalised seaweed growth rate with the water level depth

It shows that with increasing water depth, the growth rate decreases, and at low water depth the growth rate is highest, but the point of caution is at very low depth, the seaweed can be fully exposed to the sunlight leading to the burning of the leaves or the loss of the thallus.

Water Turbidity

The turbidity is a technical term for the cloudiness measured in water. Higher is the cloudiness in the water, more is its turbidity. A water with very high turbidity is opaque and hardly anything could be seen through it, while a water with lower turbidity is clear and most of the falling light penetrates through it. As the sunlight plays an important role in overall growth rate of the seaweed, it is necessary that the seaweed should be grown in clear water, so most of the incident light on the water can actually penetrate and reach the seaweeds. The experiment depicting the effect of *actual solar irradiance/intensity* on the growth rate of the seaweed is tabulated below [19]. Confirms how varying the solar irradiance/intensity affects the growth rate of the seaweed:

TABLE XI
GROWTH RATE OF SEAWEEDS (%/DAY) WITH THE ALLOWED SOLAR IRRADIANCE

Solar Irradiance(%)	Growth rate (%/day)
100	0.329
50	0.252
25	0.181

From the available data, using the fitting commands, the resultant normalised growth rate is (which clearly shows a monotonically increasing growth rate with irradiance factor)

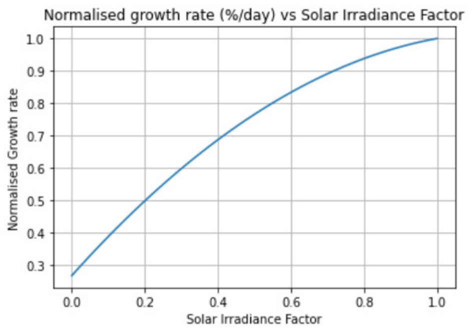

Fig. 14. Growth rate response of seaweeds to the varying solar Irradiance

Where,

$$\text{Solar Irradiance Factor} = 1 - \text{Turbidity (on scale of 0-1)}$$

Decreasing the effective solar intensity decreases the growth rate of seaweed. Hence, with increasing turbidity, which leads to the lesser effective irradiance, the growth rate is bound to decrease. The most common apparatus to measure the transparency/cloudiness/turbidity of water is Secchi disc [36]. From the relation shown in the derived water depth model of [37],

$$\text{Secchi depth (m)} = 3.39 * (\text{Turbidity})^{-0.637}$$

The graphical relation between these factors is a monotonically decreasing relation, thus the normalised turbidity can be made available by dividing each data point with maximum turbidity value, which occurs at the initial data point.

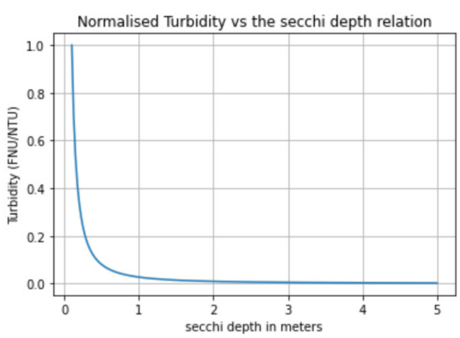

Fig. 15. The monotonically decreasing relation of (normalised) turbidity with the increasing secchi depth

Water speed/flow rate

Water flow rate is an important criteria for seaweeds grown directly in the seawater because due to higher water flow rate, which may occur because of high rainfall or high surface winds, causes rapid changes in the salinity content of the water. Such a rapid flow of essential elements and nutrients can create imbalance to the growth of the seaweeds, and they would prefer calm water, than the stormy water for their growth. [31]

5) Skill Assistance: The skill assistance is seemingly an important factor for the obtained yields in the country. One of the opportunities in the farming sector is the availability of low cost labour, but it can prove to be fatal if no emphasis on proper training of labour is given. The paper also discusses the fact that how prior knowledge of maintaining a seaweed bamboo raft is necessary for a beneficiary to obtain proportional returns to the efforts. Manuals having all the data and procedure to begin seaweed aquaculture are available on the internet [38]. There are also efforts being made (as shown here [39]) in certain countries and by certain organisations to give adequate training to initiate fruitful seaweed farming, by conducting training workshops.

