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Exploring Co-Location Opportunities of OTEC and Offshore Fish Farms to Support the Blue Economy in the Southeast U.S.

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Abstract

This study explores the feasibility of co-locating Ocean Thermal Energy Conversion (OTEC) systems with offshore Kanpachi fish farms in tropical and subtropical waters of the southeastern United States, Puerto Rico, and the U.S. Virgin Islands. A spatial analysis framework was developed using OTEC power modeling, aquaculture suitability criteria, and environmental, regulatory, and logistical constraints. Temperature profiles from HYCOM and environmental data from publicly available data sources were used to identify locations with sufficient thermal gradients and favorable aquaculture conditions. The findings highlight regions, particularly near Puerto Rico, with strong co-location potential, offering a pathway to optimize ocean space while supporting sustainable energy and food production within the blue economy.

Keywords: Ocean Thermal Energy Conversion; Co-location; Fish farm; Marine Spatial Planning

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1. Introduction

As global demand for food and energy increases, there is growing interest in co-locating offshore renewable energy systems with aquaculture. Co-location seeks to optimize the use of ocean resources by simultaneously supporting renewable power generation and fish production, as it reduces lifecycle costs, minimizes spatial conflicts, and enhances the resilience and economic viability of coastal communities [1].

Recent studies have explored the potential of integrated ocean systems through spatial modeling, techno-economic evaluation, and multi-criteria decision analysis. Garavelli et al. assessed the feasibility of co-locating wave energy systems with offshore finfish aquaculture in California and Hawaii by estimating aquaculture energy demand and applying spatial analysis to determine site suitability [2]. Ewig et al. evaluated the co-location of RM3 wave energy converters with offshore Atlantic Salmon farms in the Northeast U.S., incorporating environmental constraints, conflict zones, and a location-dependent cost model to identify suitable deployment sites [3]. Similarly, Weiss et al. developed a multi-criteria spatial framework to evaluate co-location opportunities for wave energy, wind energy, and offshore aquaculture in the Canary Archipelago. Their methodology integrated energy production, structural, operational, and biological suitability using long-term environmental datasets to generate probability-based suitability maps for each activity [4].

While much of the existing co-location research has focused on wave and wind energy, OTEC remains largely underexplored in this context. OTEC provides a reliable, continuous power source in tropical and subtropical regions by harnessing the temperature difference between surface and deep seawater [5]. Its stable output and offshore infrastructure make it a strong candidate for integration with energy-intensive fish farming operations. Recent studies optimized the economic feasibility of hybrid OTEC–diesel system with battery storage and demonstrated that it can reliably power offshore aquaculture. The results showed that for OTEC capacities above 700 kW, the system achieves a levelized cost of energy competitive with conventional diesel-only setups, supporting its viability as a sustainable and cost-effective solution [6, 7]. This study aims to explore the potential for co-locating OTEC systems with offshore aquaculture, addressing a research gap by incorporating OTEC-specific spatial, technical, and environmental criteria into site selection.

The rest of the paper is organized as follows: Section 2 describes the materials and methods used to assess OTEC–aquaculture co-location feasibility, including regional selection, OTEC power production modeling, biological suitability thresholds for Kanpachi fish, and integration of regulatory and logistical constraints using GIS. Section 3 presents the spatial analysis results, and Section 4 concludes with key findings and recommendations for future research and development.

2. Materials and Methods

This study focuses on four marine regions: the Gulf of America, the Florida Straits, the Puerto Rico Trench, and the U.S. Virgin Islands. These tropical and subtropical regions exhibit stable and substantial temperature gradients between surface and deep waters, making them suitable for further exploration of OTEC applications [5,8,9].

Potential sites for the co-location of OTEC systems and offshore aquaculture were identified through a three-step evaluation process. First, each region was assessed for OTEC suitability based on power production potential. Second, the feasibility of cultivating Kanpachi in offshore cages was evaluated, considering biological tolerances and operational requirements. In the final step, results from both assessments were combined to identify overlapping zones suitable for dual use, with further screening based on environmental, regulatory, and logistical constraints. All analyses were conducted using MATLAB R2023a and QGIS 3.32.

