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Photo: Santiago Estrada



Sustainable Development Goals
Life Below Water



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CONTENT

Editorial

1 - ODS 14 "Life Below Water"

Global Tendencies

2 - Digital Twins of the Ocean

CEMarin Projects

4 - ICMS 2023

6 - MMM6 and Post-Congress Workshop

8 - Pre-Congress Course

12 - Providencia Citizen Science

15 - Insect-based Sustainable Shrimp
Aquaculture

17 - Sustainable Aquaculture in Turbo

18 - Tribugá Expedition with NatGeo

CEMarin Reports

21 - Research Report I

23 - Research Report II

24 - Ex Alumni Report



Diving Into Sustainable Development Goal 14 - Life Below Water -

1 Objective. 10 Targets. 1 Ocean emergency.

Since 2015, the Sustainable Development Goals (SDGs) and the Paris Agreement have been pillars of global governance and are part of the framework that guides human actions in order to balance their environmental, social and economic dimensions. The ocean is key to these efforts as it covers more than 70% of the planet's surface and provides essential services that support life as we know it: it regulates our climate by absorbing excess carbon dioxide and heat, and it generates the oxygen we breathe. The ocean also serves as the primary source of food, livelihood and transportation for some three billion people around the world.

Interestingly, the ocean was not included in the Millennium Development Goals, but it is the only ecosystem that has an SDG dedicated to its preservation and management, something that has raised global awareness of the ocean's importance. This change could be because, as all of us who work in the marine sciences know, the ocean is currently facing a crisis on an unprecedented scale, encompassing many dimensions: coastal eutrophication, acidification of the waters, increased ocean temperature, plastic pollution, and illegal, unreported and unregulated fishing, among others. Since the adoption of the SDGs, the number of ocean-related initiatives has increased substantially, the latest success being the Agreement on Biodiversity beyond National Jurisdiction, and with the United Nations Decade of Ocean Sciences for Sustainable Development (2021-2030) as a clear sign of the need to take concrete actions to ensure the sustainability of the ocean and its hydrobiological resources in the short and long term.

So, eight years after its adoption, how far have we come in achieving SDG 14?[1] According to the World Economic Forum, \$175 billion USD is needed annually to achieve SDG 14, but between 2015 and 2019, just under \$10 billion USD was invested in total[2]. Moreover, the vast and mysterious world beneath the ocean's surface remains one of the most vital but least explored and understood ecosystems

on Earth. In this sense, science and education - like all sectors - can make a key contribution to achieving SDG 14. A concerted global effort is the only way we can conserve and sustainably use the ocean for the benefit of current and future generations.

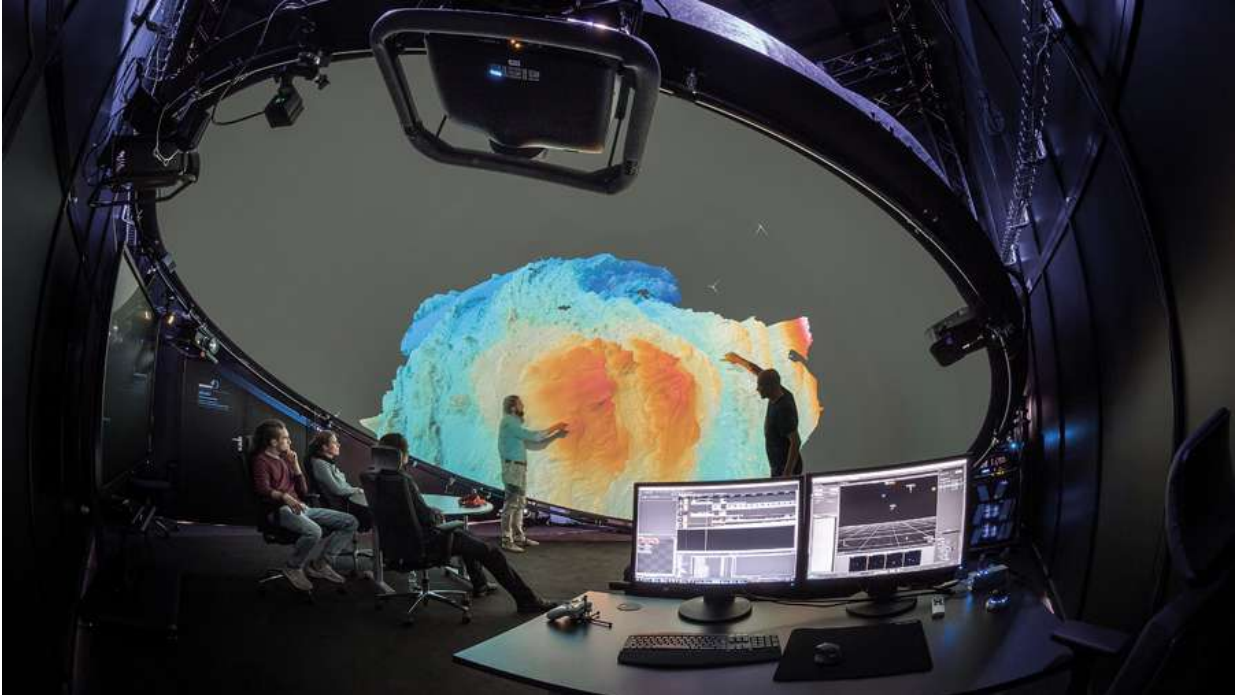
International cooperation and intersectoral and interdisciplinary network-building are crucial to share the knowledge, technology and resources necessary to address common challenges. Therefore, as a binational (Colombian-German) academic consortium, at CEMarin we recognize that Colombia has ecosystem particularities and all the scientific-academic potential to become an example of research and sustainable development at a regional and global level. We invite you to read the content prepared by several CEMarin Researchers and Early Stage Researchers, and by national and international collaborators and experts, on various emerging topics and CEMarin projects, and their relationship with the SDGs.

There are many challenges facing the country, which must be articulated with the region of Latin America and the Caribbean, and with the entire planet, but given our strategic geographical location and taking into account the scientific and technological capabilities that are growing and are increasingly articulated, we will continue working not only to sustain marine life, but to promote a healthier and more sustainable planet for all.

¹ For a complete analysis, see Haas B (2023) Achieving SDG 14 in an equitable and just way. *International Environmental Agreements: Politics, Law and Economics*. 23, 199–205. <https://go.ly/0xLDZ>

² World Economic Forum. 8 June 2022. <https://go.ly/Kb79g>

Digital Twins of the Ocean: Opportunities to Future Proof Sustainable Development



Digital Twins of the Ocean - Photo: Nikolas Linke / GEOMAR

Digital Twins of the Ocean (DITTO) propose a new way of talking about this marine ecosystem, redefining the way we interact and make decisions regarding the ocean and promoting sustainable actions. Digital Twins are virtual and interactive representations of the ocean, which allow the establishment of two-way connections.

Digital Twins of the Ocean allow stakeholders to explore different development scenarios, addressing issues such as energy, mining, fisheries, tourism and nature-based solutions. This tool has the ability to quantify environmental benefits and changes, providing powerful and accurate visualizations. Likewise, it offers the possibility for ocean professionals to create their own local or thematic Digital Twins, allowing customization according to the specific approach of each user. Therefore, it is important to highlight that they are a valuable tool to optimize development. By inputting data into the digital system, the best option can be determined, providing a solid foundation for making informed decisions based on an observation system around the physical twin, data and models.

Everything we know about the ocean is thanks to theory, modeling and, to a large extent, observation.