6) Formulating the Model: : The Final biomass Yield after completion of days of cultivation/harvest cycle is given by

$$W(doc) = W_i \left(1 + \frac{GR}{100}\right)^{doc}$$

Where,
$W(doc)$ denotes the final weight of seaweed after the harvest cycle
W_i is the initial biomass planted, which is equal to the initial stocking density
GR denotes the overall growth rate of the seaweed
The overall growth is given by,

$$GR = \alpha_1 \alpha_2 \alpha_3 GR_{temp}$$

Where,
GR_{temp} is the growth rate variation with temperature
α_1 is the normalisation parameter of Solar Intensity, and
α_2 is the normalisation parameter of Water depth, and
α_3 is the normalisation parameter of Secchi transparency.
From the relation of stocking density,

$$W_i(\text{per area}) = \text{Stocking density}$$

Therefore, the obtained biomass can be given by,

$$W_{final}(\text{per sq. m}) = \text{Stocking density} \left(1 + \frac{GR}{100}\right)^{doc}$$

Important observations and Conclusions

- All marked parameters do influence the yield, biomass, and growth of the seaweeds and all these factors are crucial to be maintained in the optimal range in the farm
- The salinity and temperature variations shows that the temperature of Indian ocean region and availability of seawaters water with higher salinity than the fresh waters can be used for growth of seaweeds.
- Higher stocking density upsets the organism and this is the cause of the diminishing growth rate and therefore, the farmers should have adequate knowledge of the trade-off between increasing stocking density to achieve higher yield which in turn causes decrease in growth.
- The intensity of light affects the rate of photosynthesis, the production of energy molecules, and synthesis of

lipids within the body. Therefore, the adequate presence of sunlight is a life governing condition.
- The water depth plays crucial role as it affects how much of the available light is actually available to the seaweed. With higher turbidity, the attenuation of the light wave in the water also increases.

V. Real time Data Accumulation

This section mainly covers how far the technology had came to provide us with sensors that are capable of accumulating real time useful data about the farms. The following description [40] shows the working of the sensors.

- UV light is absorbed by many chemical molecules that are dissolved in water. As a consequence, the amount of **dissolved organic contaminants** in water may be determined reliably using the KH-COD-N01-1, The COD sensor employs two light sources: one UV light for detecting COD content in water and the other for determining water turbidity.
- If the **ammonia and nitrogen content** in the water is too high, it will poison the fish and shrimp and cause them to die. As a result, the KH-NHN-N01-1 ammonia and nitrogen sensor is especially important for monitoring ammonium ion level in water with temperature correction.
- The **oxidation-reduction potential (ORP)** is used to monitor the water quality of aquaculture waters. It reflects the water body's oxidation-reduction status. The greater the ORP value, the greater the water body's oxidising property, and the lower the value, the greater the water body's reducing property. It is typically used in conjunction with a PH sensor.
- The **scattered light turbidity measurement** idea is used to build the turbidity sensor, which detects the amount of light passing through the water to accurately measure the suspended solids in the water, and these suspended particles may reflect pollution of the water body. This method is used to measure the turbidity of a water sample, and the final result is obtained after linearisation processing.

The following table tabulates some popular and developed sensors which can be employed by us in aquaculture for monitoring of farms.

TABLE XII
Water Quality Sensors and their use

Water Sensor	Sensor Application
RS-EC-*-2EC	Conductivity measurement
RS-PH–2-	PH value, H^+concentration index
RS-PM200	water level/depth
RS-LDO-N01	Dissolved oxygen
RS-SHT-*	Temperature sensor probes
AS EZO-CO2	Detect gaseous CO_2
KH-CL-N01-1	Measure Residual Chlorine and Ozone
KH-ZD-N01-1	Turbidity sensor
ORP	Measure Quality of aquaculture water
KH-COD-N01-1	COD sensor
KH-NHN-N01-1	Ammonia and Nitrogen sensor
RS-GZ*-*-2	sunlight sensor