2.1. Energy Production

A numerical model was developed in MATLAB to assess the energy production potential of an OTEC system. The system was designed to generate a net power output of approximately 80kW, using warm surface water at 26°C and deep cold water at 5°C. This target output was selected based on an analysis of the base load, average, and peak power demands of a proposed Kanpachi fish farming facility in South Florida. While the system does not fully satisfy peak energy needs, the 80kW benchmark offers a practical and representative basis for evaluating co-location feasibility.

To evaluate OTEC performance across the study regions, daily ocean temperature profiles for the year 2021 were obtained from the HYbrid Coordinate Ocean Model (HYCOM), spanning depths from 300m to 1000m in 100m intervals [10]. Sea surface temperature was approximated using values at 20m depth. A spatial resolution of 0.04° was used for the Gulf of America and Florida Straits, while a coarser 0.08° resolution was applied to the Puerto Rico Trench and U.S. Virgin Islands due to data availability. These temperature profiles were used to simulate daily OTEC power output at each site and depth combination. From the results, the average net output power over a year was calculated to identify areas with the strongest thermal potential. The resulting OTEC energy potential map was imported into QGIS for spatial analysis and overlaid with other datasets to support co-location site selection. Locations producing less than 51 kW on an annual average basis were excluded, as they would not meet the minimum energy requirement of the fish farming operation.

2.2. Aquaculture Parameters

Interviews with Gulfstream Aquaculture confirmed that Kanpachi (*Seriola rivoliana*) is a suitable candidate for offshore aquaculture in the southeastern U.S. and Caribbean regions. This high-value species is well-adapted to warm, open-ocean environments and demonstrates resilience under a range of environmental conditions. In this study, aquaculture suitability was evaluated based on key environmental parameters known to affect the health and growth of this species. These parameters include dissolved oxygen (DO), salinity, temperature, current speed, and depth.

Spatial datasets for DO, salinity, and temperature were acquired at a resolution of 1° and imported into QGIS for processing. Although Kanpachi are generally robust, they exhibit defined tolerance limits. DO levels below 5ppm can cause stress during feeding, with survival possible down to 3-4ppm for short durations when not being fed. Salinity levels below 25ppt are considered stressful, though the species can survive in levels as low as 12ppt if unfed. However, excessively high salinity levels are also suboptimal for growth and health. Optimal growth occurs at temperatures above 23°C, with reduced performance below this threshold and growth cessation around 16-17°C. Temperatures up to 30°C are tolerable but may increase susceptibility to skin fluke infestations. Current speed is another critical factor: moderate flow (>0.05m/s) supports water exchange and maintains water quality within cages, while sustained speeds above 0.5m/s may negatively affect feed conversion efficiency, as the increased swimming effort required by the fish diverts energy away from growth. Depth was not considered a limiting factor, as Kanpachi are naturally found from reef edges (~10m) to depths of ~75m. The suitability scores assigned to each parameter range, along with their corresponding data sources, are summarized in Table 1.

Following the integration of environmental datasets into QGIS, each parameter was reclassified based on the suitability ranges defined in Table 1. These reclassified layers were then overlaid to generate a composite suitability map for Kanpachi aquaculture, identifying optimal locations across the study regions. Ocean current data, with a finer spatial resolution of 0.05°, were processed separately using the dataset and methodology outlined in [13], visualized in MATLAB, and subsequently imported into QGIS. Regions where average current speeds exceeded 0.5m/s or fell below 0.05m/s were excluded from the final suitability map. To maintain consistency and avoid introducing interpolation error, each parameter was analyzed at its native spatial resolution throughout the process.