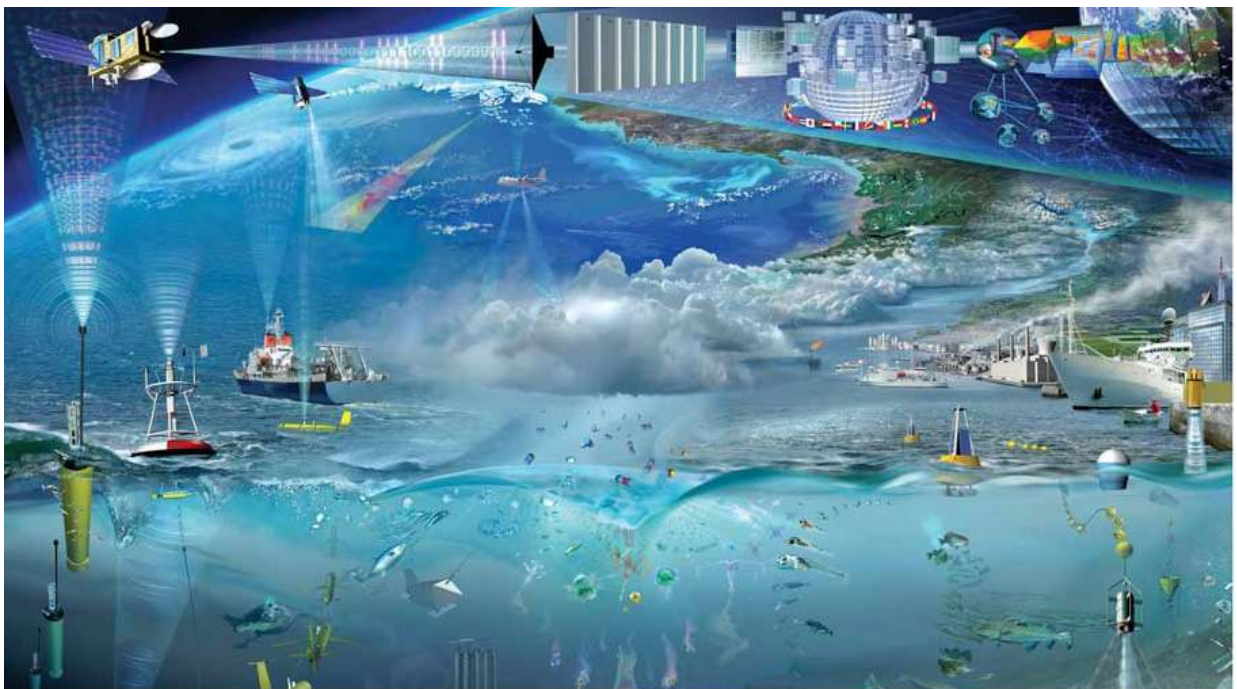
The latter remains a central pillar, since the observations made are based on data available from various specialized agencies. However, Digital Twins are a system that allows one to answer 'what if' questions based on global and local data, allowing stakeholders to share, explore and expand the information available about the ocean.

This technology encourages the continued exploration and study of the ocean, identifies environmental problems, and helps decide the best course of action to mitigate harmful events such as pollution, and represents a revolutionary science that brings together previously separate fields of research, combining atmospheric, geological and demographic information to optimize practical sustainable development, in turn transforming knowledge about the oceans into benefits for citizens

These advances in ocean development, management and understanding align closely with the United Nations' Sustainable Development Goals (SDGs). From the promotion of "Climate Action" (SDG 13) to the conservation of "Life Under Water" (SDG 14). Furthermore, Digital Twins of the Ocean make valuable contributions towards a sustainable future and contribute to (SDG 1) "No Poverty", by promoting responsible use of ocean resources and facilitating the active participation of different actors.



Professor Dr Martin Visbeck presenting the DITTO project at the ICMS 2023 - Photo: CEMarin



Digital Twins of the Ocean - Photo: Glynn Gorick

In summary, Digital Twins of the Ocean offer a window into a new paradigm in our understanding of the ocean taking into account that, as a virtual representation combining observation, artificial intelligence and advanced modeling, DITTO provides important tools when sustainably using and preserving and taking care of the ocean.

If you are interested in learning more and/or becoming a partner of the DITTO program, we invite you visit the following page:

<https://ditto-oceandecade.org/engagement/>

The International Conference on Marine Science 2023 “Working today for the ocean of tomorrow”



ICMS 2023 Participants - Photo: CEMarin

In February, the city of Cartagena was the epicenter of marine action thanks to the International Conference on Marine Science 2023: Working today for the ocean of tomorrow (ICMS), organized by CEMarin. In this event, we brought together around 100 high-level experts - and with a gratifying active participation from early stage researchers also - affiliated with institutions in Aruba, Australia, Austria, Belgium, Cameroon, Chile, Germany, Mexico, Russia, Saudi Arabia, South Africa, Spain, the UK, Venezuela and Colombia.

During the three busy days of the conference, the presentations, panels, workshops and poster sessions were focused on three key axes: i) Marine environmental change; ii) Sustainable use and protection of marine resources; and iii) Understanding the interactions between the oceans and society. Besides the analyses related to marine-coastal ecosystems and the communities that depend on them, talks were given on diverse topics ranging from biology and engineering to art. Issues like blue carbon, the phenomena of El Niño and La Niña, digital twins of the ocean, and the chemical ecology of sponges in Caribbean coral reefs were all up for discussion, issues that opened the way for proposals regarding challenges and opportunities by different actors, including: academia, policy-makers, non-governmental organizations, private enterprises including Ecopetrol, Nortek and Sepia Rov, and startups like Neowave Energy, all of which are committed to facilitating the development and implementation of high-impact projects for the oceans.



Panel on oceanographic expeditions - Photo: CEMarin



A regular talk at the ICMS 2023 - Photo: CEMarin



WELCOME TO

ICMS 2023

CARTAGENA
COLOMBIA

WORKING TODAY FOR THE
OCEAN OF TOMORROW



In the ICMS 2023, the diversity of the participants stood out: we were delighted to have participants from all of the coastal regions of Colombia, including the Caribbean and Pacific coasts and the Archipelago of San Andrés, Providencia and Santa Catalina, who discussed their daily realities and necessities, and play a crucial role in achieving concrete results



Our Executive Director with some CEMarin Early Stage Researchers and members of the logistics team - Photo: CEMarin

So far, the ICMS has been held three times, gathering interdisciplinary teams from across the marine sector with the aim of guaranteeing the protection and sustainability of the oceans. The first event, in 2018, Towards a Sustainable Ocean, was held in Medellín with around 140 participants from 17 countries. The second, Tropical Oceans for the Future took place online in 2020, with more than 1000 participants and virtual interventions from eminences like Sylvia Earle and Daniel Pauly. In this third edition, the additional topic of the United Nations Sustainable Development Goals was a universal theme, regarding the current and future of the world's oceans.

We invite you to watch the Highlights video of this unforgettable event, and to stay tuned for more information soon about the next ICMS!



CEMarin PROJECTS

Dr. Juan-Felipe Blanco Libreros

Institute of Biology, Universidad de Antioquia; MMM6 Scientific Director; CEMarin Researcher

Colombia, Host of the World Mangrove Conference



MMM6 Participants - Photo: CEMarin

The eyes of the world's scientists passionate about mangroves were fixed on Cartagena, Colombia, between July 24 and 28, 2023. Yes, this iconic city in the South American Caribbean was the site of the world conference of specialists in this ecosystem. This was the sixth conference on "Macro-benthos and Mangrove Management" (MMM), a series that has already completed two decades of existence. It has been a long road since the first meeting held in 2000 in Mombasa (Kenya), passing through Coolangatta (Australia, 2006), Galle (Sri Lanka, 2012), St. Augustine (United States, 2016) and Singapore (Singapore, 2019).

The meeting held in Cartagena was a demonstration of the growth of a scientific community dedicated to an ecosystem that before the Paris Agreement (2015) was seen with little interest. Starting from a meeting of less than 30 people at the first conference in Kenya, it has grown to a crowded meeting with nearly 400 participants during the MMM6 in Colombia. Many participants have expressed their gratitude to the conference organizers: the Colombian Network of Estuaries and Mangroves (RedCEM) and the Center of Excellence in Marine Sciences (CEMarin), who accepted the challenge during the MMM5.