VI. Opportunities

- **Digital presence of the project**: Contrary to the pen-paper-based researches done till date, where the results are fixed and more cannot be achieved apart from what is being mentioned in the paper, a digital tool will also give this project a presence on the internet, the reader can readily see the visualisations on his own and can check all the parameters online. It can also help the students to delve into the maritime-related researches by understanding and analysing the Indian aquaculture economy.
- **Blue Economy**: Increased support for the growth and cultivation of seaweeds will enhance the rural people livelihoods and boost the economy in a sustainable manner. Seaweed as a bio-fuel can replace the carbon emitting counterparts and looks promising in the near future with increasing advanced technologies. With the optimised approach for shrimps cultivation, now the losses will be lowered and better use of the input resources could be made. Overall, it benefits the social, economical, and environmental counterparts. [41]
- **Implications of climate change**: The seaweeds organisms are highly sensitive to varying parameters. On the one hand, we are trying to employ seaweeds to mitigate climate change. On the other, the impacts of the current climate change scenario can prove to be fatal or harsh enough to crash the seaweed aquaculture and its associated prospects. The study brings out serious negative implications of climate change on seaweed farming and sustainability. This APY study also creates a pathway to look in regard of changing climatic conditions over time. [42]
- **Self Reliance**: With advanced versions of development of *APY monitoring tool*, the farmers can monitor their fields sitting far away and can precautionary actions if required. Do not need to rely on different sources for the current condition of their pond as they have the tools to handle it all.
- **Geographical Strengths**: The average annual temperature of Indian region is $25 - 26^{o}$C, and hence provide the optimum climate for the traditional outdoor shrimp farms.
- **Area dependence**: Practically, having very high dependence of production on the area is not very optimal. It is desired to harness as much available area under cultivation but with increased dependence on area to increase production, the risks also increases. Any natural calamity, biodiversity or livelihood trade-offs can counter the demand of the land and thus efforts should be made to make yields higher so as to increase production with just available amount of land.
- **Polyculture**: If the integrated shrimp and seaweed farming is economically feasible, this will be a lucrative opportunity for us to take a leap forward in developing a sustainable aquaculture framework by poly-cultivated

shrimps farming [21], which shows prominent degrading effects on the environment, with the seaweed farming, a pioneer in sustainable farming. The experimental results of polyculture/co-culture of shrimps and seaweeds [43] showed that this method is promising for fetching higher yields.
- **Better estimated returns**: The document [44] by the national organisation Department of Fisheries mentions how beneficial in monetary terms seaweed farming can be for farmers to enhance their regional prosperity. The results of the efforts being made by CSIR-CMFRI also recently turned into a success for the growth of gracilaria in the IOR, Gujarat region. [2]

VII. Limitations

- **Reluctance to adapt to Digital Footprint**: For the coverage of yield analysis, it is important to get the data about how labour capital is being currently used. It is important for building an identity of farmers through which the willingness of people joining the aquaculture farming industry can be mapped.
- **Unavailability of structured Data**: For research purposes, large amount of structured data are required for conducting data analytics, training models for prediction and obtaining the trends and variations in the associated parameters. The lack of required data in the Indian Ocean region in a structured tabular way is the biggest hindrance in carrying out fruitful researches.
- **Resistance to employ available Technology**: Sophisticated models of water parameter sensors have been designed over the years. They are capable of even providing software support for real time alerts about the degrading parameters. Despite being rapid advancements in technology, the affinity of farmers to adapt to them is quite low.
- **Slight Inaccuracies in models**: Due to different researches performed at different period of time and no two conditions are the same, sometime, making certain assumptions can lead to slight inaccuracies or conflicts between the theories of two different research or estimations, which can only be corrected by available practical real-time data which can be accumulated with advanced sensors in section V.

VIII. IOR Production status

1) Shrimp Farming: Shrimps production has increased significantly over the last decade as evident from the figures [1]. It is also important to study the spatial variations in production over all the states and variations of production between each species in the market. The growth rate of production in the CAGR (compound annual growth rate) model [45] is given by

$$r = 100 * \left(\left(\frac{Y_{final}}{Y_{ref}} \right)^{\frac{1}{t}} - 1 \right)$$

Where,
r denotes the growth rate as a percentage
Y_{final} denotes the final production over time
Y_{ref} denotes the initial or reference production from which the study have started
t denotes the time of final observation measured by taking the initial moment as 0
Using the obtained growth rate as a percentage, the extrapolation can be performed to predict the production in the upcoming years assuming all conditions remains to be same as now.

