

## Webinar Concept Note

# Fisheries & Aquaculture: Digital Transformation, APY Framework and Multi-Parameter Habitat Analytics for Sustainable Blue Growth 10 March 2026 at 1630 hrs IST

### Background & Rationale

Seafood exports from tropical and monsoon-driven coastal economies have grown substantially in recent years, driven by expanding aquaculture production and increasing global demand. Aquaculture now contributes a significant share of seafood supply across warm-water coastal systems, supporting food security, livelihoods, and export revenues. However, the sector faces structural and operational challenges including low productivity, disease outbreaks, nutrient imbalances, habitat degradation, and limited scientific training in optimal farm management practices. In response to rising demand, horizontal expansion of aquaculture areas has often been pursued as the primary growth strategy. Such expansion is increasingly unsustainable in ecologically sensitive coastal zones where aquaculture intersects with agriculture, salt plains, mangrove ecosystems, and urban development. Increasing land use without improving yield efficiency places long-term ecological and socio-economic resilience at risk.

To address these challenges, the Maritime Research Center (MRC) has developed a holistic Area Production and Yield (APY) Framework, focusing on productivity optimization rather than geographical expansion benefitting a sustainable growth in the Indian Ocean Region. The APY approach aims to enhance farm-level performance through:

1. Development of mathematical growth models that simulate aquaculture culture under varying environmental conditions, enabling optimization of growth parameters.
2. Integration of seaweeds into shrimp aquaculture systems to improve water quality through nitrate and phosphate absorption, thereby enhancing sustainability and reducing disease vulnerability.

Complementing farm-level productivity enhancement, the webinar will present a Multi-Parameter Biogeochemical and Thermal Habitat Analysis Framework implemented as a pilot study in the eastern Arabian Sea (16.5°N–17.5°N, 72.0°E–73.5°E), specifically the regions of Ratnagiri (Maharashtra) and Veraval (Gujarat) in the Konkan coast.

While regionally applied, the framework is designed to be scalable across tropical, monsoon-influenced coastal systems. Traditional fisheries advisory systems frequently rely on single-

parameter indicators such as Sea Surface Temperature (SST) or chlorophyll concentration. However, fisheries productivity and habitat availability are governed by a complex interaction between physical oceanography, biogeochemical cycles, oxygen constraints associated with Oxygen Minimum Zones, nutrient gradients linked to upwelling intensity, and species-specific thermal physiology

The proposed framework integrates four environmental domains into a Composite Suitability Index:

- Biogeochemical productivity (Net Primary Productivity – NPP)
- Oxygen habitat constraints
- Nutrient gradients as proxies for upwelling intensity
- Species-specific thermal preferences

This multi-layered analytical system addresses emerging challenges such as habitat compression caused by concurrent ocean warming and deoxygenation, particularly in monsoon-driven upwelling regimes.

The initiative represents a structured effort toward digital transformation in fisheries and aquaculture by integrating farm-level productivity modeling with ecosystem-scale habitat intelligence. It seeks to democratize the returns of the fisheries economy by ensuring that small-scale farmers, fishers, and marginalized coastal communities are not excluded from technological advancement. With adequate institutional support, the framework can be adapted across tropical coastal systems facing similar oceanographic and climate stressors.

## **Objectives**

**The Webinar aims to:**

- Highlight the economic and strategic importance of fisheries and aquaculture.
- Present the APY framework for yield optimization without coastal expansion.
- Demonstrate seaweed integration for nutrient management and system resilience.
- Introduce a multi-parameter habitat suitability index for predictive fisheries advisories.
- Examine habitat compression risks from ocean warming and deoxygenation.
- Explore scalable digital advisory models for coastal and island regions.
- Promote inclusive growth for small-scale producers and vulnerable communities.

## **Expected Outcomes**

- Enhanced understanding of productivity-driven aquaculture expansion strategies.
- Policy-relevant insights into integrating APY and digital modeling frameworks within PMMSY.
- Demonstration of multi-parameter fisheries advisories beyond conventional SST systems.
- Framework for habitat compression monitoring under climate change scenarios.
- Pathways for inclusive and equitable Blue Economy growth.
- Documentation of methodological and governance insights for further dissemination.