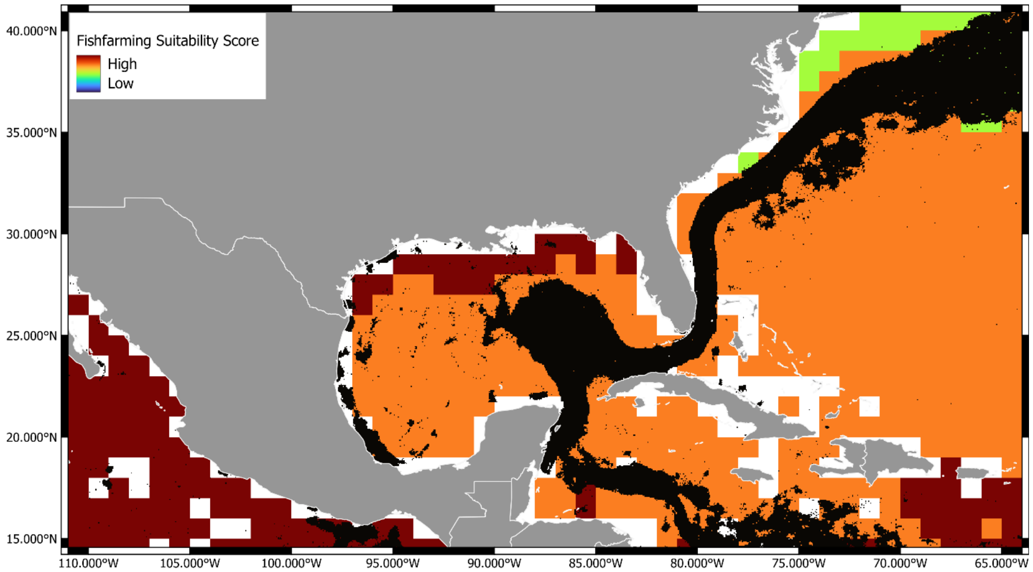

Figure 1. Fish farming suitability map for the study region.

The overall aquaculture suitability score for each location was calculated using Equation 1.

$$\text{Fishfarming Suitability Score} = (DO\ \text{score} + S\ \text{Score} + T\ \text{Score}) \times U \qquad (1)$$

where DO represents dissolved oxygen, S is salinity, T is temperature, and U is ocean current speed. Equal weights were assigned to the first three parameters, while the suitability score was multiplied by the ocean current factor (U) to effectively exclude areas that fall outside the acceptable ocean current range

Figure 1 illustrates the Kanpachi suitability map, where higher scores (shaded in red) indicate more favorable environmental conditions for offshore aquaculture. Although the selected study sites do not fall within the areas of absolute highest suitability, they are situated in regions classified as highly favorable, underscoring their viability for Kanpachi cultivation. Notably, the waters surrounding Puerto Rico and the U.S. Virgin Islands feature multiple zones with top suitability scores, reflecting ideal conditions for fish farming. A small but noteworthy area in the Gulf of America also meets the upper suitability thresholds. Black regions on the map indicate areas excluded from the analysis due to ocean current speeds falling outside the acceptable range, while white regions represent locations with insufficient environmental data.

Table 1. Constraints for a sample offshore Kanpachi farm

Variable (unit)	**Suitability Score**			**Source [11, 12]**
	0	**1**	**2**	
Dissolved Oxygen (ppm)	DO < 5	-	DO ≥ 5	National Center for Environmental Information
Salinity (ppt)	S < 25, S > 40	35 < S < 40	25 ≤ S ≤ 35	National Center for Environmental Information
Temperature (°C)	T < 17, T ≥ 30	17 ≤ T < 23	23 ≤ T < 30	National Center for Environmental Information
Ocean Current Speed (m/s)	U < 0.05, U > 0.5	0.05 ≤ U ≤ 0.5	-	National Oceanic and Atmospheric Administration

2.3. Regulatory and logistical factors

To assess the feasibility of co-locating OTEC systems with offshore aquaculture, a range of regulatory, spatial, and logistical constraints were incorporated into the analysis. These constraints are visualized in Figures 2 and 3, which depict relevant exclusion zones and maritime boundaries for the Gulf of America, Florida Straits, Puerto Rico, and the U.S. Virgin Islands. As summarized in Table 2, marine protected areas and designated danger or restricted zones were excluded entirely from consideration. In addition, military use zones were examined using two separate datasets: (1) military ship shock boxes and (2) military operating areas. Although these zones were not automatically excluded, they were flagged for further review, as the deployment of OTEC infrastructure in these areas would likely require special authorization and coordination with defense agencies. Transit Count Vessel data were used in this study to assess navigation routes and marine traffic density. Areas with more than 50 vessel transits per year were excluded to reduce potential conflicts with OTEC and aquaculture infrastructure.