$$Y(t, t_{ref}) = Y_0 \left(1 + \frac{r}{100}\right)^{(t-t_{ref})}$$

Where,
$Y(t, t_{ref})$ denotes the production as a function of upcoming year and reference year
Therefore, the three nonintersecting cases of the growth rate arise

- Negative Growth rate: A negative growth rate projects that the future production is bound to decrease if the current procedures are only followed and no such crucial step is taken.
- Zero Growth Rate: The region have the constant production output over time. The conclusions may be either they are already at the verge of harnessing the full returns out of their inputs, or somehow the additive and reductive factors cancel out the overall growth pattern.
- Positive Growth Rate: The future production will be enhanced with time even if conditions are met at the current pace. Positive steps can be taken and higher investments could be made to boost the rate of growth of production.

TABLE XIII
GROWTH RATE (PERCENT) OF PRODUCTION(SHRIMPS) IN THE DECADE 2010 TO 2021

States	Tiger shrimp	L.vannamei
West Bengal	-4.98	159.14
Orissa	-16.22	164.14
Andhra Pradesh	-16.81	71.75
Tamil Nadu	-27.30	164.72
Kerala	-15.39	73.21
Karnataka	-4.07	101.18
Goa	-100	-100
Maharastra	-100	56.89
Gujarat	-26.83	88.95

Apart from the growth rate, it is also important to study the variations in the production over the period of study. The statistical parameter at our disposal is the coefficient of variation (CV) [46]. It can give the relative deviation of the data about the mean. Mathematically, it is given by

$$CV = 100 * \left(\frac{\sigma}{\mu} \right)$$

Where,
σ denotes the standard deviation of the data set
μ denotes the mean of the data set
On the basis of the value of coefficient of variation, following conclusions can be made:

- High CV: It implies that the variability of the concerned parameter over the region is high. The fluctuations could occur due to climatic impacts, economic disparity, self-dependency, social disputes, prevalent migrations or any other negative factor causing wide variations over the period.
- Low CV: It implies that the parameter is relatively stable over the period and in the near future can be treated as a constant and the analysis built upon such data would be fruitful.

Correlation is another statistical parameter which can signify the interaction between area and the production. As the production is related to the other two factors, yield and area, by the relation,

$$\text{Production} = \text{Yield} * \text{Area}$$

Using the Pearson's correlation coefficient [47],

$$\rho_{xy} = \frac{COV(x,y)}{\sigma_x \sigma_y}$$

The interpretation of the obtained value can be given by

- Positive correlation implies that the area and production are related in a way such that increasing area will result in the increase in the production. The value of 1 signifies that both parameters go strongly hand in hand.
- Negative correlation implies that with increasing area under the cultivation, the production lowers. This can be used to understand the marginal gains. The value of -1 signifies that both parameters strongly oppose each other.

Finally, we will be tabulating the Area Effect, which is essentially the percent change of the area under cultivation over the period of study.

$$\text{Area Effect} = 100 \left(\frac{A_{final} - A_{ref}}{A_{ref}} \right)$$

Where,
A_{final} denotes the final year considered in the data set A_{ref} denotes the initial year or the reference year of the study From the obtained value, based on whether it is positive or negative, it can be concluded that the area cover used for the cultivation decreased (if negative) or increased (if positive) and by what amount as a percentage.

TABLE XIV
AREA EFFECT ON AREA UNDER SHRIMP CULTIVATION (SHRIMPS) IN THE DECADE 2010 TO 2021

States	Tiger shrimp	L.vannamei
West Bengal	-0.03	60490
Orissa	-88.45	106390
Andhra Pradesh	-92.32	27143
Tamil Nadu	-98.74	85900
Kerala	-70.52	1480
Karnataka	46.56	9600
Goa	-96.32	0
Maharastra	-98.46	11730
Gujarat	-98.17	99744

Note: *At the points where there was no data available about the area under cultivation, the area is taken to be practically close to negligible (10 in our case) to depict the increase in the area under cultivation over the decade. Therefore, as the data about L. vannamei is less structured therefore the values are formula wise very high. But the analysis gives a fair enough idea that area under the cultivation of L. vannamei is increasing rapidly.*

Observations

- The production of the white leg shrimp has soared in the last decade. Most of the states even witnessed the growth rate of about 150%, showing great prospects associated with the commercial importance of the L. vannamei species.
- The production of tiger shrimp has declined over the last decade, and the main reason seems to be the increased willingness or interest for the production of L. vannamei instead.
- *Some of the values are not reliable for making predictions because of missing values in the data-set we are referring to and due to high variations because of limited data.*
- The scampi shrimp data cannot be analysed because of the highly missing values and unstructured data at our disposal, which cannot be used for the development of a tool. Overall, the data can be theoretically analysed which suggests the decreasing trend of production of scampi.

