Rufford Project Update Report – August 2025

Project Title: *Surfgrass Under Threat: Developing Conservation Tools by Monitoring Seagrass Meadows in Baja California (Mexico)*

Grant ID: 43604-1

Project Leader: Manuel Vivanco Bercovich

Institution: Universidad Autónoma de Baja California

1. Executive Summary

This midterm progress report outlines the achievements and ongoing efforts of the project *Surfgrass Under Threat: Developing Conservation Tools by Monitoring Seagrass Meadows in Baja California (Mexico)*, funded by The Rufford Foundation. Since the project's launch in early 2024, substantial progress has been made toward all major objectives, as assessed through the PRISM framework.

Two seasonal monitoring campaigns have been completed across four surfgrass meadows, Isla Todos Santos (TSI), Ensenada (ENS/3MS), Bahía Tortugas (BTO), and San Juanico (SJU). These campaigns have yielded a robust dataset on *Phyllospadix* meadow structure, physiology, and environmental conditions.

Key accomplishments include the establishment of time series on seawater temperature, generation of spatial coverage maps, analysis of structural-biometric relationships, and the development of the SURFMEX multivariate index. Additionally, an unplanned but valuable germination experiment was conducted using *Phyllospadix* seeds collected across a latitudinal gradient, providing insights into early life-stage responses to warming.

The project is also delivering on its communication and outreach goals. Undergraduate students have been actively engaged in monitoring activities; results have been presented at both community and scientific forums; and project updates are regularly shared on social media (@surfgrass.project). Two scientific publications are in preparation addressing surfgrass responses to marine heatwaves and their role in carbon and nitrogen cycling.

The project remains on track for completion in late 2025, with one final field campaign planned, continued data integration for index calibration, and publication and outreach products under development. Overall, this work contributes to a deeper ecological understanding of *Phyllospadix* meadows and provides actionable tools for their conservation under climate change.

2. PRISM-Based Project Evaluation

2.1. Adherence to Timeline

The project remains on schedule, with all core activities executed according to the proposed timeline. Field expeditions were completed as planned, while sample processing and data analysis, although slightly delayed, have progressed without causing any cumulative setbacks. Each milestone has been addressed sequentially, ensuring steady momentum across field, laboratory, and analytical phases.

Considering the successful completion of key milestones, the fourth field campaign has been canceled, and the final synthesis and reporting phase has been brought forward. The project will now conclude with the third campaign and the anticipated submission of the final report in October 2025, ahead of the original 2026 schedule.

Date		Activity Description	Status
2024			
	Feb - Jun	Preparatory phase	Completed
	Jul - Aug	1st monitoring campaigns.	Completed
	Sep	Laboratory analysis of collected samples.	Completed
	Oct - Nov	Preliminary data analysis and reporting.	Completed
	Dec - Jan (25)	2nd monitoring campaigns at all sites.	Completed
2025			
	Feb	Laboratory analysis of collected samples.	Completed
	Mar	Throughout the year: Data analysis, progress report preparation and initial publication drafts	Ongoing
	Jul - Aug	3rd monitoring campaigns.	Ongoing
	Sep	Laboratory analysis of collected samples.	Planned
	Oct	Submission of final report and two scientific articles.	Planned*
	~~Dec-Jan (26)~~	~~4th monitoring campaigns at all sites.~~	Archived
~~*2026*~~			
	~~Feb~~	~~Submission of final report and two scientific articles.~~	Archived

Table 1. Timeline of project activities and their completion status. * Newly scheduled to anticipate original 2026 deadline

2.2. Action Plan Completion

The project's action plan established the goal of monitoring three surfgrass meadows - Isla Todos Santos (TSI), Ensenada (ENS), and Magdalena Bay (MAG) - with at least one campaign per year per site. While field conditions required adjustments to site selection, the overall number of monitored sites and annual campaign frequency have exceeded the targets.

In the first field season (Summer 2024), we substituted Magdalena Bay (MAG) with two additional sites: Bahía Tortugas (BTO) and San Juanico (SJU), due to logistic constraints in the south. As a result, four sites were successfully surveyed, surpassing our original expectations for spatial coverage.

In the second field season (Winter 2024–25), we reached MAG, but unfavorable ocean conditions prevented underwater fieldwork. SJU was also not surveyed due to the same reason. Nevertheless, we completed full surveys at TSI, ENS, and BTO, maintaining full annual coverage at the three core sites defined during the first campaign.

The third campaign (Summer 2025) is currently underway, targeting all four accessible sites, pending weather and safety conditions. The fourth campaign (Winter 2025–26) has been canceled, based on the cumulative success of previous fieldwork and the known difficulties of winter conditions. This adjustment reflects a strategic shift to focus on data analysis, integration, and early completion of deliverables.

Campaign	Sites Visited	Status
2024 Summer	TSI, ENS, BTO, SJU	✔ 4 sites surveyed
2024–2025 Winter	TSI, ENS, BTO	✔ 3 sites surveyed; SJU and MAG reached but not sampled
2025 Summer	TSI, ENS, BTO, SJU	🛠 Ongoing
2025–2026 Winter	TSI, ENS, BTO, SJU	🗂 Archived

Table 2. Monitoring campaign completion relative to the action plan and core site targets.

2.3. Output Obtainment

Over the past year, we have collected and processed a substantial dataset encompassing both biological and environmental variables across multiple surfgrass meadows. While a large portion of the data has been fully processed and analysed, some samples, particularly those from the most recent expedition, are still undergoing processing or are scheduled for analysis later in 2025.

Certain variables, such as shoot density, morphometrics, and genetic diversity, were analysed only during the first expedition. These datasets provide a valuable comparative baseline across sites, but will not be included in subsequent campaigns to streamline the workload and focus on core monitoring indicators.

The table below summarizes the progress on each key variable across the four seasonal campaigns of the project:

Data		**2024 Summer**	**2025 Winter**	**2025 Summer**	**2026 Winter**
Environmental variables	Water temperature	Analysed	Analysed	Planned	Archived
	Marine heatwave occurrence	Analysed	Analysed	Planned	Archived
Biological variables	Above and below ground biomass	Analysed	Processed	Planned	Archived
	Coverage	Analysed	Sampled	Planned	Archived
	Carbon and nitrogen content	Sampled	Sampled	Planned	Archived
	Shoot density	Analysed	Skipped	Archived	Archived
	Morphometrics	Processed	Skipped	Archived	Archived
	Genetics	Analysed	Skipped	Archived	Archived

Table 3. Status of environmental and biological data collection and analysis across the four planned monitoring campaigns.