The numbers speak for themselves: five keynote speakers, 120 oral presentations, and 280 posters, among which the 45 most notable gave a lightning talk. Scientists, natural resource managers, conservationists and representatives of local communities addressed various topics that were organized under six challenges aligned with the Decade of Ocean Sciences for Sustainable Development, declared by the United Nations: conservation and restoration of mangroves and their biodiversity, understand and solve the problem of marine pollution, achieve sustainable and equitable socioeconomic development, develop and implement climate actions and nature-based solutions to climate change, expand the global mangrove observation system and implement technological and educational innovations to increase knowledge about mangroves, and change human relationships with these ecosystems.

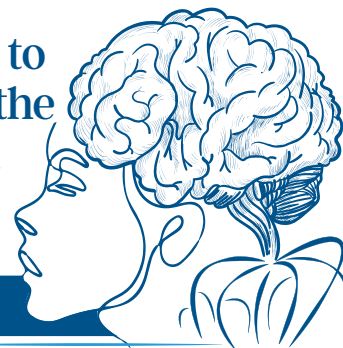
The quality of the event was overseen by 26 international and 11 national members of the scientific committee. The works presented confirm that mangroves are superheroes in mitigating and adapting to the effects of climate change, particularly with regard to sea level rise and strong waves. They contribute to regional and global carbon capture, being five times more effective per

unit area due to their greater storage capacity in soils compared to terrestrial forests. They are a habitat for species such as tigers, primates and birds. But they are also the cradles and nurseries of fish of economic importance and therefore sustain fisheries and coastal communities. They provide multiple services, which motivates scientists and conservationists to protect them by creating marine reserves and monitoring their condition from space with multiple satellites. Today there are also great efforts to increase mangrove-based education. During the event, several video games, digital applications and even methods for making music from data were presented. In addition, examples of soft or mixed engineering that use mangroves as nature-based solutions to climate challenges were presented.

With great enthusiasm, the participants in the MMM6 celebrated on July 26, the “International Day for the Conservation of the Mangrove Ecosystem”, with visits to different areas of the Bay of Cartagena, the Ciénaga de la Virgen and the “El Corchal, Mono Hernández” Fauna and Flora Sanctuary. Some found the iconic piñuelo mangrove, *Pelliciera rhizophorae*, a species of mangrove endemic to the American continent. That night, there was a celebration organized jointly with UNESCO, FAO and the China Mangrove Foundation. UNESCO highlighted the mangrove restoration project in the Mangrove and Biosphere Reserves in Latin America, the FAO launched the book “Mangroves of the World 2000-2020” and the China Mangrove Foundation announced the launch of the International Mangrove Center in Shenzhen, China.

The highlight of the closing of the MMM6 was the recognition of the life and work of three great scientists of the community: Ilka C. Feller (Smithsonian Environmental Center, United States), Norman Duke (James Cook University, Australia) and Ricardo Álvarez -León (Verdes Horizontes Foundation, Colombia). Unlike sports world championships, MMM conferences are a friendly gathering in which to learn from each other as a community, they are not a competition. Everyone wins: the communities win, the mangroves win, and biodiversity wins. This time it was in Cartagena, and we will meet again at MMM7 in 2026 in Okinawa, Japan. Otsukaresama Deshita!

A workshop to think about the present and future of mangrove sciences



After the MMM6, between July 30 and August 3, a group of 29 participants met in Maguipi, Buenaventura with the objective of identifying the challenges and opportunities in the implementation of mangrove-based solutions to climate change and the challenges of society, to subsequently disseminate the discussions and conclusions to the international scientific community through publications in high-impact journals. Although nature-based solutions using mangroves have been very useful for erosion and flood control, more projects need to be implemented to address multiple climatic and social challenges.

In a dialogue of knowledge and wisdom, 17 international and 12 national participants, including representatives of Afro-descendant collective councils from both coasts of Colombia, the need to listen to the voices of local communities was highlighted. During a visit to the La Plata Community Council in the Bay of Malaga, visitors from seven countries and 20 institutions learned from the experience of pianguera women, that is, those who collect a mollusk called piangua typical of the Pacific coast of America. The activity of collecting pianguas, as well as issues of collection, cultural rescue, conservation of natural resources and education for young generations, showed the empowerment of the association. The sustainable management of a resource like the piangua can be an example of a nature-based solution to face the biodiversity crisis but also the social crisis. Good management of the piangua fishery has helped conserve the resource and habitat, which has allowed the ecosystem to respond to the rise in sea level and the community to achieve sustainable socio-economic growth. The participants learned about a novel solution based on the mangrove under the leadership of women. An unmissable learning opportunity from the Global South.

Would you like to know what Colombian mangroves sound like through data sonification?
<https://mmm6.co/colombian-mangrove-ringtone/>

CEMarin PROJECTS

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The Ciénaga Grande de Santa Marta: Where the Communities are Just as Resilient as the Mangroves

CEMarin, together with the Colombian Network of Estuaries and Mangroves, organized the course Mangroves as Foundations for the Blue Economy as part of the VI Mangrove Macrobenthos and Management Meeting – MMM6, from July 19 to 22, 2023. For this incredible event, the ecoregion of the Ciénaga Grande de Santa Marta was selected as a natural laboratory for several reasons: first, due to its great biological productivity and ecosystem richness; second, due to the presence of ancestral amphibian communities; and third, because it is a Biosphere Reserve designated by UNESCO that is also a Ramsar wetland, and it has two protected areas that are managed by National Natural Parks of Colombia.



Participants and instructors in the stilt town of Buena Vista - Photo: Emilio Posada

From the beginning, one of our key objectives for the course was to bring together actors from different sectors and disciplines, and we were pleased to have 21 participants from nine countries, mainly from Latin America, Europe and Asia, including both the private and public sectors, as well as high-level research institutes and young researchers. Together with the international and national instructors, we developed an experiential dynamic, through active learning activities that stimulated reflection and commitment to the need for knowledge management to guarantee well-being and equity from the services provided by mangrove socio-ecosystems.

Direct contact with the communities of the Ciénaga Grande de Santa Marta was also another important objective for us. We had the participation of Jhon Cantillo, a native of the Ciénaga Grande, who shared

with us his deep knowledge of the region, its people and its ecosystems. We are proud to say that the objectives of the course were fully achieved and that all participants finished the four days full of enthusiasm to stay in touch and to develop action plans, from their different sectors, regarding the blue economy. In addition, the results will be incorporated into the national research plan prepared by the Colombian Network of Estuaries and Mangroves, as established by Law 2243 of 2022, which is the law for the protection of mangroves in Colombia.

We invite you to continue reading to learn about the testimonies of the three early stage researchers from different regions of Colombia who received scholarships from CEMarin, CAPAZ and TRAJECTS to participate in this memorable event.

Research and Participation from the Territories: The Experience of Early Stage Researchers on the Course “Mangroves as Foundations for the Blue Economy”

We are Yennifer Lorena Hoyos Cazulú^[1], marine biologist and student of the Master’s in Marine Science at the Universidad de Bogotá Jorge Tadeo Lozano, Ballantyne Puin Castaño^[2], environmental engineer and student of the Master’s in Environment and Development of the Universidad Nacional de Colombia in Medellín, and Jorge Enrique Casas^[3], anthropologist and student of the Master’s in Environment and Development of the Universidad Nacional de Colombia in Bogotá.

For almost a week we had the opportunity to interact with a group of more than 20 people from around the world and to visit two places in the Colombian Caribbean: Vía Parque Isla de Salamanca (VIPIS), a protected area, and the stilt communities of the Ciénaga Grande de Santa Marta (CGSM), specifically Buenavista and Nueva Venecia. We carried out different activities that allowed us to learn about the generalities of mangroves, their hydrodynamics and morphodynamics, and the threats and vulnerabilities of this ecosystem. On the other hand, it was also possible to see and understand the relationship between local communities and mangrove ecosystems, the economy around this ecosystem, the valuation of its services at different scales and the concepts and techniques for measuring blue carbon.