REFERENCES

[1] AQUACULTURE DATA - Marine Products Export Development Authority - MPEDA site
[2] Seaweeds Cultivation and Utilisation: Prospects in India, October 2018, DOI:10.13140/RG.2.2.24056.70408
[3] The Environmental Impact of Shrimp Aquaculture: Causes, Effects, and Mitigating Alternatives FEDERICO PA´ EZ-OSUNA, DOI: 10.1007/s002670010212
[4] Other Uses of the seaweeds - Food and agriculture organisation Site
[5] Denny - Wave-Energy Dissipation: Seaweeds and Marine Plants Are Ecosystem Engineers, DOI: 10.3390/fluids6040151
[6] The django framework official documentation Documentation link
[7] TNAU Agritech portal site link
[8] Wyban, Walsh, Godin, Temperature effects on growth, feeding rate, and feed conversion of the Pacific white shrimp (Penaeus vannamei), 1995/12/01, vol. 138, pp.267-279, 10.1016/0044-8486(95)00032-1
[9] J.A. Wyban, C.S. Lee, V.T. Sato, J.N. Sweeney, W.K. Richards, Effect of stocking density on shrimp growth rates in manure-fertilized ponds, Aquaculture, Volume 61, Issue 1, 1987, Pg 23-32, https://doi.org/10.1016/0044-8486(87)90334-6.
[10] Effect of different stocking density on growth, survival of Litopenaeus vannamei (Boone, 1931) in summer and monsoon crop in province of Gujarat States in India, Kotia, Anil, Vadher, K., 2021/05/09, pg.71 99, Vol. 7
[11] Sadek, Nabawi, Effect of water salinity on growth performance, survival, feed utilization and body chemical composition of the Pacific white shrimp, L.vannamei juveniles Paper link
[12] EFFECT OF pH ON PACIFIC WHITE SHRIMP Litopenaeus vannamei GROWTH AND SURVIVAL, Wilson Wasielesky Junior, Heidi Atwood, Ryan Kegl, Jeff Bruce, Al Stokes e Craig Browdy Paper Link
[13] Nonwachai, Purivirojku, Chuchird, Limsuwan's Effect of oxygen levels on growth, survival and Immune response of juvenile pacific white shrimp, Litopenaeus vannamei Paper link
[14] Low Feed Conversion Ratio (FCR) is the Indicator of Efficient Aquaculture article link
[15] Soil Quality Analysis of Brackishwater Shrimp Farming in Coastal Areas of Indonesia DOI: 10.5296/jee.v5i2.7043