Intermediate products derived from this dataset include:

a) Time series of seawater temperature

The temperature time series spans from December 2019 to February 2025 (Fig. 1), capturing seasonal variations and thermal anomalies recorded at Todos Santos Island (TSI). Continuous maintenance of the submerged HOBO temperature loggers has ensured the collection of a high-resolution, uninterrupted dataset, which is essential for detecting long-term trends in seawater temperature. The data presented reflects local environmental conditions influenced by broader climatic phenomena such as El Niño/La Niña cycles, seasonal changes, and regional oceanographic dynamics. Notably, the sensor remains operational, ensuring the ongoing expansion of this valuable time series for future conservation-oriented analyses.

This dataset is particularly relevant to the study of *Phyllospadix* seagrass meadows, which depend on specific thermal conditions for growth and reproduction. Shifts in seawater temperature can directly impact the distribution, productivity, and resilience of these meadows, which play a critical ecological role by providing habitat, stabilizing sediments, and mitigating coastal erosion. Moreover, extreme temperature events such as marine heatwaves may negatively affect *Phyllospadix* physiology, highlighting the importance of sustained temperature monitoring to guide adaptive management and conservation strategies for these vulnerable ecosystems.

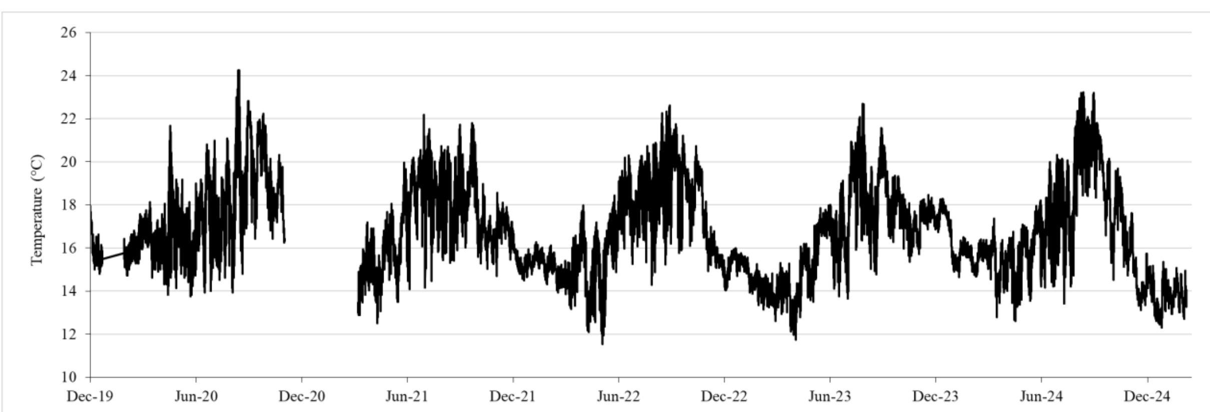


Figure 1. Time series of seawater temperature recorded by continuously maintained HOBO loggers at Todos Santos Island (TSI), Ensenada, Baja California.

b) Spatial maps of surfgrass coverage from summer 2024

The preliminary coverage maps reveal marked differences in the spatial distribution of *Phyllospadix* meadows across the surveyed sites (Fig. 2). At Tres Emes beach (3MS), in Ensenada (ENS), the meadow appears fragmented into two large, separated patches. This may be driven by the site's shallow bathymetry, which becomes exposed at low tide and experiences strong wave action. Potential anthropogenic impacts may also contribute, although further investigation is needed.

In contrast, Todos Santos Island (TSI) and Bahía Tortugas (BTO) exhibited more continuous seagrass coverage. TSI benefits from a stable topography and lacks evident human pressures. At BTO, although adjacent to urbanized areas, no visible impacts were observed during this phase, though ongoing monitoring is necessary to confirm meadow stability over time.

San Juanico (SJU) presented the most fragmented seagrass cover, potentially associated with more extreme environmental conditions, including higher seawater temperatures that approach the southern distribution limit of *Phyllospadix*.

These early observations highlight the likely influence of both environmental and anthropogenic factors on meadow structure. While continuity at TSI and BTO may be linked to more favorable conditions, fragmentation at 3MS and SJU may reflect the interplay of shallow topography, hydrodynamics, and climate-related stress. Continued long-term monitoring will be essential to detect trends in spatial coverage and inform adaptive management strategies.

