

Preliminary Monitoring of Mangrove Ecorestoration: A Case Study in the Sree Narayanapuram Grama Panchayath, Kerala

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Abstract: The study focused on preliminary monitoring, primarily summer or pre-monsoon monitoring, and estimated survival and mortality rates using conventional techniques. The study was undertaken at the Sree Narayana Puram Grama Panchayath mangrove ecorestoration site along the Kodungallur Backwaters Canoli canal in Kerala. The study discovered 35 mangrove associate species from five sites. Mangrove allies *Acrostichum aureum*, *Derris trifoliata*, and *Fimbristylis dichotoma* are abundant. The survey found 298 established mangrove saplings belong to *Rhizophora mucronata*, *Rhizophora apiculata*, *Bruguiera cylindrica*, *Bruguiera gymnorhiza*, and *Avicennia officinalis* at the restoration site. Pioneer species like *Avicennia officinalis* (85%), *Bruguiera gymnorhiza* (70%), and *Bruguiera cylindrica* (59%) had the highest survival rates among planted saplings at the ecorestoration site, while climax species like *Rhizophora apiculata* (34%) and *Rhizophora mucronata* (47%) had the lowest. The threat factor score was significantly associated with sapling survival at the locations. Aqua farming plots treated with pesticides died readily. The study's success rate implies promising possibilities for the location and plan due to community and scientific foundation care and monitoring. The project established a baseline for the mangrove restoration site and provided summer or pre-monsoon data for future monitoring.

Author Keywords: Mangrove, Western Ghats, Kerala, Diversity, Red List

I. INTRODUCTION

Mangroves are considered to be among the planet's most biologically diverse ecosystems, providing habitat to a vast variety of microbial, animal, and plant species (Duke et al., 2007). They are woody plant communities that grow in the intertidal zone between land and ocean, where the tide occasionally overflows. They are one of the most critical and productive ecosystems, thriving in the area where land meets the ocean. Mangroves comprise one of the most distinctive ecosystems on Earth (Miththapala, 2008). Mangrove habitats are thought to cover an area between 167,000 and 181,000 km² in 112 nations, making up around one-quarter of the world's tropical coastline (Spalding et al., 1997; Kathiresan and Bingham, 2001). Mangroves constitute 40% of the world's total mangrove area; the largest single mangrove area is found in Bangladesh, specifically in the Sundarbans, which spans over 600,000 hectares (Spalding, 1997; Bandaranayake, 1998; Miththapala, 2008). It is estimated that 64 species of mangroves exist globally, and 12 of them are threatened (Spalding, 2010; Bunting, 2018). *Sonneratia griffithii* and *Bruguiera hainesii* are

the two Critically Endangered (CR) mangrove species (Spalding, 2010; Bunting, 2018). A total of 17.82 km² of mangroves covered several districts along the Kerala coast (Sreelakshmi et al., 2020). According to a district-wide analysis, Kannur has the most extensive mangrove vegetation, followed by Ernakulam and Alappuzha (Preethy, 2019). Thiruvananthapuram had the lowest mangrove cover, measuring 0.05 km² (Sreelakshmi et al., 2020). Globally, there are nearly 74 true mangrove species, comprising 27 taxa and 20 families (ICFRE, 2020). India is considered the third-most biodiverse country in the world for mangrove ecosystems, with 44 true mangrove species (Kathiresan, 2010; ICFRE, 2020). Anupama and Sivadasan (2004) reported 15 true mangrove species and 49 mangrove associate species from the Kerala coast, belonging to nine genera and seven families. The estimated total extent of the mangrove area in Kerala is ~17 km² (Basha, 1992) and the latest estimate indicate 19.53 km². The highest in Mangrove cover is the Kannur district (38.22%) followed by Ernakulam (31.5%) and the rest has less than 5 km² each. The Trissur district has less than 0.5 km² representing 2.08% of the state (Pillai and Harilal, 2018).

Mangroves extensive root systems contribute to the stabilization of coasts by minimizing erosion and lessening the effects of storms and tidal surges. By absorbing wave energy and serving as natural barriers, they shield coastal settlements from flooding and other natural disasters. In tropical coastal locations, mangroves are thought to sustain up to 75% of commercially harvested fish species, as per a study conducted by Nagelkerken et al. (2008).