### **Proposed Schedule (2 hrs)**

- **10 minutes** – *Inaugural Address* – **Dr (Cdr) Arnab Das** (Founder and Director, MRC)
- **20 minutes** – *Keynote Presentation* – **Mr. Shlok Nemani** (MRC Fellow)
- **20 minutes** – *Keynote Presentation* – **Mr. Ashwini Singh** (MRC Fellow)
  
- **10 minutes each** – Expert Interventions by:
  - **Prof. P.B.Terney Pradeep Kumara** (Director General of CC&CRMD, Ministry of Environment, Sri Lanka)
  - **Dr. Poonam Singh** (Director of ICAR-National Bureau of Fish Genetic Resources, India)
  - **Rear Admiral Md. Khurshed Alam (Retd)** (Director at Centre for Bay of Bengal Studies, Independent University Bangladesh, Dhaka)
  - **Dr. P Krishnan** (Director Bay of Bengal Programme (BoBP), Inter Governmental Organization (IGO))
  
- **20 minutes** – *Concluding Remarks* – **Amb Anup Mugdal (Retd)** (Former Indian Diplomat & Member of the Blue Economy Task Force at FICCI, India)
- **5 minutes** - *Closing Remarks* – **Mrs. Cathrine J** (Research and Publication Head, MRC)

### **Convenor**

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## Multi-Parameter Biogeochemical and Thermal Habitat Analysis

Traditional fisheries management often relies on single-parameter indicators such as Sea Surface Temperature (SST) or chlorophyll concentration. While operationally simple, these metrics do not capture the coupled dynamics of physical oceanography, biogeochemical productivity, oxygen limitation, nutrient transport, and species-specific thermal physiology.

This study develops a composite suitability index integrating four environmental domains to identify optimal fishing zones within a pilot coastal domain in the eastern Arabian Sea (16.5°N–17.5°N, 72.0°E–73.5°E). The framework explicitly addresses habitat compression arising from concurrent ocean warming and deoxygenation, as well as seasonal variability driven by monsoon-induced upwelling.

The Composite Index integrates:

1. Net Primary Productivity (NPP) – biogeochemical energy base
2. Dissolved Oxygen (O<sub>2</sub>) – habitat constraint
3. Nitrate Gradient (∇NO<sub>3</sub>) – upwelling intensity proxy
4. Thermal Suitability (T<sub>opt</sub>) – species-specific physiological preference

Biogeochemical data are derived from daily NetCDF ocean model outputs for the year 2025, with 548 valid grid cells across the study domain. Parameters include NPP integrated over the 0–100 m depth (mg C m<sup>-2</sup> day<sup>-1</sup>), dissolved oxygen extracted at 50 m depth (mmol m<sup>-3</sup>), nitrate gradients computed between surface (0.5 m) and deep (100 m) layers, and surface chlorophyll-a as a phytoplankton biomass proxy. Physical parameters are obtained from satellite-derived datasets comprising 3,644 valid grid cells, including Sea Surface Temperature (°C) and Sea Surface Salinity (PSU) at 0.5 m and 50 m depths. Temporal coverage spans 365 days (2025), with missing values interpolated using nearest-neighbor temporal alignment to maintain continuity.

$$\text{Suitability Index} = 0.35 \times \text{NPP}_{\text{norm}} + 0.30 \times \text{O}_2_{\text{norm}} + 0.20 \times \nabla\text{NO}_3_{\text{norm}} + 0.15 \times \text{T}_{\text{opt}}^{\text{norm}}$$

*Figure 1: The Composite Suitability Index is formulated*

Weight allocation reflects ecological hierarchy: NPP (35%) represents the primary energy base of marine food webs; oxygen (30%) captures increasing habitat limitation associated with Oxygen Minimum Zone (OMZ) shoaling; nutrient gradients (20%) indicate upwelling intensity; thermal suitability (15%) regulates species-specific metabolic performance and distribution. All parameters are normalized to a 0–1 scale for comparability.