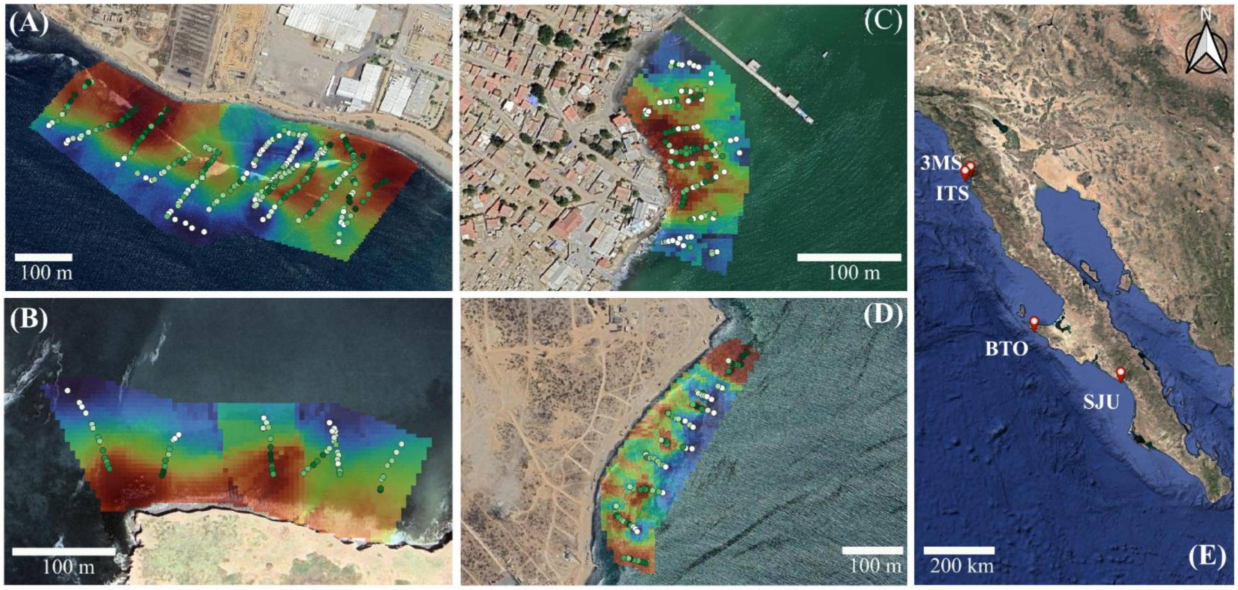


Figure 2. Spatial coverage maps of *Phyllospadix* generated for four study sites along the Baja California Peninsula: (A) Tres Emes (3MS), (B) Todos Santos Island (TSI), (C) Bahía Tortugas (BTO), and (D) San Juanico (SJU). White-to-green dots represent georeferenced photo locations with visually estimated coverage; white indicates low coverage and green high coverage. The background color gradient from red (high coverage) to blue (low coverage) reflects kriging interpolation. (E) Reference map showing the location of study sites along the peninsula (red markers).

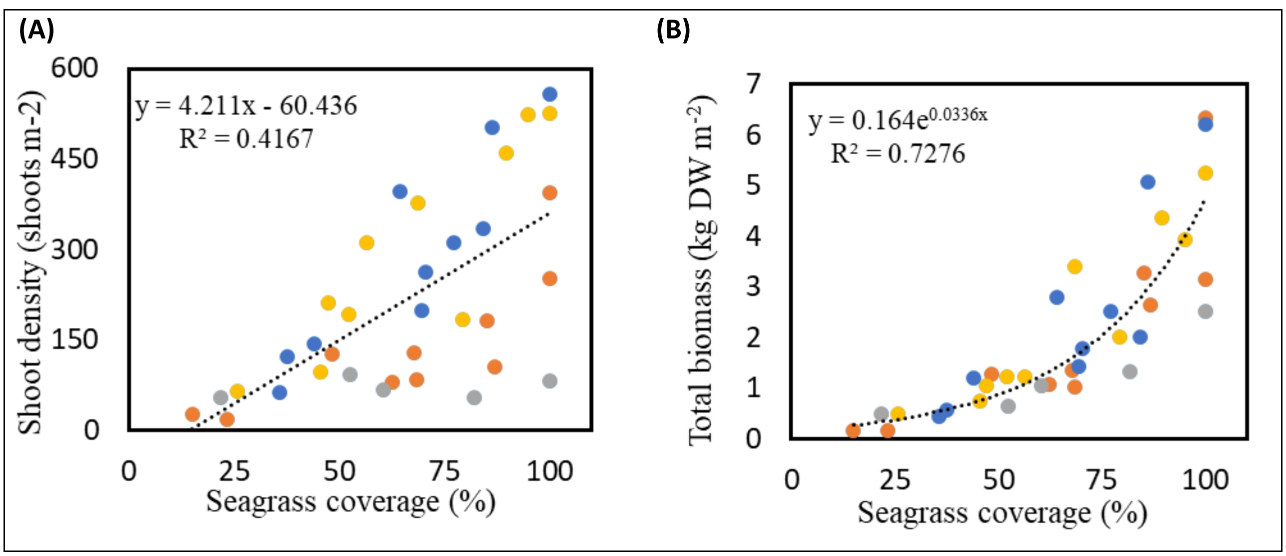
c) Coverage as a Proxy for Biometric Variables

The results indicate varying degrees of correlation between *Phyllospadix* coverage and several biometric metrics (Fig. 3), including aboveground biomass, belowground biomass (rhizomes and roots), shoot density, and total biomass. The strongest relationship was observed between coverage and aboveground biomass (R^2 = 0.80), followed by total biomass (R^2 = 0.73), belowground biomass (R^2 = 0.46), and shoot density (R^2 = 0.42). These findings suggest that visual coverage is a particularly robust proxy for estimating aboveground and total biomass, while it is a less reliable predictor of shoot density or belowground biomass.

The strong correlation between coverage and total biomass highlights the ecological importance of densely vegetated areas, both in terms of carbon storage and overall productivity. In contrast, the weaker association with shoot density may reflect the influence of local habitat conditions or morphological variability within *Phyllospadix* populations.

Although coverage proved to be a strong predictor of aboveground biomass, its accuracy diminished in meadows with more than 70% coverage. This is likely due to morphological variation not fully captured by photo-quadrat analysis, such as overlapping leaves, shoot size, and complex three-dimensional structure, which can introduce bias in high-density areas. This limitation points to the need to complement visual analysis with direct measurements, such as volumetric profiles or detailed morphological characterization, to improve biomass estimation accuracy in dense meadows.

These findings reinforce the value of monitoring seagrass coverage as a key indicator, especially in conservation contexts, where dense meadows tend to be more productive and resilient to environmental disturbances. However, complementary studies that consider local and seasonal variation will be essential to deepen our understanding of the dynamics governing these critical ecosystems.