U.S. coastal waters are governed by a combination of federal and state laws, with jurisdictional boundaries defined by distance from the shoreline. State waters typically extend up to 3 nautical miles (nm) from the coast, except for Texas, Florida, and Puerto Rico, where they extend to 9 nm. Beyond this, the federal government manages the Exclusive Economic Zone (EEZ), which stretches out to 200 nm. In addition, each coastal state may claim a territorial sea extending up to 12 nm from its baseline, over which it exercises full sovereignty, including the airspace, seabed, and subsoil. For the purpose of this study, waters within this 12 nm boundary were considered federal waters.

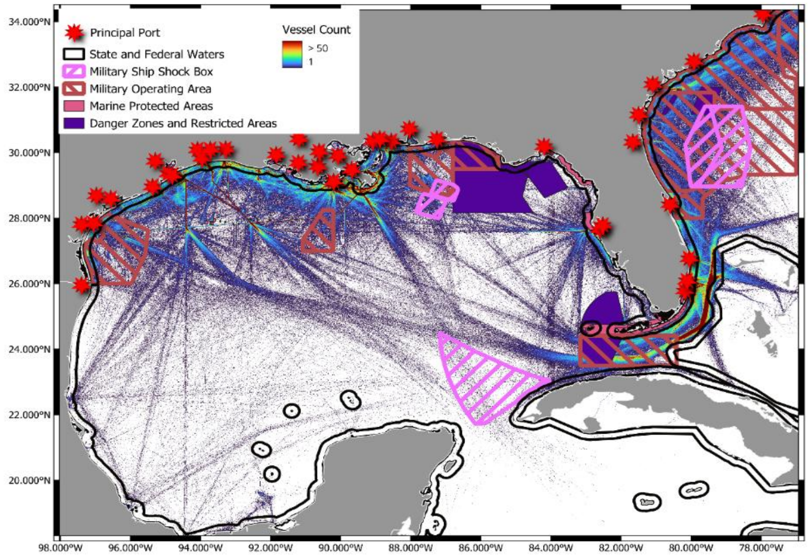

Figure 3. Regulatory and logistical parameters of Gulf of America and Florida Straits.