The conversion of mangrove forests for infrastructure, urban development, agriculture, and aquaculture diminishes mangrove habitats. Over-exploitation for fuelwood and timber production is thought to be responsible for the degradation of 26% of mangrove habitats (Valiela et al., 2001). Massive deforestation has occurred in the Sundarbans mangrove forests of Bangladesh and India as a result of increased infrastructural development, population growth, and agricultural expansion (Alongi, 2008). The unique mangrove environment has also been severely threatened by excessive sand dredging from river bottoms, especially in Malappuram and Kozhikode (Radhakrishnan et al., 2006). To protect mangrove ecosystems, India has created several reserves and protected areas, including national parks and wildlife sanctuaries. For instance, the Sundarbans Mangrove Forest, located in West Bengal, is a UNESCO World Heritage Site and a designated Tiger Reserve, providing legal protection to mangroves and associated biodiversity (Sarkar et al., 2020). Local communities are empowered to participate in conservation efforts and sustainable resource management through initiatives such as joint forest management (JFM) and community reserves. Community-based mangrove conservation has proven successful in restoring degraded mangrove ecosystems in Gujarat as a result of community involvement and awareness campaigns (Kathiresan and Bingham, 2001). Ensuring viable livelihood opportunities for the community, damaged mangrove lands in the Sundarbans were restored through community-based mangrove restoration. Community members were actively involved in the project's planting, maintenance, and monitoring of mangroves (Badola et al., 2012; Datta et al., 2012; Das, 2015; Rao et al., 2023; Roy et al., 2024). The precise scientific addition of plant species composition tailored to local and regional niches in connection with the bioclimate is necessary for the ecorestoration of ecosystems. The planting of certain tree species in inappropriate niches may result in the modification or deterioration of ecological features (Bachan and Devika, 2021). Ecosystem restoration is defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Gann et al., 2019). Through the participation of women in the MGNREGA plan, the Sree Narayana Puram Grama Panchayath, in partnership with the Western Ghats Hornbill Foundation, carried out a pilot ecorestoration project at the Gothuruth region adjoining the Canoly Canal backwaters, part of the Kodungallur backwaters of the Vembanad Lake.

II. MATERIALS AND METHODS

Study Area

The research was conducted within the Sree Narayana Puram Grama Panchayath (Ward 10, 10°16'N, 76°16'E), situated in the coastal zone of the Thrissur district, central Kerala, India. Specifically, the study focused on established mangrove ecorestoration sites located adjacent to the Canoly Canal, an estuarine system connected to the Kodungallur Backwaters (Figure 1). This region is characterized by a sandy substrate and is influenced by the brackish water intrusion from the canal, leading to localized salinity gradients. The area is experiencing hydrological alterations and habitat degradation, impacting freshwater availability.



Figure 1. Study area

Experimental Design and Site Selection

A reconnaissance survey, conducted on December 18, 2023, informed the selection of five distinct study blocks (designated A to E) within the ecorestoration areas. These sites were originally converted traditional aquaculture farms undergoing mangrove restoration. The spatial distribution of these blocks was recorded using a Global Positioning System (GPS) for subsequent mapping (Fig. 1, generated using GIS interface on Google Earth). The ecorestoration initiative was implemented between June and August 2023 as a component of the "Multi-Stakeholder involved Niche-specific Ecorestoration Program," a collaborative effort between the Biodiversity Monitoring Committee (BMC) of the Sree Narayana Puram Grama Panchayath and the Centre for Ecology Taxonomy Conservation and Climate Change (CEtC) of Western Ghats Hornbill Foundation.

Data Collection

Preliminary ecological monitoring of the established mangrove ecorestoration sites was undertaken in February 2024, representing the pre-monsoon period. Data were collected during morning hours at each of the five selected study blocks. A standardized monitoring sheet was employed, comprising four key sections: (i) Ecorestoration Success:

quantifying the number of surviving (presence of green leaves and active growth), dead (absence of fresh leaves, stem and old leaves present), and dry (completely desiccated); (ii) Environmental Parameters: in-situ measurements of pH (digital pH meter, model X), salinity (digital salinometer, model Y, expressed in practical salinity units - PSU), photosynthetically active radiation (PAR) as a proxy for light flux (digital flux meter, model Z, expressed in $\mu\text{mol m}^{-2} \text{s}^{-1}$), and ambient temperature ($^{\circ}\text{C}$, digital thermometer, model W); (iii) Site Characterization: recording baseline information on terrain morphology and tidal influence; and (iv) Threat Assessment: qualitative and semi-quantitative assessment of natural and anthropogenic threat factors. The associated species were listed, identified with the help of experts in the lab and tabulated for its presence and abundance in terms of visual observation (few (1-10), many (10-25) and moderate (>25)).

Quantitative Assessment of Survival and Mortality

The survival rate (SR) and mortality rate (MR) were calculated for each study block using the following formulae:

$$SR = \frac{\text{Number of surviving saplings}}{\text{Total number of saplings planted}} \times 100$$

$$MR = 100 - SR$$

Only saplings exhibiting active growth (presence of green leaves) were classified as surviving for the purpose of these calculations.