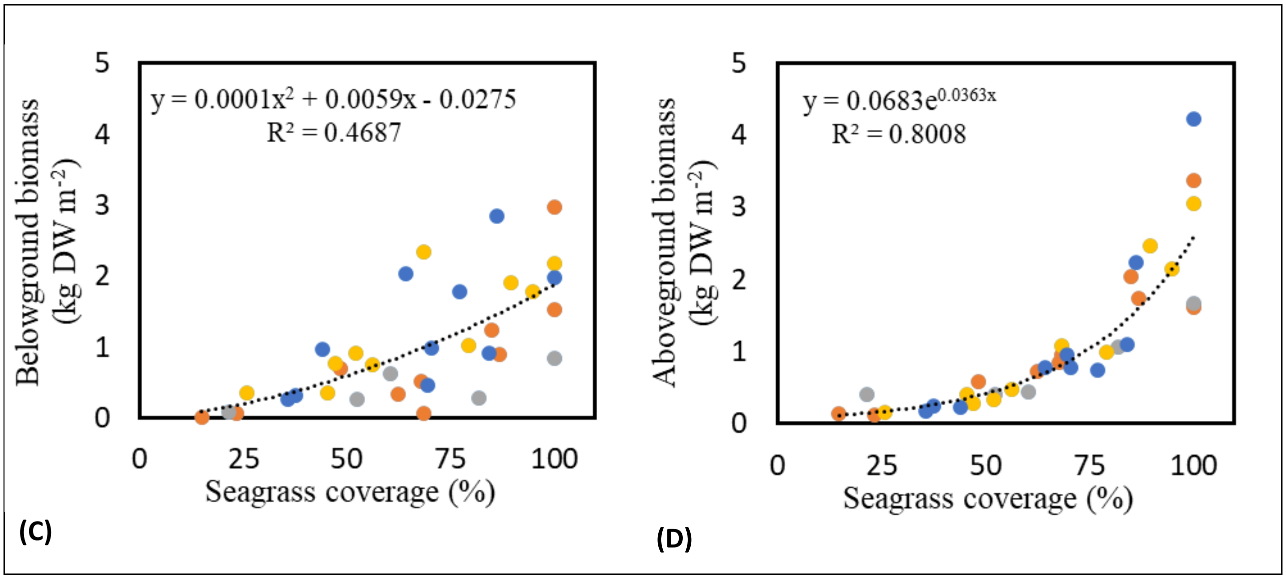


Figure 3. Relationships between *Phyllospadix* coverage (%) and structural metrics across four Baja California sites: Todos Santos Island (blue), San Juanico (orange), Tres Emes (yellow), and Bahía Tortugas (gray). Panels show correlations with (A) shoot density (shoots m^{-2}), (B) total biomass (kg DW m^{-2}), (C) belowground biomass (kg DW m^{-2}), and (D) aboveground biomass (kg DW m^{-2}). Dotted lines represent fitted regressions, and R^2 values indicate the strength of each correlation.

d) Development of the SURFMEX Multivariate Index

We have made significant progress in developing SURFMEX, a multivariate biological index designed to assess the response of *Phyllospadix* seagrass meadows to thermal stress and environmental variability. The index integrates key physiological and morphological indicators into a comprehensive metric of ecological health.

To date, we have compiled data from three independent laboratory experiments in which *Phyllospadix* individuals were exposed to a range of temperature treatments. These trials generated a rich dataset of physiological variables, such as photosynthetic rate, chlorophyll fluorescence, respiration, and daily productivity, measured under controlled thermal gradients.

Preliminary analyses using Generalized Additive Mixed Models (GAMMs) and Random Forest revealed strong correlations between these variables and foliar growth. Positive relationships were observed between growth and effective photosynthetic performance, daily productivity, and maximum oxygen production. In contrast, negative relationships were found with basal fluorescence and compensation irradiance, highlighting their role as potential indicators of stress (Figure 4).