Based on this experience, we were able to make reflections and/or investigative approaches from our fields of action, which we want to share below.



L-R: Ballantyne Puin Castaño, CEMarin Executive Director
Dr. Andrés Osorio, Yennifer Lorena Hoyos Cazulú,
Jorge Enrique Casas Mosquera - Photo: CEMarin

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3 <https://www.linkedin.com/in/jorge-enrique-casas-mosquera>

Amphibian communities, architects of conservation

Yennifer Lorena Hoyos Cazulú

This immersive experience, passing through all the senses, left a clear message and that is that human beings, with their cultural diversity, are an integral component of ecosystems.

Active conservation actions are becoming more and more evident, going beyond strict protection and understanding the importance of working hand in hand with local communities, since only then is there a guarantee that they will last over time and will achieve their proposed objectives. In this way, it was very satisfying to see that during the visit to VIPIS the park rangers were people from the same community and, on the other hand, in Buenavista, the mangrove nursery of National Natural Parks and the Fiatmar foundation is managed by fishermen from this district.

Among the lessons that I have taken home after this wonderful experience, I highlight the importance of implementing an ecosystem approach when thinking about conservation strategies, since it is essential to consider the social, economic and cultural aspects in addition to the biophysical and ecological ones. The ecosystem approach is a tool for the integrated management of land, water and natural resources, while promoting their conservation and sustainable use in a fair and equitable manner. Actively involving communities in the sustainable management of natural resources can be the only guarantee to conserve these ecosystems and a great example of this was evident in the sustainable businesses carried out in the CGSM, such as ecotourism and artisanal crafts.

Ecotourism, a conservation strategy and economic alternative for local coastal communities

Ballantyne Puin Castaño

It was evident that both in the VIPIS and in the CGSM communities, ecotourism has emerged as an alternative for the conservation of mangrove ecosystems and the generation of economic resources for the community. It is relevant to highlight that in the case of the CGSM, tourism represents an important economic opportunity for women, who previously did not have sources of income due to their limited participation in the area’s main economic activity, which is fishing. Consequently, they are the ones who are leading and

playing a fundamental role in the provision of tourist guide services.

At the same time, one can observe that, in the Colombian Pacific, there is also great interest in the communities to promote ecotourism in their territories. For example, in the case of the Community Council of the Black Community of Punta Soldado, they are trying to consolidate a community, cultural and scientific nature tourism strategy. There, together with the community and different actors, we are promoting the Territorial Center for Conservation: a community-scientific tourism effort based on the bioeconomy^[1]. Likewise, in Bahía Málaga, the Ecomanglar^[2] Community Association is dedicated to offering an opportunity to experience the natural and cultural beauty of the Bahía Málaga-La Plata archipelago. Their tourist activities revolve around the mangroves and natural attractions and, at the same time, contribute to conservation (Piangua route^[3]).

In this panorama, some questions arise that I am in the process of investigating and answering. Is ecotourism a conservation strategy and economic alternative for coastal communities in Colombia? Do mangroves and other coastal ecosystems represent an ally to promote the blue economy? What are the socio-environmental conflicts that we must consider to give way to ecotourism and the blue economy as alternatives?

Common goods, socio-ecosystems and socio-environmental conflicts

Jorge Enrique Casas Mosquera

Understanding the importance of common goods and the right to the commons is a fundamental notion that has been a personal concern for me for a long time: understanding the use and right to natural goods over the ecosystem services provided by an ecosystem as neuralgic and central as the CGSM, undoubtedly became a valuable opportunity to delve into the concept of the common. This socio-ecosystem, where various actors coexist, is key to the conservation of marine-coastal ecosystems and the Caribbean life of amphibian societies, which Fals-Borda explains in his famous book *Double History of the Coast*, which is an invitation to travel through the memories, not only literary but also of oral tradition, of the low flood zones of the Magdalena – Cauca aquatic system, whose crown jewel is the CGSM, as a regulator of life and as in the



*A crab fisherman in the Ciénaga Grande de Santa Marta
Photo: Emilio Posada*

words of the locals it would be “the swamp as the kidney of Colombia”. Of all this hydrosocial territory, or in the words of Camargo “aquatory”, so complex and so diverse that it is part of the essence of coastal life in the Caribbean.

Coastal life and the economies related to the CGSM are fundamental to understanding the cultural world of the “Cienagueros” or the people of the CGSM. One of the key economic activities associated with this ecosystem has been fishing, which is intrinsically related to the amphibious ecosystems of the floodplains of the Magdalena - Cauca complex and marine-coastal. The complexity, multi-scalarity and multi-spatiality that has historically existed in the CGSM has caused these disputes and has consolidated them as socio-environmental conflicts, which are generated, as Mariana Walter would say, by the divergence of interests over the territory as the driving force of the conflicts, since their juxtaposition is expressed as disputes about provisions, but behind them, conflicting needs, fears and concerns that could be resolved.

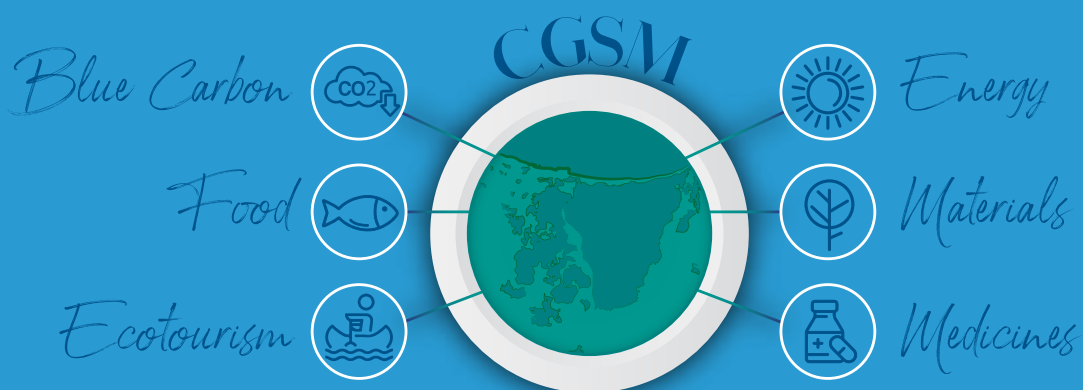
Several of these conflicts that I was able to evidence in the CGSM are related to unequal access to resources and the divergence in the relationships between non-human and human nature. Some of the conflicts that could be identified were: overfishing of species, intermediation networks within the fishing economic chain, and indebtedness as a control system for the fishermen.

1 <https://www.solucionescosteras.org/ballantyne-puin-castano/>

2 <https://ecomanglar.org/>

3 <https://ecomanglar.org/project/ruta-de-la-piangua/>

Blue Economy / Ecosystem Services



Final reflections

Although each of us made reflections and investigative approaches from different backgrounds, we agreed on the close relationship between the ecosystems of this area of the country and its people, and how they have become ecosystems of opportunities for all, since the economic activities, which should be highlighted, are focused on sustainability. However, it is necessary to continue aiming for fisheries management oriented towards sustainable fishing, as this is the nutritional base of the stilt population.




Daily transport in Nueva Venecia - Photo: Emilio Posada

In this way, little by little, these strategic ecosystems are being protected at the initiative of their inhabitants, added to the conservation strategies of the entities that are present and are now participants in them. It is important to highlight that conserved mangroves and their relationship with local communities, in addition to being key to the development of the blue economy, are also important agents for mitigation and adaptation to climate change.