Parameter	Normalization Method	Formula / Threshold	Rationale
NPP	Min-Max Scaling	$(NPP - NPP_{\min}) / (NPP_{\max} - NPP_{\min})$	Linear scaling preserves relative productivity differences
O <sub>2</sub>	Threshold-Based	$\text{clip}[(O_2 - 60) / 140, 0, 1]$	60 mmol m <sup>-3</sup> = hypoxia threshold; 200 = optimal
∇NO <sub>3</sub>	Min-Max Scaling	$(\nabla NO_3 - 0) / (20 - 0)$ , clipped [0,1]	Gradient strength indicates upwelling intensity
T <sub>opt</sub>	Gaussian-like	$1 -  SST - 24  / 12$ , clipped [0,1]	24°C optimal; ±12°C tolerance window for pelagic species

Figure 2: Normalization schemes are parameter-specific.

The analytical workflow consists of spatial subset extraction from NetCDF datasets (latitude-longitude slicing), depth integration of NPP within the euphotic zone, oxygen extraction at 50 m, nitrate gradient computation between 100 m and 0.5 m layers with temporal alignment, parameter normalization, and weighted composite index generation on a daily 0–1 suitability scale.

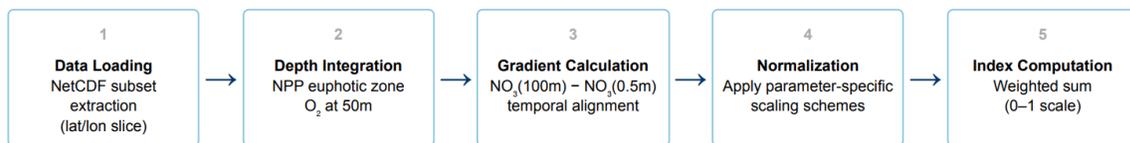


Figure 3: Analytical workflow

Species-specific thermal habitat classification is derived from literature-based physiological constraints reflecting evolutionary adaptation and metabolic requirements. The percentage of days within optimal thermal windows is calculated under the 2025 thermal regime, which exhibits a +2.3°C anomaly relative to the 1980–2010 baseline.

A Habitat Compression Detection Algorithm is implemented to identify zones where concurrent thermal and oxygen stress occurs. Critical Compression Zones are defined as the intersection of SST > 26°C and O<sub>2</sub> < 120 mmol m<sup>-3</sup>. This dual constraint forces oxygen-demanding species into narrow surface layers, increasing ecological vulnerability and fishing pressure. Phase-space analysis (O<sub>2</sub> versus SST scatter) is used to visualize compression events across seasonal cycles and identify high-risk intervals.

Seasonal oceanographic interpretation validates the mechanistic consistency of the framework. During winter convective mixing (November–February), surface cooling enhances vertical mixing, injecting nutrients without significant OMZ intrusion, resulting in peak habitat suitability. During monsoon-driven coastal upwelling (June–September), Ekman transport elevates nutrient-rich but oxygen-poor deep waters, generating high productivity alongside increased habitat compression risk. Pre-monsoon thermal stratification (April–May) produces strong pycnocline development, trapping nutrients below the euphotic zone and resulting in minimum suitability conditions.

Correlation analysis supports process validation. A statistically significant negative correlation between temperature and NPP ( $r = -0.608$ ,  $p < 0.001$ ) confirms enhanced productivity during cooler mixing phases. A strong inverse relationship between nitrate gradients and oxygen ( $r = -0.925$ ) confirms OMZ shoaling during upwelling events.

Key methodological contributions include multi-parameter integration of productivity, oxygen, nutrients, and thermal habitat into a unified fisheries index for the Arabian Sea; quantification of habitat compression through phase-space analysis; explicit incorporation of species-specific thermal windows for five commercial species; and mechanistic validation through correlation analysis consistent with established oceanographic processes.

The implementation is executed in Python using xarray, numpy, and pandas libraries. The processing pipeline involves daily NetCDF extraction, spatial averaging, temporal alignment, normalization, and weighted composite computation. Outputs include daily suitability indices (0–1 scale), monthly climatology, species thermal habitat maps, and habitat compression alerts for the Ratnagiri coastal domain (16.5–17.5°N, 72.0–73.5°E) at daily resolution for 2025.