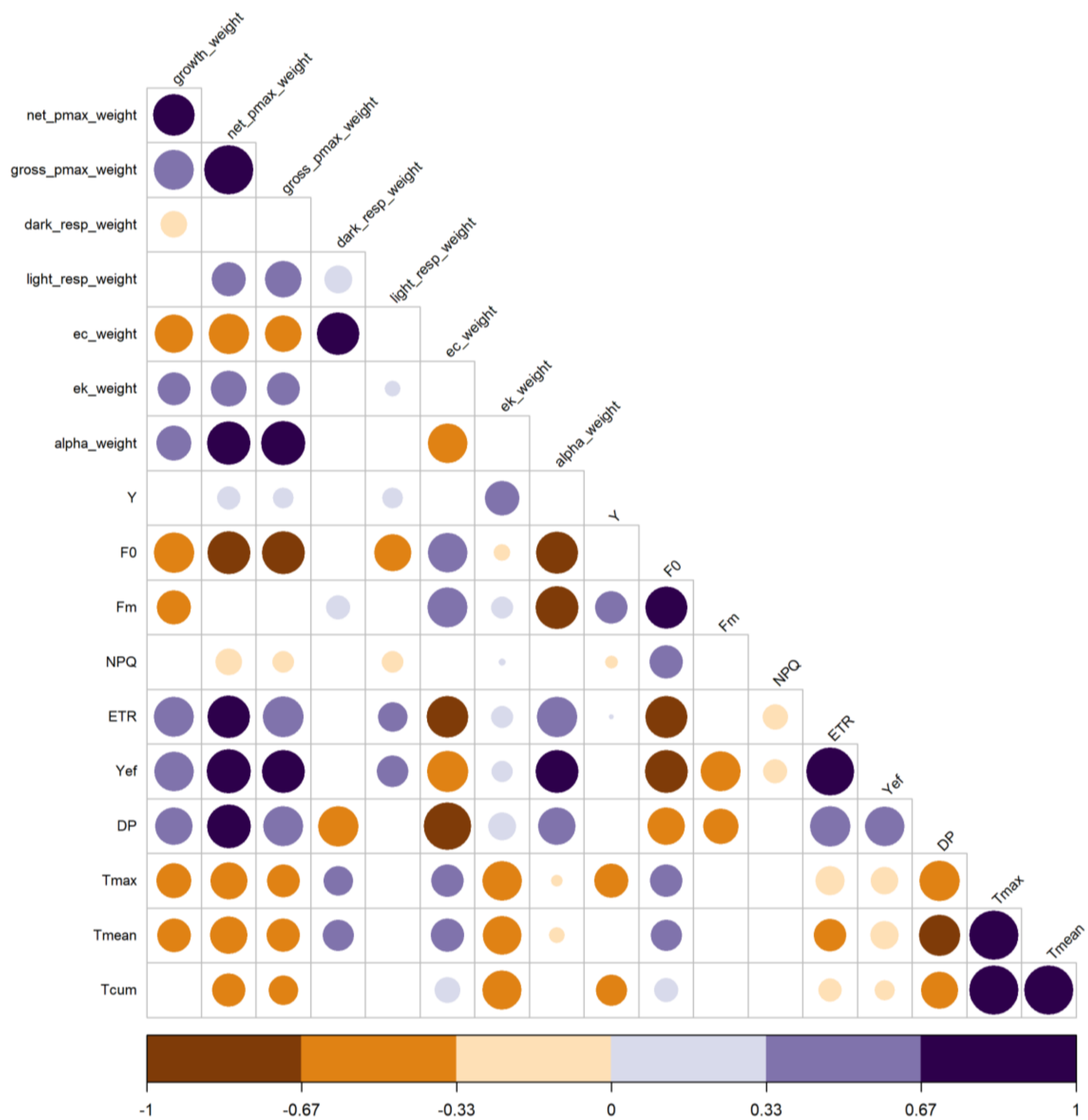


Figure 4. Correlation matrix of physiological and environmental variables under different experimental temperature conditions. Circle color indicates the direction of correlation (purple = positive, brown = negative); circle size and shade indicate strength, from weak (light/small) to strong (dark/large).

Model outputs (Fig. 5) emphasize the predictive power of a core group of physiological traits that respond consistently across temperature regimes. These relationships suggest that *Phyllospadix* growth is shaped by a balance between photosynthetic efficiency and metabolic cost, factors that can be quantified and tracked using this integrative index.

It is important to note that SURFMEX is currently in a proof-of-concept phase, based on experimental data. As we continue to accumulate field data through ongoing monitoring campaigns, these real-world observations will be incorporated to refine, validate, and calibrate the index for use in natural populations.

This outcome lays the foundation for a scalable and scientifically grounded monitoring tool that can support adaptive management and conservation of surfgrass ecosystems under changing environmental conditions.

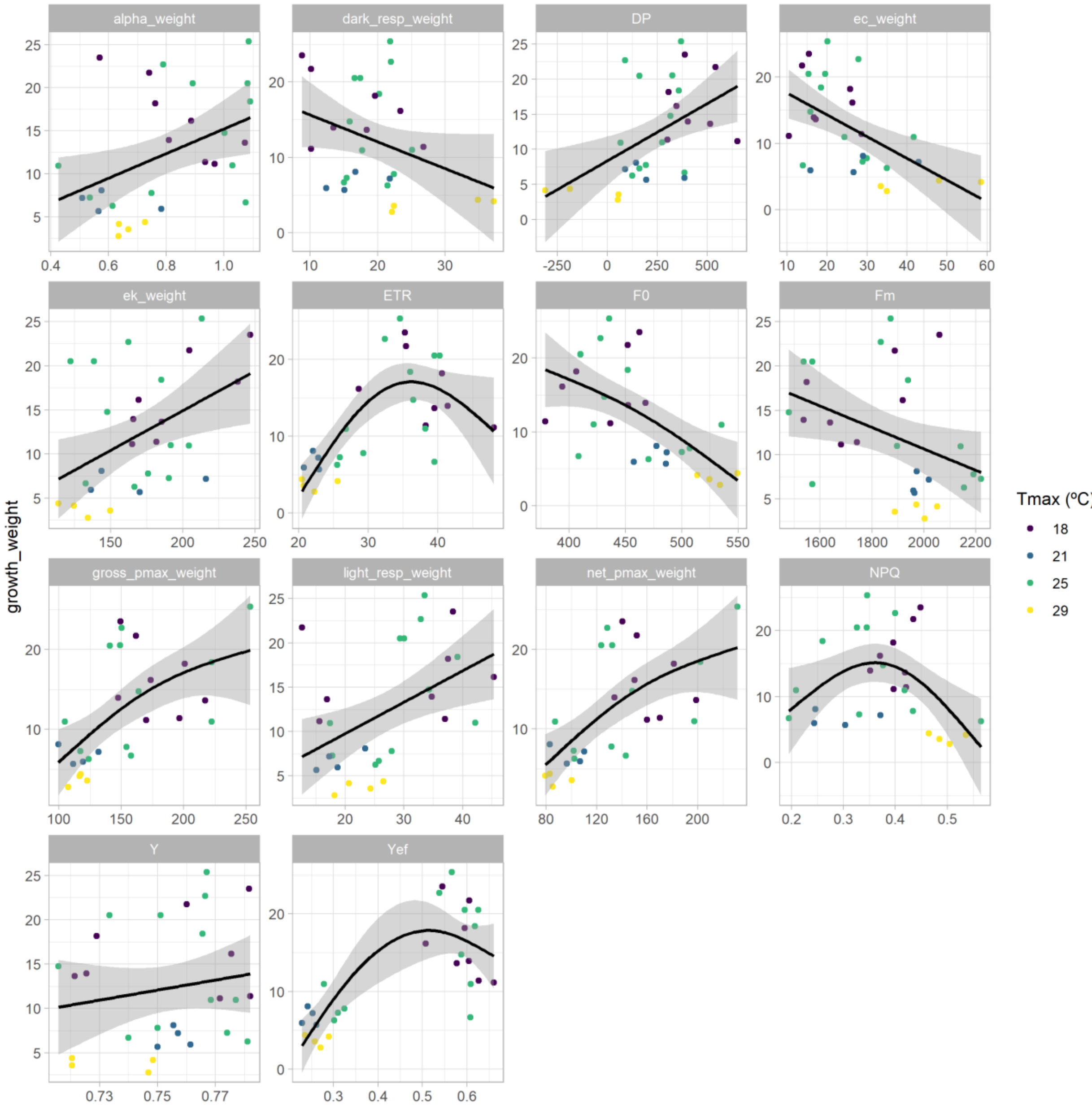


Figure 5. GAMM models relating *Phyllospadix* foliar growth rate to different physiological variables under experimental temperatures (18, 21, 25, and 29 °C). Each panel shows the fitted model (shaded area = confidence interval), with colored points representing data across temperatures (purple, green, blue, yellow).