Citizen–Science Based Evaluation of Coral Reef Recovery in Post-Hurricane Providencia

In November 2020, Hurricane Iota devastated many parts of the Archipelago of San Andrés, Providencia and Santa Catalina, with Providencia being particularly badly affected, and the recovery process continues to this day. Recognizing the value of coral reef ecosystem services to the Archipelago, CEMarin, with allies at the Pontificia Universidad Bolivariana, Corales de Paz and National Natural Parks of Colombia, and the National University of Colombia - Caribbean Campus, led this citizen-science based project. This initiative, funded by the Conservation, Food and Health Foundation, uses science and technology to contribute to coral reef restoration efforts

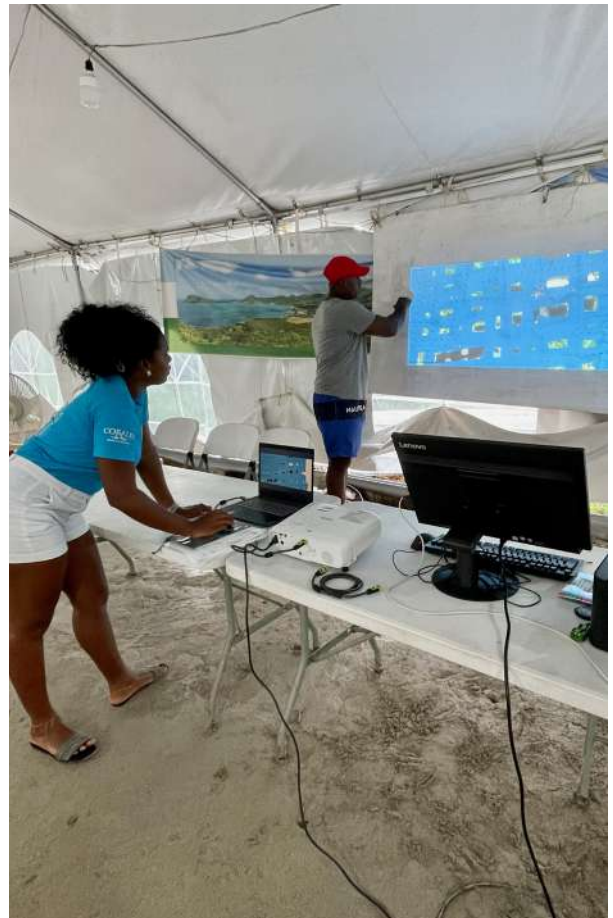
We spoke with Josselyn Bryan (JB), the project’s Local Scientific Coordinator, to learn more.

 Can you tell us about the objective of this project?

JB: In general terms, the objective was to transfer knowledge and experience to the local community and local environmental authorities to build capacity for participatory monitoring and evaluation of coral reef recovery in the islands of Providencia and Santa Catalina. In addition to the use of technology and the training this required, enhancing local ownership of the coral reef rehabilitation processes was also central to the project’s planning and execution. Thus, by involving this community of fishermen in technical-scientific issues, they became aware that they can play a key role in this type of project, as cultural and environmental experts, and that they can expand their knowledge thanks to this type of new initiative.

 Where exactly did you carry out the monitoring activities?

JB: The work was carried out on and around the islands of Providencia and Santa Catalina. The area of interest was divided into two areas, one within the Old Providence McBean Lagoon National Natural Park (NNP), specifically in the northeastern end of the island, where data were collected in four plots (monitoring and/or restoration) plus four areas outside the protected area.




Analyzing images - Photo: Josselyn Bryan

Old Providence McBean Lagoon NNP, created in 1995, is a marine-coastal area for in situ biodiversity conservation. Within the protected area, photomosaics were conducted at the Maracaibo, Marcelas Place, White Shoal and Three Brothers stations; these plots were installed in the park prior to Hurricane Iota. Outside the protected area, we selected four sites with characteristics of coral formations, three of which were located to the northwest of the island of Santa Catalina, called Fly Spot, Basalt Cay and Morgan Head. The last site was located to the southeast of the island of Providencia, called Mantas City, traditionally used for recreational diving.

During the eight months of the project, the team constructed sixteen photomosaics inside and outside the Old Providence McBean Lagoon NNP protected area, resulting in a total of five 3D orthomosaics and the beginning of the coral cover assessment of these sites.

 What were the biggest problems you encountered during the project?

JB: The biggest challenge was the quality and availability of the internet service on Providencia, which generated difficulties in sending the material to the researchers in charge of processing the images (they are located at the UPB facilities in Medellín), which caused us many delays. Of course, natural conditions like the weather, and a high presence of ctenophores and macroalgae in some plots also caused us problems by making it impossible to take images.


 How did you approach the training of the citizen scientists?

JB: We started with four training and socialization sessions for the nine fishermen involved: John Robinson Archbold, Benjamín Suarez Borden, Nageer Archbold Webster and Jordie Guerrero Suarez - who were in charge of taking images inside the protected areas - and Mauricio Webster, Truman Davila, Eusebio Webster, Uriah Steele, and Simon Eloy James, who were responsible for taking images outside the protected area. Additionally, a contractor and three professionals were assigned to undertake the same tasks within the Old Providence McBean Lagoon National Natural Park (NNP).

The project has increased the skills of these local fishermen who, through the training, increased their abilities to ensure the correct and optimal handling of both the GoPro cameras used to collect data from

the photomosaics, as well as additional technological equipment. They also improved their skills in the use and adjustment of cell phones and the use of control points to take samples.


During the development of the project, most of the anglers went through the entire process of setting up the camera themselves. Each of them carried out the procedure themselves, which generated an achievement in terms of the appropriation of knowledge regarding their work in the field and the steps that must be carried out, with a self-sufficient group of fishermen at the time of carrying out the image survey.

 How did the citizen scientists respond to challenges they faced over the course of its implementation?

JB: As the project progressed, the fishermen involved became bolder and increased their skills in taking photomosaics. After the training, socialization and field work, the fishermen were able to play an auditing role in obtaining the images and they helped evaluate the quality of the photographs and the conditions of the sites. If they saw it necessary, they could decide to make a new outing or take new images so that the quality of the photomosaics remained constant.

Likewise, through a process of trial and error they learned through their mistakes about the best methods for taking videos and images, and to analyze the coverage for each site. This flexibility and autonomy allowed them to improve both their professional and personal skills, thus improving their performance and offering better products for research activities, the community and tourism in the future.

Finally, and perhaps most gratifyingly, they also became scientific ambassadors in their communities, letting them know that science is not only for academics or researchers, but that everyone, and even more so as local experts, can participate in its development and as disseminators of knowledge and best management practices in the areas where they live or where they carry out their daily work.

 How does this project connect to the Sustainable Development Goals (SDGs)?

JB: For me, this project covers a whole range of the SDGs, including issues related to food security (SDG 2 “Zero Hunger”), community empowerment and

education (SDG 4 “Quality Education”, SDG 8 “Decent Work and Economic Growth”, SDG 10 “Reduced Inequalities” and SDG 11 “Sustainable Cities and Communities”), and environmental protection and ecosystem services (SDG 13 “Climate Action” and SDG 14 “Life Below Water”). Of course, due to the many actors involved in the project, it is also a great example of SDG 17 “Partnerships for the Goals”).

Finally, as a Raizal woman - a native of the Archipelago - and a trained marine biologist, what does this type of citizen-science based project mean to you?

JB: This type of project, where there are so many national scientists who have contributed to the innovation and conservation of ecosystems at a global level, fills me with gratitude. Being from Providencia and contributing together with the Raizal community to this type of research is of vital importance for our island, even more so after the passage of two destructive hurricanes and because of the increasing environmental problems caused by anthropogenic factors.

I know that involving the community in this type of scientific project will bear many fruits in the future, and the results are gratifying both for my professional growth and for the personal growth of the participating fishermen.



At CEMarin, we are delighted to congratulate Josselyn and all those involved in this project, which received an award for its innovative nature and participatory citizen environmental education from the Colombian Ministry of Environment and Sustainable Development at its “Green Carpet” event in September 2022.