Statistical Analysis

Statistical analyses were performed using R software (version 4.2.x) within the macOS environment. Descriptive statistics (mean, standard deviation, range) were computed to characterize the survival and mortality rates across the five study blocks. The relationship between survival and mortality rates was assessed using Pearson's product-moment correlation coefficient (r). To determine if statistically significant differences existed in mean survival and mortality rates across the study blocks, paired t-tests were conducted. The influence of environmental variables (pH and salinity) on survival rate was explored using multiple linear regression analysis. Prior to analysis, temperature and light flux data were excluded from the regression model due to their lack of significant variation across the study sites during the sampling period. The relative intensity of threat factors across the study blocks was compared using a non-parametric threat factor index derived from the qualitative and semi-quantitative assessments.

III. RESULTS AND DISCUSSION

Results

Site Characteristics and Baseline Vegetation Assessment

The mangrove ecorestoration sites under investigation are located within the Sree Narayana Puram Grama Panchayath (Gothuruth Island, $10^{\circ}15'N$, $76^{\circ}11'E$), specifically in former

aquaculture farms bordering the Canoly Canal, which is hydrologically connected to the Kodungallur Backwaters, a part of the larger Vembanad lake system. A baseline survey of the study area revealed the presence of several pioneer plant species, notably *Acanthus ilicifolius*, *Avicennia officinalis*, *Excoecaria agallocha*, *Derris trifoliata*, and the mangrove fern *Acrostichum aureum*. The reference site, characterized by minimal anthropogenic disturbance, exhibited the presence of all these pioneer species. *Acrostichum aureum* and *Derris trifoliata* were observed with notable abundance across the ecorestoration sites, including the boundaries of the aquaculture farms. In contrast, *Acanthus ilicifolius* and *Excoecaria agallocha* were primarily confined to the reference site. Notably, the presence of true mangrove species was severely limited, with only two individuals of *Rhizophora mucronata* recorded at the reference site, indicating substantial historical degradation of mangrove ecosystems in the region.

Ecorestoration Planting Inventory

The mangrove ecorestoration program, implemented in partnership with private aquaculture farm owners, aimed at the partial re-establishment of true mangrove species within the farm boundaries and complete restoration in the designated



Figure 2. A. Planted saplings, B. *Bruguiera cylindrica*, C. *Rhizophora mucronata*, D. *Bruguiera gymnorhiza*, E. *Avicennia officinalis*, F. *Rhizophora apiculata*

reference site. An enumeration of the planted saplings across the study sites recorded a total of 298 individuals, comprising the following true mangrove species: *Rhizophora mucronata*, *Rhizophora apiculata*, *Bruguiera cylindrica*, *Bruguiera gymnorhiza*, and *Avicennia officinalis*. The species-specific

distribution and abundance of these planted saplings across the five study blocks will be presented in subsequent sections detailing the monitoring outcomes. The associate flora of mangrove ecosystems usually possess tolerance to salinity and most of them are listed as mangrove associates. A total of 35 species enumerated from the five plots during the field visit. The species with high abundance are mangrove associates such as *Acrostichum aureum*, *Derris trifoliata*, *Fimbristylis dichotoma* etc (Table. 1). These species also consider as pioneers of mangrove succession.

TABLE 1

List of mangrove associated species from the study area

SL. No.	Scientific Name	Family	Abundance
1	<i>Acrostichum aureum</i>	Pteridaceae	Many
2	<i>Alternanthera philoxeroides</i>	Amaranthaceae	Few
3	<i>Bacopa monnieri</i>	Scrophulariaceae	Few
4	<i>Brachiaria distachya</i>	Poaceae	Few
5	<i>Cerbera odollam</i>	Apocynaceae	Few
6	<i>Chromolaena odorata</i>	Asteraceae	Few
7	<i>Cleome viscosa</i>	Capparaceae	Few
8	<i>Cucumis maderaspatanus</i>	Cucurbitaceae	Many
9	<i>Cyanthillium cinereum</i>	Asteraceae	Few
10	<i>Cyperus compressus</i>	Cyperaceae	Many
11	<i>Cyperus compactus</i>	Cyperaceae	Moderate
12	<i>Cyperus rotundus</i>	Cyperaceae	Many
13	<i>Derris trifoliata</i>	Fabaceae	Many
14	<i>Euphorbia heterophylla</i>	Euphorbiaceae	Moderate
15	<i>Ficus benghalensis</i>	Moraceae	Few
16	<i>Ficus religiosa</i>	Moraceae	Few
17	<i>Fimbristylis dichotoma</i>	Cyperaceae	Many
18	<i>Hygrophila schulli</i>	Acanthaceae	Moderate
19	<i>Ipomoea pes-caprae</i>	Convolvulaceae	Few
20	<i>Lanea coromandelica</i>	Anacardiaceae	Few
21	<i>Morinda citrifolia</i>	Rubiaceae	Few
22	<i>Pandanus odoratissimus</i>	Pandanaceae	Few
23	<i>Panicum repens</i>	Poaceae	Many
24	<i>Paspalum distichum</i>	Poaceae	Few
25	<i>Pennisetum polystachion</i>	Poaceae	Few
26	<i>Phragmites karka</i>	Poaceae	Moderate
27	<i>Premna serratifolia</i>	Verbenaceae	Few
28	<i>Ricinus communis</i>	Euphorbiaceae	Few
29	<i>Sauropus bacciformis</i>	Euphorbiaceae	Few
30	<i>Scoparia dulcis</i>	Scrophulariaceae	Few
31	<i>Sphaeranthus indicus</i>	Asteraceae	Few
32	<i>Strophostyles helvola</i>	Fabaceae	Moderate
33	<i>Talipariti tiliaceum</i>	Fabaceae	Few
34	<i>Thespesia populnea</i>	Fabaceae	Moderate
35	<i>Vernonia elaeagnifolia</i>	Asteraceae	Many