2.4. Outcome Achievement

The project was designed to achieve four key outcomes, each contributing to the overarching goal of improving the conservation and management of Phyllospadix meadows in the face of climate change and human impact. Below is a summary of progress toward each outcome:

- *Outcome 1 – Improved ecological understanding of surfgrass responses to climate and anthropogenic stressors*

As detailed above, preliminary results reveal significant site-dependent variability in surfgrass condition across spatial scales, from shoot-level physiological performance to meadow-scale structural attributes. Meadows at Todos Santos Island (TSI) and Bahía Tortugas (BTO) exhibit relatively high shoot density and spatial continuity, whereas those at San Juanico (SJU) and Ensenada (3MS) appear more fragmented and physiologically stressed. These differences likely reflect both environmental gradients (e.g., temperature, nutrient inputs, hydrodynamics) and localized anthropogenic pressures. While the current dataset does not yet capture temporal variability, continued monitoring is expected to reveal interannual trends and site-specific responses to discrete events such as marine heatwaves and storms.

- *Outcome 2 – A multivariate index (SURFMEX) to assess meadow condition*

The foundation of the SURFMEX index is being established using data from controlled experiments in which *Phyllospadix* was subjected to a range of temperature conditions. Relationships between key physiological variables and foliar growth have been modeled using Generalized Additive Mixed Models (GAMMs) and Random Forest algorithms. In parallel, we are evaluating field-based correlations between coverage and biomass to assess which structural indicators are suitable for integration into the index. As additional field data are processed, they will be incorporated to calibrate and validate SURFMEX, enabling its future application in long-term ecological monitoring and conservation planning.

- *Outcome 3 – Scientific publications to support evidence-based conservation*

Two peer-reviewed manuscripts are currently in preparation:

1. A study on thermal physiology, investigating how increased marine heatwave intensity influences *Phyllospadix* photosynthetic efficiency, stress response, and growth dynamics.
2. A study on the biogeochemical role of surfgrass meadows as carbon and nitrogen sinks, combining elemental composition (C:N ratios), biomass estimates, and sediment context.

Both publications aim to advance the scientific understanding of surfgrass ecosystems and provide evidence-based guidance for coastal resource management.

➢ *Outcome 4 – Outreach materials and stakeholder engagement to support management*

The project has actively promoted engagement with both the general public and early-career researchers (Appendix 2):

- Undergraduate students have been directly involved in field monitoring and mapping activities, contributing to data collection while gaining valuable research experience.
- A scientific seminar presentation introduced the project to the broader academic community.
- Participation in two public outreach events facilitated dialogue with local educators, students, and coastal stakeholders.
- Project updates and ecological insights are consistently shared via our dedicated social media platform (Instagram account: surfgrass.project), helping raise public awareness of the ecological importance of surfgrass meadows and the threats they face.

3. An unexpected outcome: Germination Experiment Across Latitude

During the first field campaign, reproductive *Phyllospadix* individuals were observed at all surveyed sites. This prompted the decision to collect seeds and conduct an unplanned germination experiment to investigate early developmental responses to thermal variation.

The experiment was carried out in mesocosms using seeds from five populations distributed along a latitudinal gradient of the Baja California Peninsula: San Juanico (SJU), Bahía Tortugas (BTO), Isla San Gerónimo (ISG), Tres Emes (3MS), and Todos Santos Island (TSI). The main objective was to evaluate how early life stages of *Phyllospadix* respond to varying temperatures, providing insight into potential climate change impacts on seedling establishment.

Seeds from each population were exposed to four experimental temperatures: 18°C, 22°C, 26°C, and 30°C. For each population-temperature combination, five beakers containing 20 seeds each were maintained under controlled conditions. Variables assessed included initial seed carbohydrate content, germination rate (monitored weekly), foliar growth, pigment concentrations, lipid peroxidation, photosynthesis and respiration rates, and photosynthetic performance via fluorometry, all measured at the end of the two-month experiment.

Preliminary results (Fig. 6A) indicate that lower temperatures (18–22°C) promoted higher germination success across most populations, while elevated temperatures (26–30°C) significantly reduced germination, with varying degrees of tolerance between populations. These differences may reflect local adaptation or variation in thermal sensitivity along the latitudinal gradient.

Although full analysis is still underway, these initial findings suggest that *Phyllospadix* populations in Baja California may face reduced recruitment success under warming scenarios, especially in southern sites nearing upper thermal limits. Further analysis of physiological variables will help refine our understanding of thermal stress effects during early developmental stages.

(A) (B)

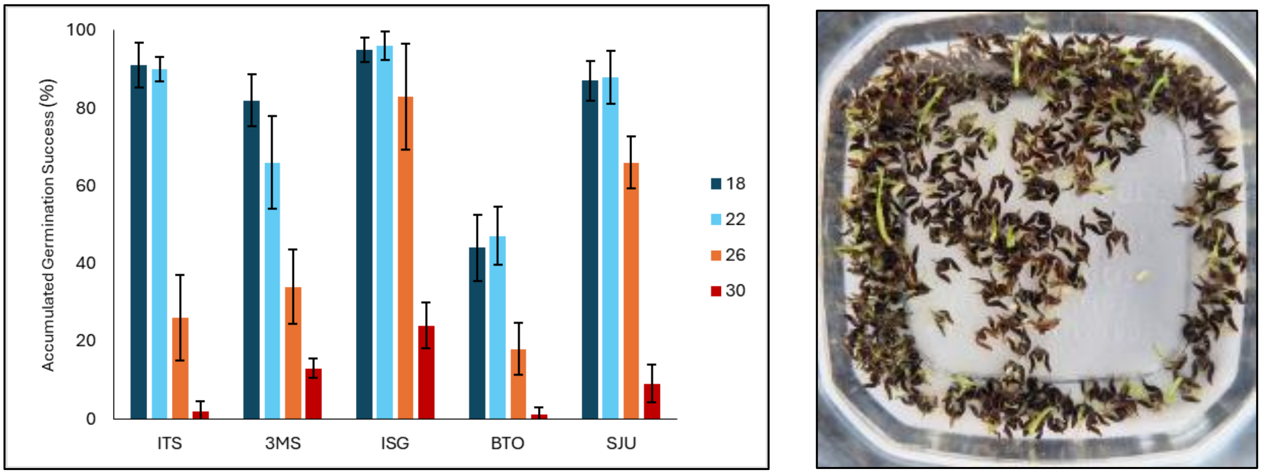


Figure 6. (A) Cumulative germination success (%) of *Phyllospadix* seeds from five populations along the Baja California Peninsula: Todos Santos Island (TSI), Tres Emes (3MS), Isla San Gerónimo (ISG), Bahía Tortugas (BTO), and San Juanico (SJU). Seeds were exposed to four experimental temperatures (18°C, 22°C, 26°C, 30°C), shown in different colors. Values represent mean ± standard error. (B) Representative photograph of *Phyllospadix* seedlings emerging from seeds during the germination experiment under controlled conditions.