<http://bit.ly/47Z5qkL>



A citizen scientist in action - Photo: Josselyn Bryan

Insect-based Sustainable Shrimp Aquaculture

In the race to meet the growing global food demand, aquaculture has emerged as a frontrunner and is recognized as an important pillar for achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 “Zero Hunger” and SDG 1 “No Poverty”. Aquaculture has garnered attention as a potentially sustainable alternative to traditional fisheries, contributing to SDG 14 “Life Below Water” and SDG 15 “Life On Land”. However, aquaculture intensification may also cause various sustainability issues, such as increased greenhouse gas emissions related to SDG 13 “Climate Action”, massive habitat destruction and overfishing of feed species related to SDG 14 and SDG 15 as well as social problems such as SDG 10 “Reduced Inequalities” and SDG 16 “Peace, Justice and Strong Institutions”.

Therefore, the aim of this project is to push the limits of sustainability in aquaculture, more specifically in recirculating aquaculture of the Pacific whiteleg shrimp (*Penaeus vannamei*). This visionary endeavor focuses on two critical areas: feed and farming systems.

We believe that the key to increasing the sustainability of shrimp aquaculture may lie in locally produced insect-based feed. This could help reduce habitat destruction due to unsustainable fishing techniques, overfishing of feed species and carbon footprints due to shorter transport distances. This project delves into using well-characterized and studied species, like the black soldier fly (BSF), which is characterized by a rapid reproduction rate, low disease transmission risk and relatively low rearing costs. Furthermore, the BSF is proving to be a compelling sustainable protein source with an amino acid profile similar to fishmeal. The sustainability of feed in aquaculture can be further improved by using unexploited organic side-streams from agriculture to rear the BSF, as it can be reared on a variety of substrates. In our project, the shrimp can feed on BSF in two ways: a low-tech approach in which shrimp feed directly on BSF larvae, and a high-tech approach where the larvae are converted into meal, formulated with other ingredients.

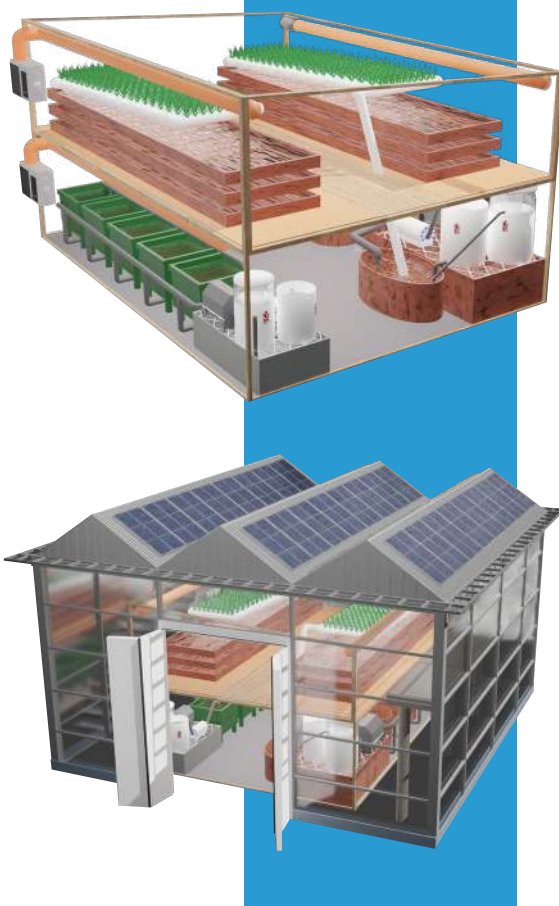


Whiteleg shrimp eating a BSF larva - Photo: Patrick Schubert

In a pilot project at Justus Liebig University Giessen, Germany, this vision is being realized in collaboration with several research and business partners. The facility is sheltered in a house-in-house polycarbonate and wooden structure meant to recycle energy and material streams. The facility hosts two systems, one operating in a low-tech, moderate sustainability scenario and the other in a high-tech, high sustainability scenario. The latter uses wooden tanks and reduced plastic for piping.

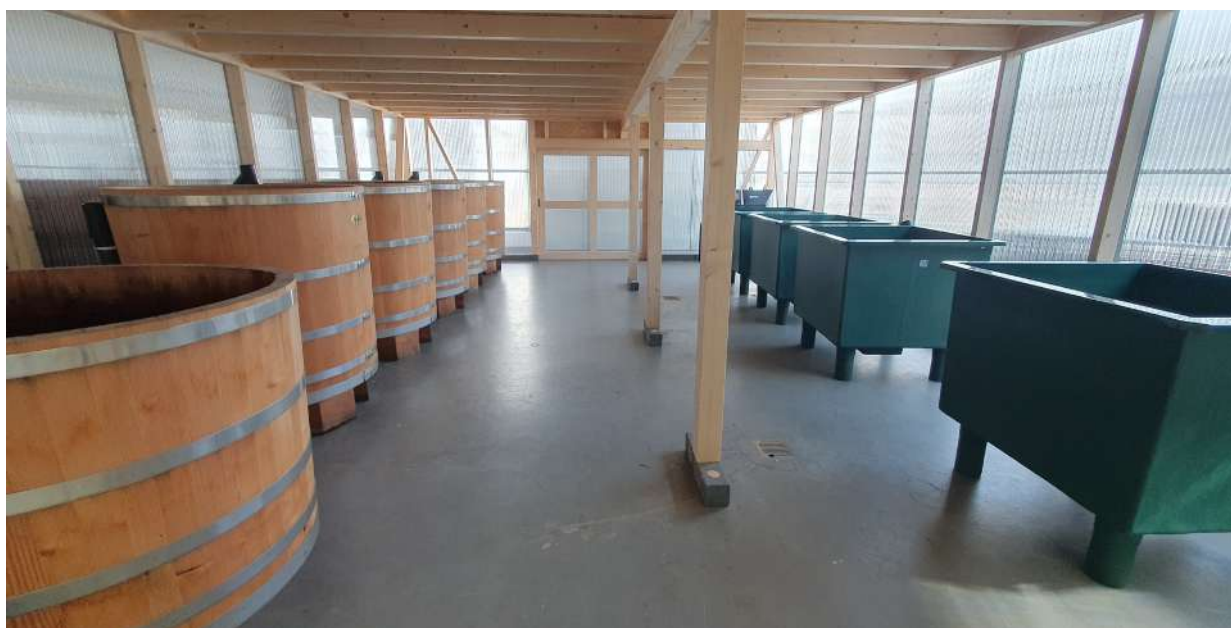
It follows the Circular-economy multi-Trophic Aquaculture System (CTAS) model by reusing all outputs from the system's various components and species (shrimp, filtrating polyculture and aquaponics), maximizing biomass diversity, and minimizing filtration effort and water discharge. Both systems are monitored by sensors, which are controlled via a KNX smart control system. This allows numerous tasks to be automated, reducing human error, reducing energy consumption, and enabling comprehensive management of various parameters both remotely and on-site. The pilot project is powered by solar energy with respect to SDG 7 "Affordable and Clean Energy".

In summary, our new insect-based shrimp aquaculture facility is consistent with SDGs 1, 2, 7, 9, 10, 12, 13, 14, 15 and 16, and is a model project for what sustainable aquaculture can look like.



3D renders of the design of the facility - Photo: Slim Bendag

Team: Slim Bendag, Annalena Barth, Patrick Schubert, Thomas Wilke



Wooden and plastic aquaculture tanks - Photo: Slim Bendag

Participatory Aquaponics in the Fishing Communities of Urabá

The project “Participatory Aquaponics in the Fishing Communities of Urabá” is another example of sustainable aquaculture, whose purpose is to generate a positive impact for the communities of the municipalities of Turbo and Carepa, Antioquia. Aquaponics is an innovative system to cultivate plants and fish which combines traditional aquaculture - that is, the raising of aquatic animals like fish, crabs and shrimp, with hydroponics, which refers to the cultivation of plants in water.