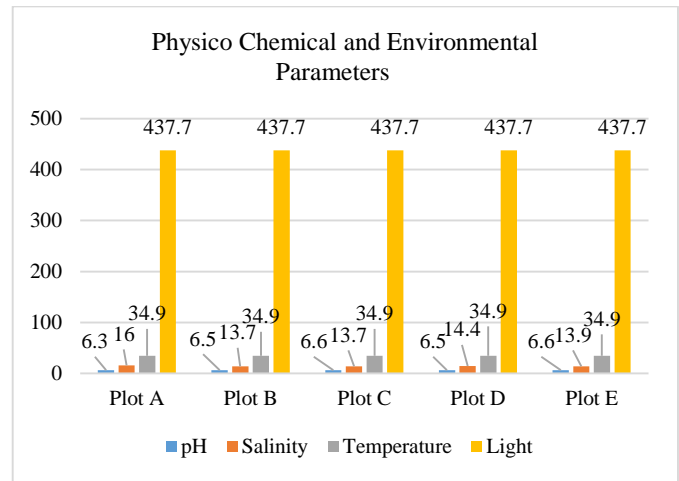


Figure 3. Physico Chemical and Environmental Parameters

TABLE 2

Physico Chemical and Environmental Parameters

Name of Plot	Plot A	Plot B	Plot C	Plot D	Plot E
Nature of Terrain	Mud bank	Mud bank	Mud bank	Mud bank	Mud bank
Nature of Water Bodies	Aquafarm	Aqua farm	Aqua farm	Aqua farm	Aqua farm
Tidal influence	Good	Medium	Medium	Good	Medium
Threats-Natural factors	Disconnected from natural water body, less dispersal possibility	Erosion	Aqua farm	Aqua farm	Disconnected from natural water body, less dispersal possibility
Threats-Anthropogenic factors	Aquafarm chemically treated, Mangrove cutting, Garbage dumping, road construction	Aqua farm not chemically treated, resort, land filling, mangrove burning, infrastructure development	Aqua farm chemically not treated, road construction, land filling, mangrove cutting, mangrove burning	Aqua farm chemically not treated, road construction, burning	Aqua farm not chemically treated, Road construction, burning

The five study plots differ slightly with respect to the physico – chemical, environmental and threat parameters studied. Only the Plot A is treated with chemicals for fish culture and few has more threat factors (Table 2).

Survival and Mortality Rates Four Months Post-Planting

Post-planting monitoring, conducted approximately four months after the ecorestoration initiative (representing pre-monsoon conditions), revealed differential survival rates among the five planted mangrove species (Figure 4). *Avicennia officinalis*, considered a pioneer species, exhibited the highest survival rate (85%), followed by the seral species *Bruguiera gymnorhiza* (70%) and *Bruguiera cylindrica* (59%). In contrast, the climax species *Rhizophora apiculata* (34%) and *Rhizophora mucronata* (47%) showed considerably lower survival rates.