4. Final Thoughts

4.1. Challenges

Despite the overall success of the project to date, several challenges were encountered and are important to acknowledge:

- **Logistical and weather constraints** affected access to some remote southern sites, such as Magdalena Bay (MAG) and San Juanico (SJU), particularly during the winter season. Weather conditions and sea state limited diving operations, impacting planned sampling.
- **Laboratory processing delays** occurred due to the high volume and diversity of collected samples. While all samples from the first campaign were processed on time, some from the second expedition remain under analysis, particularly those related to elemental composition and image analysis.
- **Outreach coordination** during the busiest field periods posed challenges in balancing scientific commitments with community engagement goals. Nonetheless, creative partnerships and flexibility enabled a meaningful level of interaction with students and the public.

4.2. Conclusions

The first year and a half of the project has yielded valuable insights into the structure, function, and environmental sensitivity of *Phyllospadix* meadows across Baja California. Key accomplishments include:

- The establishment of a solid ecological baseline across diverse surfgrass sites.
- Preliminary identification of structural and physiological indicators for meadow condition assessment.

- Promising development of the SURFMEX multivariate index, which integrates laboratory and field data to assess thermal stress and ecological performance.
- Engagement with students, local stakeholders, and the broader scientific community through presentations, campaigns, and online communication.

These achievements not only fulfill the original objectives of the project but also open new lines of inquiry, such as early life stage vulnerability to warming, that were not originally foreseen but are critical for adaptive conservation planning.

4.3. Next Steps

Looking ahead, the project will continue to advance along four fronts:

1. **Final Field Campaign**
   The last seasonal campaign is scheduled for August – September 2025, targeting all accessible monitoring sites, with flexibility built in to account for sea conditions and logistics.
2. **Data Integration and Indicator Validation**
   Full processing of 2025 data will be completed, allowing for the integration of field results into the SURFMEX index. Statistical validation and sensitivity testing will be conducted to refine the index before its application in final assessments.
3. **Scientific Publications**
   Drafts of both manuscripts are expected to be finalized and submitted by late 2025. These will include findings from both controlled experiments and field observations.
4. **Final Reporting**
   The final Rufford report will be submitted in October 2025.

5. Use of Rufford Logo and Acknowledgement

The Rufford Foundation logo has been actively used throughout the project's communication and dissemination materials. Specifically:

- It is displayed on seminar and conference posters, as well as on presentations shared during academic events.
- On social media, the logo is consistently included in visual content, and the Rufford Foundation's official account is tagged in relevant posts to enhance visibility and recognition.
- In scientific publications currently in preparation, the Rufford Foundation will be formally acknowledged in the acknowledgements section for its financial support of the project.

6. Appendix

Appendix 1. Steps in a Typical Surfgrass Monitoring Campaign

The following figure illustrates the key stages of our field monitoring protocol for surfgrass meadows:

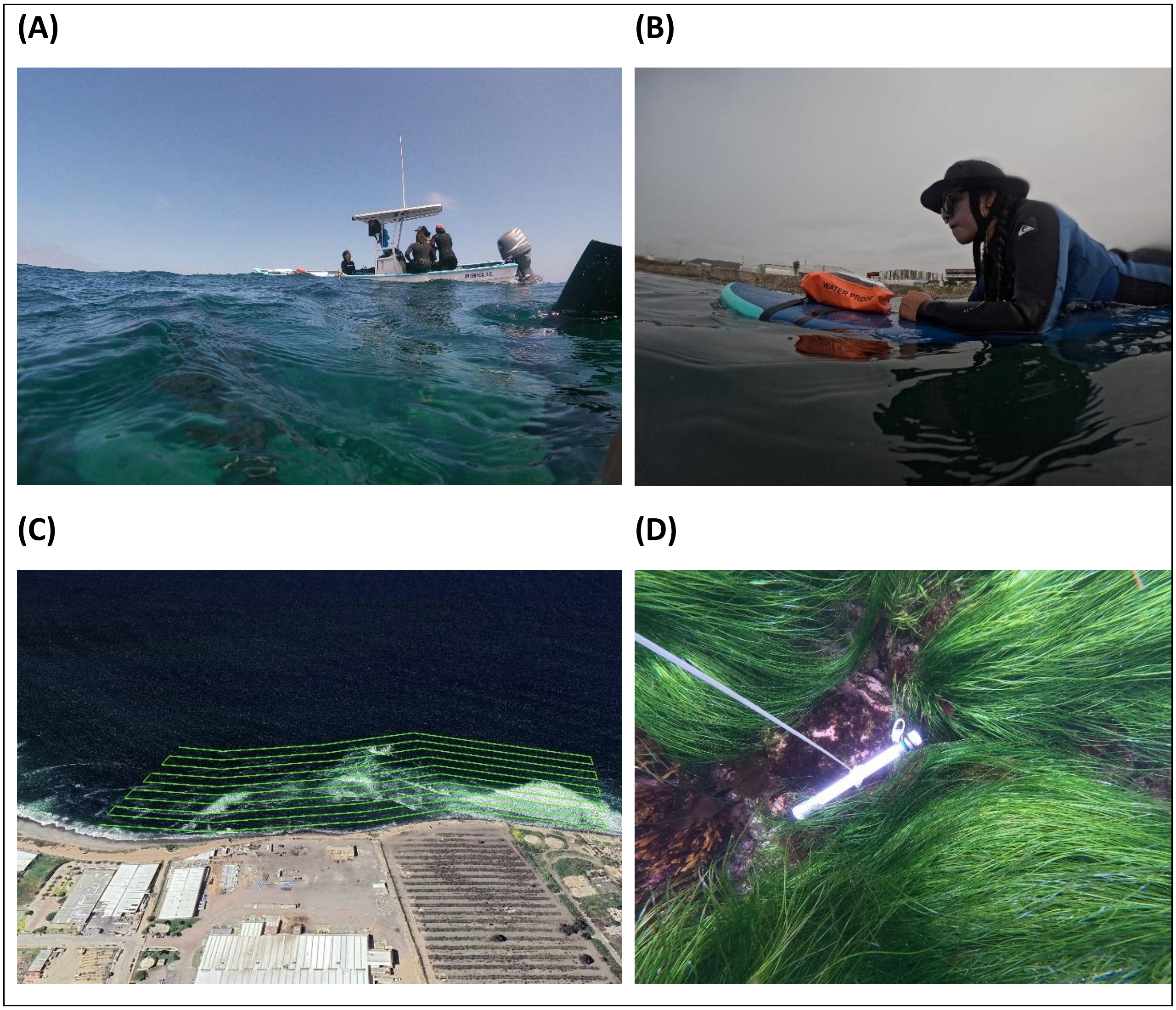


Figure A1. Field monitoring protocol steps: (A) Arrival at the surfgrass monitoring site via research vessel. (B) Mapping setup using a handheld GPS unit (Garmin GPSMAP 79S) placed inside a waterproof bag and mounted on a surfboard, which is manually navigated across the meadow. (C) Planned mapping route. (D) Georeferenced photograph taken at each sampling point by a swimmer, used for visual estimation of *Phyllospadix* coverage.

Appendix 2. Outreach and Communication Activities

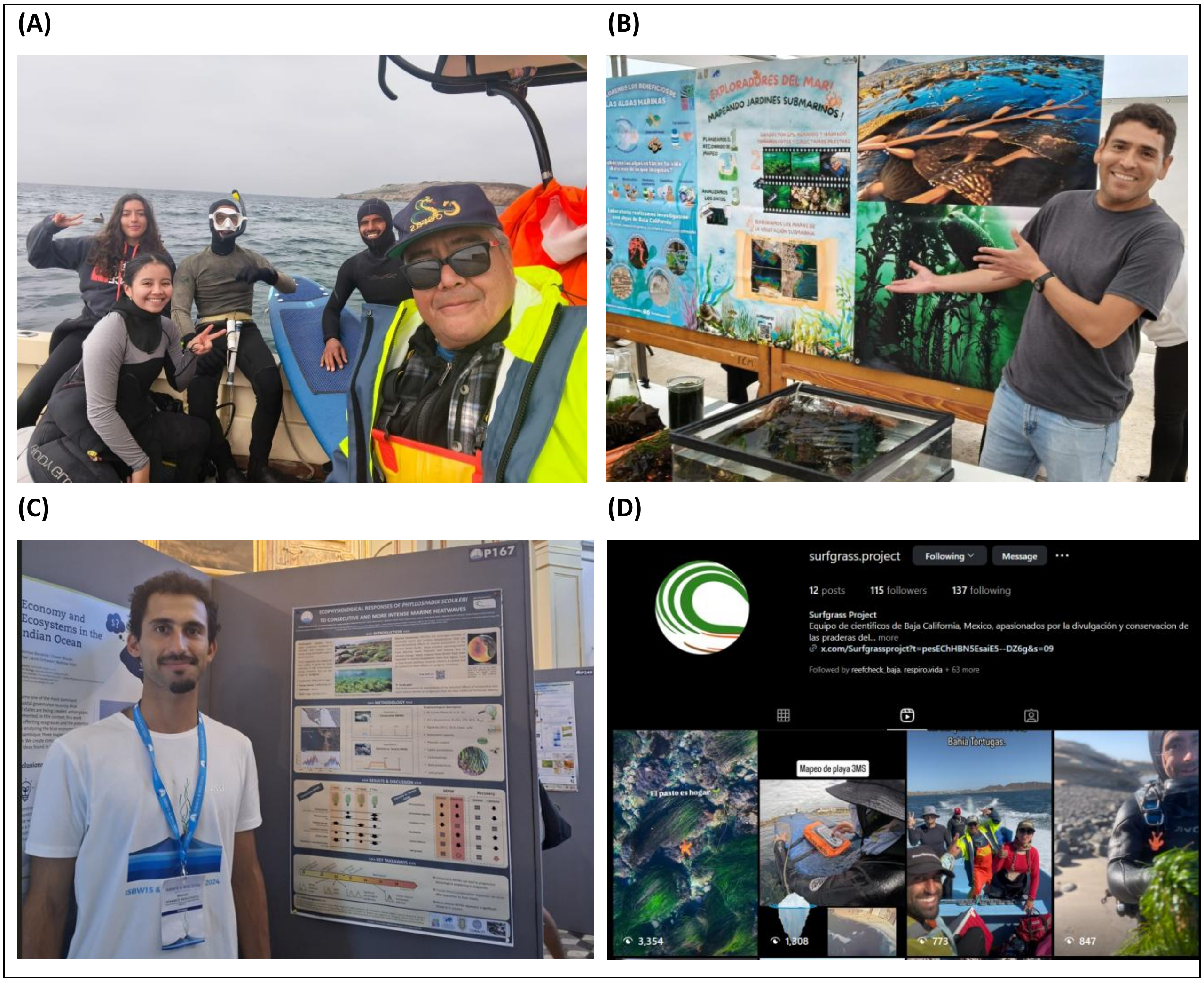


Figure A2. Highlights from the project's outreach and communication efforts. (A) Undergraduate students participating in field monitoring campaigns. (B) Poster presented at local science outreach events. (C) Presentation of project results at an international scientific congress. (D) Ongoing science communication through the project's Instagram account (@surfgrass.project).

Appendix 3. Educational Poster: Mapping Underwater Gardens

Figure A3. Educational poster titled *"¡Exploradores del Mar! Mapeando Jardines Submarinos"*, developed as part of the project's outreach activities. The poster illustrates the four main steps of the surfgrass mapping protocol: (1) mapping route planning, (2) in-water data collection using GPS, photography, and biomass sampling, (3) data analysis, and (4) generation of spatial maps showing seagrass distribution across four study sites: Tres Emes (3MS), Bahía Tortugas (BTO), Isla Todos Santos (ITS), and San Juanico (SJU). The poster is used for science communication at public events and educational settings.