In collaboration with ColombiaCONNECT, this CEMarin program is aimed at obtaining social benefits for these communities that have been strongly affected by the Colombian armed conflict (SDG 16). An essential part of the project is to promote gender equality and female empowerment (SDG 5). In this sense, single mothers, fisherwomen and workers who have not had the possibility to experience paid recognition for their work in the past have been brought into the project. Therefore, the project represents both a source of income for them, and the opportunity to train - in a participatory and culturally respectful way - in the specificities of aquaponics with native species, and in aspects such as the preparation of market studies and business plans.

This aquaponics system, led by Dr Jenny Leal, professor at the Universidad de Antioquia and CEMarin researcher, aims to achieve self-sustainability from both an economic and an operational perspective, and has two key stages: the training stage that includes testing the plants, fish, densities and general functioning, and the commercial empowerment stage, focused on producing food locally, avoiding the need to import it and in turn reducing the costs of the daily shop.



Technical training with some of the women in Turbo - Photo: CEMarin



Vegetables grown in the aquaponics system - Photo: CEMarin

CEMarin PROJECTS

Dr. Jaime Cantera Kintz

Department of Biology and Research Group on the Ecology of Estuaries and Mangroves - ECOMANGLARES,
Universidad del Valle; CEMarin Researcher

CEMarin-Nat Geo Expedition to the Heart of Coastal Biodiversity: The Gulf of Tribugá and Its Importance for the Human Communities of the Territory



The Gulf of Tribugá seen from a remotely piloted aircraft system (drone) - Photo: Expedition team

In recent years, the Gulf of Tribugá has become a symbol of the controversy between development and environmental conservation, following the proposal to build and operate a deep-water port for the Colombian Pacific, which would compensate for the failure of not having been able to make the port in a protected area: the Uramba Bahía Málaga National Natural Park. The main reason behind this failure is that the Bahía Málaga is an area recognized globally for its biodiversity, being home to more than 770 species of fauna and flora. It is also known for being the habitat of some emblematic species, including 7 species of mangrove and seasonal visits by humpback whales during their migrations to the tropics.

Although less well known, the Gulf of Tribugá is another priority conservation area that requires some degree of protection. The designation of this area as a priority site for conservation requires the integration of scientific and ancestral knowledge, to establish what should be conserved and the appropriate management plans to ensure the designation is effective and to facilitate their sustainable use by the community's territories. Designating the Gulf of Tribugá as a marine protected area, encompassing both the terrestrial

areas of the Baudó mountain range and the amphibious ecosystems and surrounding marine areas, is essential to contribute to Colombia's fulfillment of the Sustainable Development Goals (SDGs).

To deepen the incipient scientific knowledge about the characteristics of the coastal ecosystems of the Gulf of Tribugá, which include mangroves, sandy beaches and rocky coasts, the Corporation Center of Excellence in Marine Sciences - CEMarin, and the National Geographic Society - Nat Geo, planned an expedition to the coastal ecosystems of the Gulf of Tribugá, as well as to other localities near this important coastal area of the biographic Chocó.

To undertake this scientific expedition, researchers were summoned from the Universidad del Valle and the Technological University of Chocó, the two institutions in the area with the greatest knowledge of these ecosystems. The main objective was to document marine biodiversity and establish its importance for small-scale fishing by local community fishers. The mission of the expedition members was to recognize the main fish and macrofauna components of the mangrove, rocky coast and sandy beach ecosystems of the Gulf of

Tribugá, and to examine the ecological connectivity with other coastal ecosystems, comparing the composition of marine fauna species and the small-scale fisheries in ecosystems adjacent to the gulf. Two places known for their ecological importance were investigated: the rocky areas of Chachalito and the Utría cove.

For six days, four researchers from the Universidad del Valle - Jaime Ricardo Cantera-Kintz, Edgardo Londoño-Cruz, Juan Carlos Mejía Rentería and Andrés Carmona - two from the Technological University of Chocó - Mauricio Bechara and Jhasbleidy Palacios - and two from CEMarin - Ballantyne Puin Castaño and Andrés Fernando Osorio Arias - accompanied by four members of the Tribugá community, toured the gulf and its three tributaries: the Tribugá River, the Matilde and Madre Vieja estuaries, and the Honda stream.

Additionally, they explored two nearby rocky areas, one in the Chachalito region and another in the Utría cove, in order to compare biodiversity. In these locations, the team alternated their research activities between fishing in estuaries and mangroves with the fishermen of Tribugá, field observations, and the use of unmanned aerial vehicles (drones) and Geographic Information Systems on distribution patterns, mangrove structures, and the measurement of surface and deep oceanic variables in different tidal conditions, using multiparametric probes.



Researchers taking samples - Photo: Expedition team

The results of the expedition are:

- 1 the importance of fish species in small-scale fisheries.
- 2 the characteristics of the coastal ecosystems and their biodiversity.
- 3 data on some oceanographic variables in estuarine areas.
- 4 a preliminary lists of marine invertebrates of mangrove and rocky coast ecosystems.



Photos: Expedition team

Some of the species found on the expedition

21 genera and 27 species were found in the captures made. The best represented fish families were Lutjanidae (snappers) and Carangidae (horse mackerel and green jacks), with five and three species respectively. In addition, species such as

mullet, catfish, Pacific mojarra, needlefish, weakfish, Pacific Sierra and snooks were recorded. The small-scale fishing communities of Tribugá have developed fishing practices that contribute to the conservation of fish species and, in general, the resources they use to make their livelihood. Tribugá is the first town to completely prohibit the use of gillnet fishing gear smaller than 7 inches in diameter, and to use hand lines with hook sizes that do not affect juvenile individuals. This has allowed more than 75% of the residents to dedicate themselves to artisanal fishing in groups made up of families and friends, sometimes consuming 100% of the catches and, in other moments, selling them in the main town of the municipality of Nuquí or bartering with agricultural products. These activities contribute strongly to the achievement of the SDGs: No Poverty (SDG 1), Responsible Production and Consumption (SDG 12) and Life Below Water (SDG 14).

The research on mangroves allowed us to establish that in this small geographical area there are exuberant mangrove forests with all the species and the three common physiographic types of the Colombian Pacific coast: sandy bar forests (located behind beaches stabilized by creeping vegetation), riparian (around rivers, canals and estuaries) and edge (in front of elevated rock formations). Each one with structure and development corresponding to mangroves in good condition, reaching close to 30 meters in height in some coastal areas. The forests present the zonation, height and biomass characteristics of the species of these ecosystems when they have not suffered human intervention. In other regions, almost pure piñuelo mangrove forests could be observed, while some tall and very

well-preserved mangroves were found. All these indicators show an excellent state of the ecological integrity of mangrove forests (SDG 15).

The rocky intertidal ecosystems studied within the Gulf of Tribugá presented relatively lower biodiversity values than in other regions of the Pacific coast and even in the two nearby regions used for reference (Chachalito and Playa Blanca in the Utría cove). This result corresponds to the low abundance of these ecosystems in the gulf.

The oceanographic variables present variations in salinity, temperature and dissolved solids both inside and outside the cove, in accordance with the tides and also depth, presenting stratification during some tide hours and greater mixing at other times. These results demonstrate that the Ensenada has an estuarine behavior.

The results of the expedition confirmed, firstly, that it is not an appropriate area to build a deep-water dock due to its geomorphological characteristics, its estuarine behavior and its high sedimentation. Secondly, the ecological and economic importance of the Gulf of Tribugá, both for the state of conservation of its mangrove forest and for its biodiversity, as well as its relevance as a fishing site for species fundamental for the food security of the inhabitants of this region of Chocó. Finally, the expedition helped to verify that the decisions of informed and committed communities contribute to environmental sustainability and can be fundamental to establish policies for the sustainable use, management and conservation of areas strategic for the country, contributing in a practical and concrete way to the fulfillment of the SDGs.