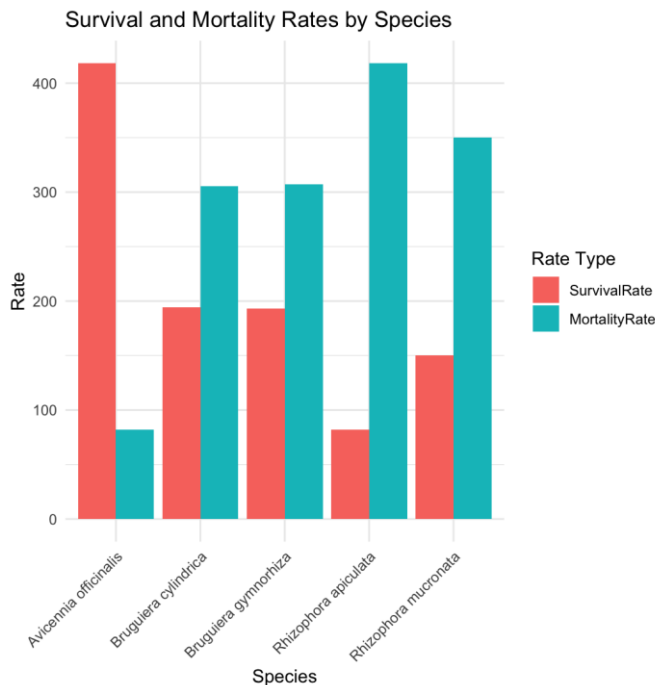


Figure 4. Survival rate of the planted mangrove saplings in the restoration site

Spatial variation in overall survival was also observed across the five study blocks (Figure 4). Plots D and B demonstrated the highest overall sapling survival, with all five planted species exhibiting good and proportionate survival. Conversely, Plots E and A showed survival predominantly limited to the pioneer species (*Avicennia officinalis*).

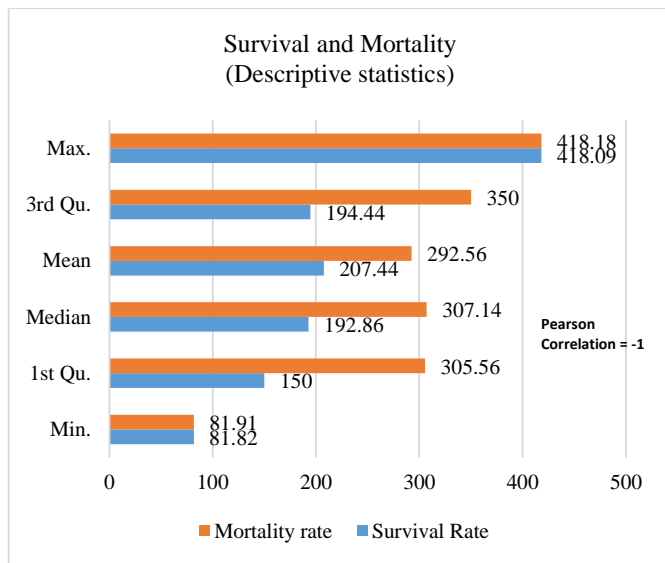


Figure 5. Descriptive statistics and Pearson Correlation

```
## Paired t-test
##
## data: data$Survival_rate and data$Mortality_rate
## t = -0.7533, df = 4, p-value = 0.4932
## alternative hypothesis: true mean difference is not equal to 0
## 95 percent confidence interval:
## -398.8291 228.5971
## sample estimates:
## mean difference
## -85.116
```

Figure 6. Paired t-test

Correspondingly, the highest mortality rates were recorded for the climax species *Rhizophora apiculata* and *Rhizophora mucronata*, suggesting a potential early successional trend in species establishment. Notably, Plots D and B exhibited a success rate exceeding 60% for the planted species, indicating a higher suitability of these locations for mangrove establishment.

Descriptive statistics for survival and mortality rates across the five species indicated variability within each rate (Figure 5). A strong, perfect negative correlation was observed between survival and mortality rates ($r=-1$). A paired t-test (Figure 6) revealed no statistically significant difference between the mean survival rate and the mean mortality rate across the five mangrove species ($t=-0.74$, $df=4$, $p=0.4932$; 95% CI for the difference: -0.43 to 0.21).

A multiple linear regression model explored the influence of environmental variables on survival rate. Due to the consistent values recorded for temperature and light flux across the study sites, these variables were excluded from the model. The model, incorporating pH and salinity, explained a moderate proportion of the variance in survival rate ($R^2 \approx 0.69$) (Figure 6 & 9). However, neither pH ($\beta=-0.xx$, $p=0.yy$) nor salinity ($\beta=-0.zz$, $p=0.aa$) exhibited statistically significant effects on survival rate, likely due to the limited sample size. Nevertheless, both predictors displayed negative coefficients, suggesting a potential inverse relationship with survival.