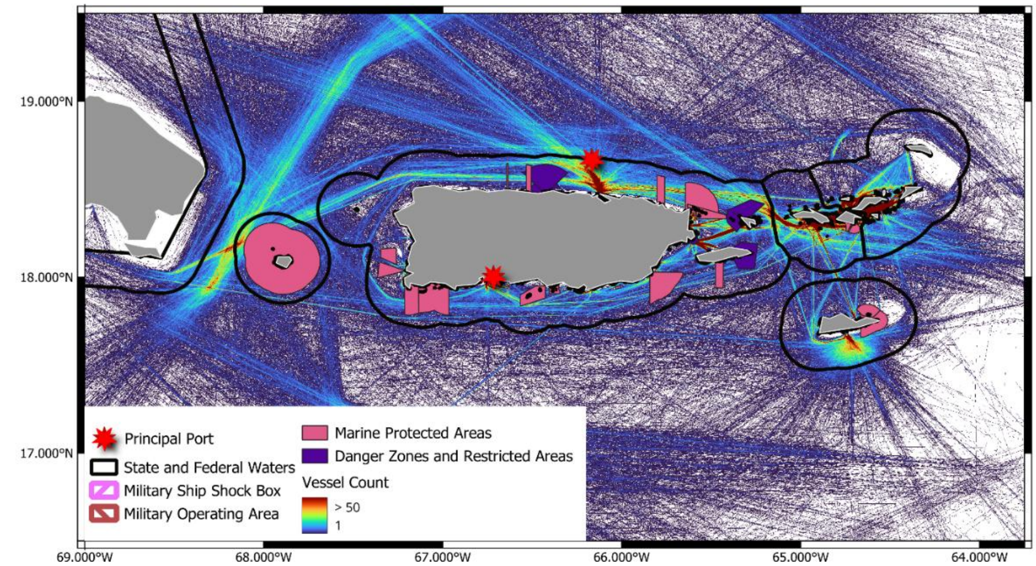

Figure 2. Regulatory and logistical parameters of Puerto Rico and the U.S. Virgin Islands.

Table 2. Environmental, regulatory and logistical parameters for co-location

Parameter	Criteria	Source
Marine Protected Areas	Exclude the entire area	NOAA MPA Inventory [14]
Danger Zones and Restricted Areas	Exclude the entire area	NOAA Office for Coastal Management [15]
Military Zones	Further consideration	NOAA Office for Coastal Management [16]
Bathymetry	-	General Bathymetric Chart of the Oceans (GEBCO) [17]
Ports	Distance to ports < 100km	NOAA Office for Coastal Management [17]
Navigation Routes	Transit Count Vessel < 50	Marine Cadastre, 2023 [19]
Maritime Limits & Boundaries	-	NOAA Office of Coast Survey [20]

3. Results

Figures 4 and 5 present the spatial distribution of average OTEC net output power across the study regions, overlaid with key regulatory and logistical constraints. Among the regions analyzed, the Florida Straits exhibit the lowest OTEC co-location.

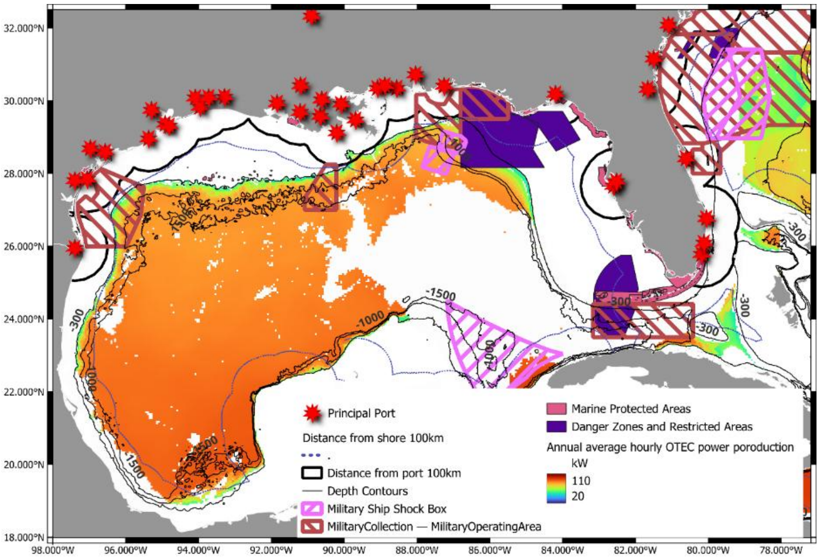

Figure 4. OTEC power potential in the Gulf of America and Florida Straits, excluding unsuitable areas based on regulatory, oceanographic, and logistical constraints.