[16] Changes in shrimp feed quality and effects on growth and survival of Penaeus monodon juveniles DOI: 10.1016/s0044-8486(96)01477-9
[17] Hayashi L, Paula EJ, Chow F, Growth rate and carrageenan analyses in four strains of Kappaphycus alvarezii (Rhodophyta, Gigartinales) farmed in the subtropical waters of São Paulo State, Brazil, DOI: 10.1007/s10811-006-9135-6
[18] Nurul Salma Adenan, Fatimah Md. Yusoff and Mohamed Shariff, 2013. Effect of Salinity and Temperature on the Growth of Diatoms and Green Algae. Journal of Fisheries and Aquatic Science, 8: 397-404 DOI: 10.3923/jfas.2013.397.404
[19] Metsoviti et. Al. (2019) Effect of Light Intensity and Quality on Growth Rate and Composition of Chlorella vulgaris DOI:10.3390/plants9010031
[20] Mujiyanto et al 2020; Suitable water quality parameters for seaweed culture at Muara Gembong coastal area, Bekasi District DOI: 10.1088/1755-1315/521/1/012012
[21] Rodriguez et. al. (2016), Effects of stocking density on the performance of brown shrimp Farfantepenaeus californiensis co-cultured with the green seaweed Ulva clathrata DOI: 10.1111/are.13114
[22] The Effect of Stocking Density on the Performance of the Seaweed Ulva reticulata as a Biofilter in Earthen Pond Channels, Zanzibar, Tanzania DOI: 10.4314/wiojms.v6i1.48227
[23] Rani et. al. Effect of Depth on the Growth and Carrageenan Content of Seaweed Kappaphycus alvarezii Cultivated Using Verticulture Method E3S Web of Conferences 147, 01011 (2020) DOI: 10.1051/e3sconf/202014701011
[24] Knowledge gaps and management recommendations for future paths of sustainable seaweed farming in the Western Indian Ocean DOI: 10.1007/s13280-020-01319-7
[25] Farming and Culture of white legged shrimp , Litopenaeus vannamei Manual link
[26] TRAINING MANUAL ON RECENT ADVANCES IN FARMING OF PACIFIC WHITE SHRIMP, Penaeus vannamei, CIBA-TM Series 2018-No.14, Manual link
[27] Recent advancements in the penaeid shrimp, culture, feeds and farming Manual link
[28] LARS HEIN, Toward Improved Environmental and Social Management of Indian Shrimp Farming, DOI: 10.1007/s00267-001-0012-4
[29] Góes HG, Reis RP,Temporal variation of the growth, carrageenan yield and quality of Kappaphycus alvarezii (Rhodophyta, Gigartinales) cultivated at Sepetiba bay, southeastern Brazilian coast, DOI: 10.1007/s10811-011-9665-4
[30] Schmidt EC, Nunes BG, Maraschin M, Bouzon ZL,Effect of ultraviolet-B radiation on growth, photosynthetic pigments, and cell biology of Kappaphycus alvarezii (Rhodophyta, Gigartinales) macroalgae brown strain, DOI: 10.1007/s11099-010-0022-7
[31] Glenn EP, Doty MS, Water motion affects the growth rates of Kappaphycus alvarezii and related red seaweeds,DOI: 10.1016/0044-8486(92)90109-X
[32] Luhan MRJ, Sollesta H, Growing the reproductive cells (carpospores) of the seaweed, Kappaphycus striatum, in the laboratory until outplanting in the field and maturation to tetrasporophyte,DOI: 10.1007/s10811-009-9497-7
[33] Yong, Y.S., Yong, W.T.L. & Anton, A. Analysis of formulae for determination of seaweed growth rate. J Appl Phycol 25, 1831–1834 (2013). DOI: 10.1007/s10811-013-0022-7
[34] Wong et. AL. Effect of different light sources on algal biomass and lipid production in an internal Leds-illuminated photobioreactor, DOI: 10.15436/2381-0750.16.1082.
[35] Zhang et. Al. (2017) Effects of Light-emitting Diodes (LEDs) on the Accumulation of Lipid Content in Microalgae, DOI: 10.12783/dteees/icseep2017/12719
[36] The use of secchi disk - https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/secchi-disk
[37] Estimation of Secchi Depth from Turbidity Data in the Willamette River at Portland, OR (14211720) Article link
[38] MANUAL ON SEAWEED FARMING - Food and agriculture organisation Manual link
[39] Seaweed Farming Training and workshop - university of washington Site
[40] Top 7 Water Quality Sensors For Water Treatment and monitoring site link
[41] Aparna Roy, "Blue Economy in the Indian Ocean: Governance Perspectives for Sustainable Development in the Region", ORF Occasional Paper No. 181, January 2019, Observer Research Foundation
[42] Kumar et. al.(2020) Impact of elevated temperature on the physiological and biochemical responses of Kappaphycus alvarezii (Rhodophyta), DOI: 10.1371/journal.pone.0239097
[43] Lombardi et. Al. Cage polyculture of the Pacific white shrimp Litopenaeus vannamei and the Philippines seaweed Kappaphycus alvarezii, DOI:10.1016/j.aquaculture.2006.04.022
[44] Guidelines for seaweed cultivation - Department of Fisheries - Seaweed_Cultivation document
[45] The application, formulation and theory of Compound annual growth rate - https://en.wikipedia.org/wiki/Compound_annual_growth_rate
[46] The application of Coefficient of Variation in research - https://www.sciencedirect.com/topics/engineering/coefficient-of-variation
[47] Pearsons Linear Correlation Coefficient under experimental research - article link