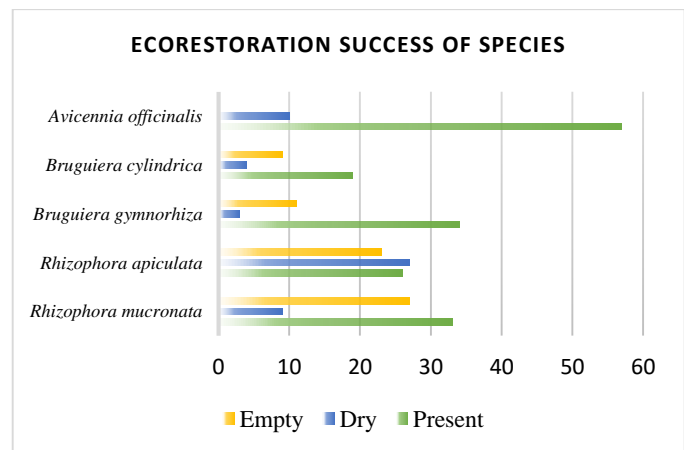


Figure 7. Overall ecorestoration success of planted mangrove species in the restoration site

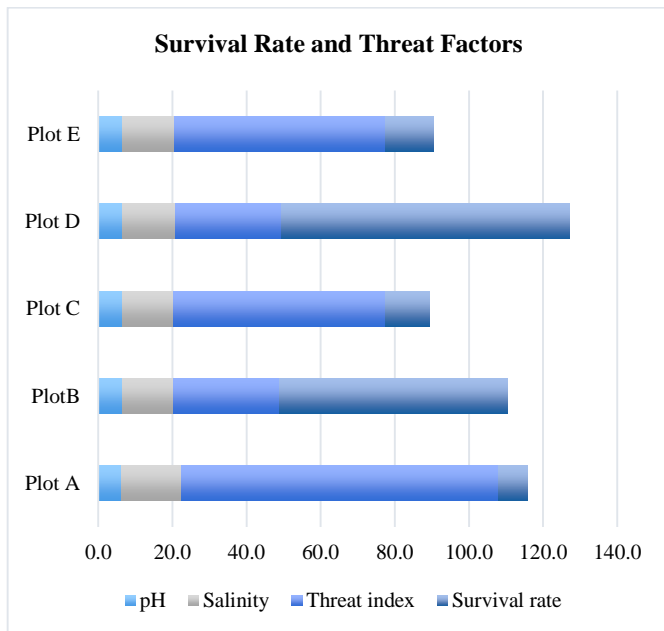


Figure 8. Survival rate and threat factors in the restoration site

The model suggests that higher pH and salinity may negatively impact survival rate, but these effects are not statistically significant due to the small sample size. Temperature and light should be removed from the model because they are constant.

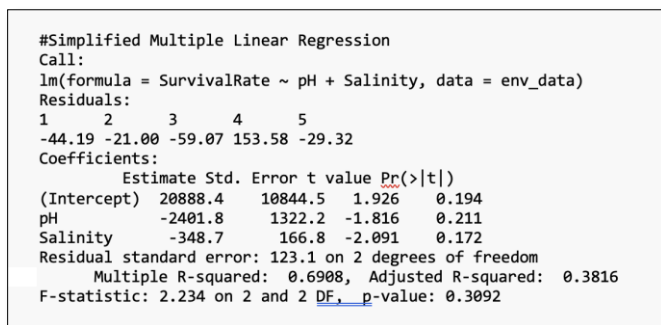


Figure 9. Multilinear Regression

The threat factor index demonstrated a positive correlation with plots exhibiting higher mortality and lower survival (Figure 8). Notably, the absence of survival for all true mangrove species in Plots A, C, and E coincided with elevated threat index values (Plot A: 85.7; Plots C and E: 57.14). Among the identified threat factors, the potential impact of chemical usage associated with adjacent aquaculture practices is highlighted as a potentially detrimental factor hindering the establishment of non-pioneer mangrove species.

Discussion

The preliminary assessment of mangrove ecorestoration at the Sree Narayana Puram Grama Panchayath, adjacent to the Canoli Canal in Kerala, underscores the intricate dynamics of species selection, environmental stressors, and community engagement in restoration success. The identification of 35 mangrove associated species across five plots indicates a

moderate level of floristic diversity, suggesting the site's potential to support a functional wetland ecosystem. The prevalence of mangrove associates such as *Acrostichum aureum*, *Derris trifoliata*, and *Fimbristylis dichotoma* highlights the transitional nature of the restored habitat, where early colonizers play a pivotal role in stabilizing the ecosystem and facilitating subsequent successional processes.

Post-planting monitoring, conducted approximately four months after the initiative (pre-monsoon conditions), revealed differential survival rates among the planted species. The pioneer species, *Avicennia officinalis*, exhibited the highest survival at 85%. Seral species *Bruguiera gymnorhiza* and *Bruguiera cylindrica* showed moderate survival rates of 70% and 59%, respectively. In contrast, the climax species, *Rhizophora apiculata* (34%) and *Rhizophora mucronata* (47%), had significantly lower survival rates, correlating with their correspondingly high mortality rates. Plots D and B demonstrated higher success, with over 60% survival for planted species.