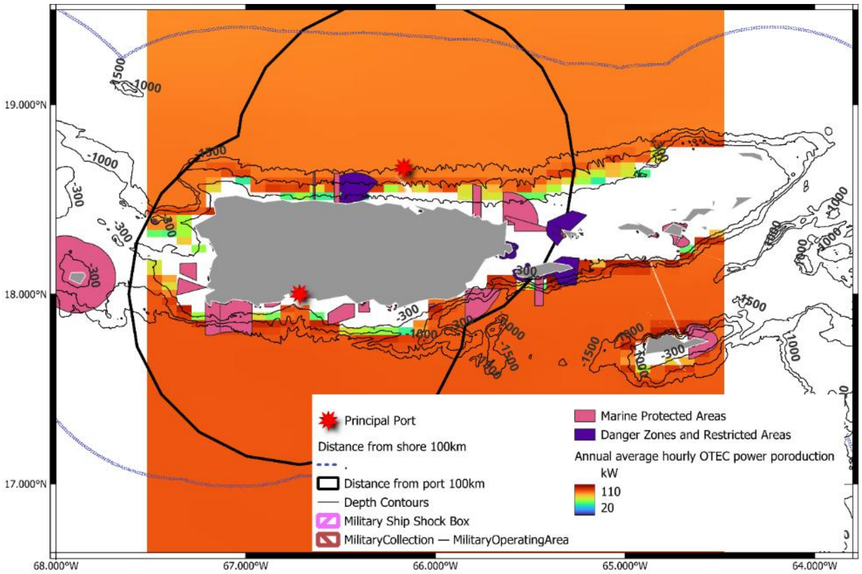

Figure5. OTEC power potential Puerto Rico and the U.S. Virgin Islands, excluding unsuitable areas based on regulatory, oceanographic, and logistical constraints.

This area poses significant challenges for co-location primarily due to high ocean current speeds driven by the Gulf Stream. Many nearshore zones experience average velocities exceeding 0.5m/s, which surpasses the upper limit considered suitable for Kanpachi aquaculture. As a result, several locations were excluded from consideration despite having favorable thermal gradients for OTEC. Furthermore, areas in the Florida Straits that exceed the 51kW minimum power threshold are typically located farther offshore, increasing logistical complexity. Bathymetric conditions in this region change gradually, with depths greater than 300 m found only at substantial distances from the coast.

The Gulf of America displays a similar pattern, where most high-potential OTEC zones are also located far from shore. However, a small area near the coast of Louisiana falls within 100 km of a major port and meets both the energy and logistical criteria, making it a promising candidate for co-location and further development efforts.

Puerto Rico presents particularly favorable conditions for the integration of OTEC systems with offshore aquaculture. Most high-potential OTEC areas lie within 100km of the island's two major ports, supporting feasible logistics for construction, operation, and maintenance. Areas of high OTEC power density were identified along both the northern and southern coasts, particularly between the 1000m and 1500m depth contours. Although the U.S. Virgin Islands lack a major port facility, numerous suitable co-location sites were identified within 100km of the shoreline. It is worth mentioning that waters surrounding Puerto Rico and the U.S. Virgin Islands exhibit steep bathymetric gradients, resulting in high OTEC power density very close to shore. In these regions, the 1000m and 1500m depth contours are situated relatively near the coastline. While this improves logistical feasibility in terms of distance to shore, it also introduces greater engineering challenges for deploying and securing mooring systems in deep water.

4. Conclusion

This study presents an integrated spatial methodology to assess the feasibility of co-locating Ocean Thermal Energy Conversion (OTEC) systems with offshore Kanpachi aquaculture. The analysis combined MATLAB-based OTEC modeling with GIS-based spatial evaluation, incorporating ocean thermal profiles, species-specific biological thresholds, and key environmental, regulatory, and logistical constraints.

The results indicate that Puerto Rico offers the most favorable conditions for co-location, with strong thermal gradients, proximity to major ports, and manageable depth contours nearshore. The U.S. Virgin Islands also demonstrate considerable potential, though limited port infrastructure may require alternative logistical strategies. In contrast, the Florida Straits face limitations due to lower OTEC performance and high ocean current speeds, while a small area near the Louisiana coast in the Gulf of America emerges as a viable candidate based on both energy output and accessibility.

This work highlights the value of multi-criteria marine spatial planning for guiding integrated offshore system development. The methodology presented here offers a replicable framework for identifying co-location opportunities and informing future policy, permitting, and investment decisions. Future research should focus on techno-economic analysis, engineering design for deepwater mooring, and field validation to support real-world deployment.

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