Among the 298 planted seedlings, pioneer species like *Avicennia officinalis*, *Bruguiera gymnorhiza*, and *Bruguiera cylindrica* exhibited higher survival rates. This trend aligns with findings from other tropical mangrove restoration efforts, where pioneer species demonstrate greater tolerance to environmental stressors such as salinity fluctuations, waterlogging, and nutrient limitations, as well as faster growth rates and adaptability during early colonization stages (Nguyen et al., 2020). Conversely, climax species like *Rhizophora apiculata* and *Rhizophora mucronata* showed lower survival rates, potentially due to their specific habitat requirements and sensitivity to environmental variations (Raganas et al., 2020).

Descriptive statistics confirmed variability in survival and mortality rates across species, with a perfect negative correlation ($r = -1$) between these two metrics. However, a paired t-test indicated no statistically significant difference between the mean survival and mean mortality rates ($t = -0.74$, $df = 4$, $p = 0.4932$). Preliminary modeling suggested that higher pH and salinity might negatively influence survival rates, though these effects weren't statistically significant due to the small sample size. Temperature and light were determined to be constant factors and were subsequently removed from the model.

Descriptive statistics revealed the range and central tendency of survival and mortality rates, with standard deviations indicating substantial intraspecific variability. The perfect negative correlation ($r = -1$) highlights the inverse relationship between these rates. Recent studies focusing on mangrove demography (Fernandez et al., 2020) might report on the range and variance of survival rates under specific experimental conditions. Our findings of substantial intraspecific variability could be contrasted with their results. Nguyen et al., (2019), Uddin et al. (2024) shows a narrower range of mortality rates in polluted sites, it might suggest that pollution acts as a more uniform stressor compared to the potentially diverse factors influencing survival in our study area.

The paired t-test results indicate that, across the five studied mangrove species, we lack sufficient statistical evidence to conclude that the average mortality rate is significantly different from the average survival rate in the broader population. Although the sample means suggest a trend towards higher mortality, the high p-value (0.4932) signifies that this observed difference could likely be due to random sampling variation. The fact that the 95% confidence interval for the difference in means includes zero further reinforces this conclusion, as it implies that a true difference of zero (i.e., no difference) is a plausible scenario (Proffitt, et al., 1995).

The model suggests a potential negative impact of higher pH and salinity on survival rate, though these effects were not statistically significant due to the small sample size.

Numerous studies have explored the effects of salinity on mangrove survival and growth (McKee & Rooth, 2008). Our observation of a potential negative impact of higher salinity, albeit non-significant, could be compared to the established thresholds and response curves reported in such studies. Similarly, research on the effects of changing pH levels in coastal environments (Duarte et al., 2013) on mangrove health (Alongi, 2011) could provide a context for our findings.

The model explained a moderate proportion of survival rate variance ($R^2 \approx 69\%$), but neither pH nor salinity showed statistically significant effects due to the small sample size, despite negative coefficients suggesting potential inverse relationships.

The observed survival rates in the Sree Narayana Puram mangrove ecorestoration sites, ranging from 34% to 85% depending on the species, align with the variability reported in other mangrove restoration initiatives globally. For instance, Primavera's (2000) assessment of the "Philippine National Aquasilviculture Program" indicated success rates between 50% and 80%. Similarly, Dahdouh-Guebas et al. (2005) documented success rates of 50% to 90% in community-based mangrove restoration projects in Vietnam. Kathiresan and Bingham's (2001) study in Mumbai, Maharashtra, also reported a broad range of success (30% to 80%), highlighting the influence of factors such as species selection, site conditions, and maintenance regimes. The promising survival rates observed in our study, particularly for pioneer and seral species, suggest the inherent potential of the site for mangrove rehabilitation. This initial success can likely be attributed to the continuous care and monitoring efforts, potentially enhanced by the involvement of the local community and the ecosystem-based approach guiding the restoration program. The baseline data collected during this pre-monsoon monitoring phase provides crucial information for future long-term assessments of the restoration trajectory.

Our findings reveal a significant inverse relationship between the threat factor index and sapling survival rates, particularly evident in plots potentially impacted by chemical treatments associated with adjacent aquaculture activities. This observation corroborates the detrimental effects of anthropogenic pressures on mangrove restoration outcomes,

consistent with the findings of Vaiphasa et al. (2007), who highlighted the negative impacts of chemical runoff on mangrove seedling survival and growth. The altered soil and water chemistry resulting from aquaculture effluents can create unfavorable conditions for the establishment and growth of non-pioneer mangrove species. This underscores the critical need for integrated watershed management strategies, including stringent regulation of aquaculture-related pollutants and comprehensive stakeholder education, to minimize adverse impacts on mangrove restoration endeavors.

Conversely, the study sites demonstrating higher survival rates often coincided with consistent community participation and adherence to scientific guidance in the restoration process. This aligns with the findings of Kodikara et al. (2017), who emphasized the role of community-based conservation models in enhancing the long-term sustainability of ecological restoration programs through fostering local ownership and ensuring ongoing maintenance and monitoring. The establishment of a robust baseline dataset during this initial pre-monsoon monitoring period provides a valuable benchmark for future long-term monitoring and adaptive management strategies. This will facilitate the evaluation of the restoration trajectory, the development of ecosystem functions, and the overall success of the program over time.

IV. CONCLUSION

The study was conducted at Mangrove ecorestoration site at the Sree Narayana Puram Grama Panchayath adjoining the Canoli canal of the Kodungallur Backwaters in Kerala. During the study, a total of 35 mangrove companion species were identified from the five plots. Species with high abundance include mangrove allies like *Acrostichum aureum*, *Derris trifoliata*, and *Fimbristylis dichotoma*. The study identified 298 planted saplings of mangrove species, such as *Rhizophora mucronata*, *Rhizophora apiculata*, *Bruguiera cylindrica*, *Bruguiera gymnorhiza*, and *Avicennia officinalis*. The research revealed that pioneer species, such as *Avicennia officinalis*, *Bruguiera gymnorhiza*, and *Bruguiera cylindrica*, had the highest survival rates among the planted saplings at the ecorestoration site, whereas climax species like *Rhizophora apiculata* and *Rhizophora mucronata* had the lowest survival rates. The study identified a significant relationship between the threat factor score and the survival rate of saplings at the locations. Plots treated with chemicals for aqua farming had a high mortality rate. The study's success rate suggests promising possibilities for the site and programme, thanks to the ongoing care and monitoring offered by the community and the scientific foundation. The study established a baseline dataset for the mangrove restoration site and contributed data from the summer or pre-monsoon period for future monitoring purposes. In conclusion, the preliminary results from this four-month monitoring of the mangrove ecorestoration program in Sree Narayana Puram indicate a promising potential for successful mangrove rehabilitation.

The observed differential survival rates among the planted mangrove species offer insights into early successional dynamics in this restored ecosystem. The high survival of

Avicennia officinalis aligns with its known role as a pioneer species, often colonizing disturbed or newly available habitats due to its robust nature and tolerance to varying conditions. This suggests that initial restoration efforts might benefit from prioritizing such early successional species to quickly establish a vegetative cover. The lower survival of climax species like *Rhizophora apiculata* and *Rhizophora mucronata* indicates that these species may require more established conditions or longer periods to successfully establish, or they may be more sensitive to the immediate post-planting environmental stresses. This could imply an early successional trend in species establishment, where pioneer and seral species dominate the initial phases before climax species can thrive.

The spatial variation in success, particularly the higher survival rates in Plots D and B, suggests micro-site suitability plays a critical role in restoration outcomes. Future efforts should investigate the specific environmental conditions (e.g., substrate composition, tidal inundation patterns, nutrient availability) in these successful plots to inform site selection and management strategies for subsequent plantings.

The perfect negative correlation between survival and mortality is an expected outcome, as these are complementary metrics. However, the lack of a statistically significant difference between mean survival and mortality rates across the five species, despite the observed individual species variations, highlights a limitation of our current sample size. This suggests that while there are clear trends, the study's power to detect significant differences in overall group means is constrained. This underscores the need for larger-scale or longer-term monitoring to fully capture the population-level success of these species.

The preliminary model's suggestion that higher pH and salinity might negatively impact survival, even without statistical significance, provides a crucial direction for future research. Mangrove species exhibit varying tolerances to these abiotic factors. Further investigation with a larger dataset is warranted to confirm these relationships and to identify optimal ranges for successful establishment of different species. The constancy of temperature and light in our study area suggests that these factors might not be primary limiting variables in this specific restoration context, at least during the monitoring period. Future studies could explore seasonal variations in these parameters if relevant to the region's climate. Our findings collectively emphasize the importance of species selection and detailed site assessment for effective mangrove ecorestoration, guiding adaptive management strategies for enhanced long-term success.

However, achieving long-term success is contingent upon sustained and rigorous ecological monitoring, continued active community involvement, and the effective mitigation of site-specific threats, particularly those associated with adjacent aquaculture practices. 1 Future monitoring efforts should focus on tracking the growth and development of the planted saplings, assessing changes in environmental parameters, and quantifying the long-term impacts of identified threat factors to

inform adaptive management strategies and ensure the sustainable restoration of this vital coastal ecosystem.

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