CEMarin REPORTS

CEMarin Early Stage Researcher: Olga Lucia Torres Suárez

Doctoral student in Marine Sciences, Universidad del Valle

Director & CEMarin Researcher: Dr José Julián Tavera Vargas

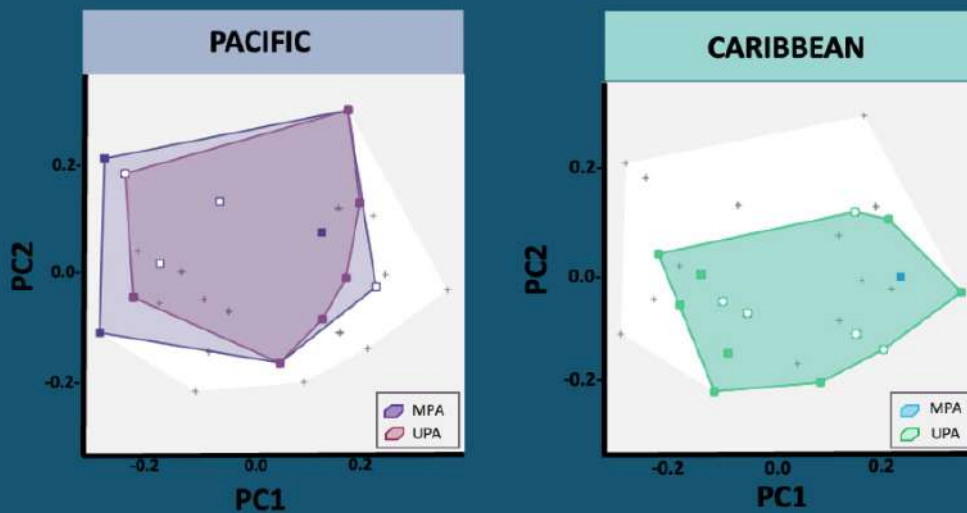
Universidad del Valle

Co-Director & CEMarin Researcher: Dr Fernando Zapata

Universidad del Valle

Effect of Marine Protected Areas on Taxonomic and Functional Diversity of Fish in Colombian Pacific and Caribbean Coral Reefs

Fishes are diverse and abundant taxa on coral reefs where they support ecosystem functions and stability as well as services to human populations. For the last decades, Marine Protected Areas (MPAs) have been created to protect coral reef biodiversity by preventing overfishing. However, the effects of such protection on the diversity of fishes are not known for Colombian MPAs. It is important that the evaluation of MPA benefits should focus not only on the taxonomic facets of biodiversity but also on other attributes such as its functional facets, that is, those that account for the ecological features of species related to their roles in these ecosystems.



Functional dissimilarity between two functional space. MPAs: Marine protected areas, UPAs: Unprotected areas.

The main goal of this study was to evaluate the community structure of three diverse and key families in the Colombian Caribbean and Pacific basins, in terms of functional and taxonomic diversity. Fish were surveyed in 13 locations with coral reefs through stereo video along 10-30m transects, allowing the identification and measuring of all individuals. The biomass of each individual was calculated, as well as the relative biomass of each species in each location. We computed taxonomic richness and entropy for each species present in our dataset, and we measured five functional traits related to fish roles: size, diet, home-range, gregariousness, and position in the water column. Five facets of functional diversity

(richness, dispersion, identity, specialization, and redundancy) were computed for each location. Additionally, we calculated taxonomic dissimilarity (turnover and nestedness components) between locations in each ocean basin. The highest taxonomic richness was within the Caribbean both in MPAs and in unprotected areas. In contrast, functional richness (FRic), functional specialization (FSpe) and functional redundancy (FNnd), had higher values in the Pacific basin, where just one MPA had the effect of protection. The highest taxonomic and functional dissimilarity was in the Pacific, though it was not affected by protection.

Overall, our study highlights the benefits of accounting for the functional facet of biodiversity in order to have a better understanding of the effects of MPAs not only in Colombia, but also in the region. Therefore, this research will be helpful to complement management policies which tend to preserve and restore strategic ecosystems like coral reefs, as well as progress in the categorization of key species. Hence, this study supports the Sustainable Development Goals (SDGs) which, in SDG 14, call for enhancing the conservation and sustainable use of oceans and their resources, and increasing the scientific knowledge in developing countries.

I have loved doing every step of this research project. Field work gave me the opportunity to visit beautiful coral reefs areas with great biodiversity, but also let me see the signs of their vulnerability. Likewise, both the laboratory and computational work were very interesting processes. Furthermore, I enjoyed my experience during my research stay, which allowed me to learn specific tools and analysis to develop this study. Similarly, working on this project allowed me to participate in congresses and workshops where I met other researchers working in this area and in other disciplines relevant to my survey. Overall, these activities have given me the opportunity to broaden the scope of my study and to start a new scientific network for future collaborations.



Fish census with stereo-video. Photo: Pocho Ortiz



Assemblages of fish families Chaetodontidae, Acanthuridae and Labridae in coral reefs from the Colombian Pacific.



CEMarin REPORTS

CEMarin Early Stage Researcher: Oscar David Caicedo Salcedo
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Richness, Diversity and Changes in the Composition of Marine Vertebrate Communities in the Gulf of Tribugá, Colombia, Based on eDNA Analysis

Advances in molecular tools have allowed innovation towards a new technique known as environmental DNA or eDNA. Environmental DNA involves being almost like a detective. You collect DNA found in the environment, whether in aquatic, terrestrial, sedimentary environments or even in the air, and proceed to carry out all the molecular work of amplification, sequencing and identification. That is, being able to decipher whose DNA it is.

My work consisted of the first eDNA analysis for the Gulf of Tribugá, one of the places with the greatest diversity on the planet. The results were incredible. We obtained more than 200 marine species, including tunas, snappers, sharks, sardines, dolphins and whales. In addition, we managed to record species of birds, land mammals and a few amphibians. Additionally, thanks to these data, we managed to identify some changes in the marine community during the migratory phenomena that occur in the Colombian Pacific: the whale season and the not very well-known sardine or gafffish season. This also generated the visualization of said information and to consider how responsible tourism could be proposed during the sardine season (from April to June).

On the other hand, the results of this work are a starting point to increase biological knowledge for the region and generate the empowerment of its communities, since they were fundamental participants in this work. From marine transportation to sample collection, the process was supported by local people, of which I want to highlight the participation of three young Coquiseños: Kevin, Kaleth and Elian. They took eDNA samples and one of them accompanied me to a science event called Annual Meeting of the Association for Tropical Biology and Conservation (ATBC 2022), an opportunity that, in his words, taught him the true importance of his home: the Gulf of Tribugá.



Oscar David Caicedo and Elian Martínez participating in the eDNA Workshop at the ATBC 2022



Kaleth Martínez taking eDNA samples in the Gulf of Tribugá



CEMarin REPORTS

CEMarin exalumna: Diana Marcela Arroyave Gómez PhD

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The Environmental Impact of Wastewater in Coastal Areas from Experimental and Modeling Approaches

As the world's population is growing, the volume of sewage has also increased, and this has eventually led to a rise in pollution load - that is, nutrients, suspended solids and chemicals substances - which has become a serious global problem affecting coastal and estuarine areas close to wastewater and river discharges. The quality of surface waters affected by untreated wastewater discharges continues to decline in many parts of the world, compromising the biological diversity of discharge receiving environments, the ecosystem services they provide, and the role of the discharges in buffering the detrimental effects of climate change.

Proper wastewater management can contribute to the achievement of several Sustainable Development Goals (SDGs), including the increase of water availability (SDG 6: Clean Water and Sanitation), and the environmental impact reduction of wastewater (SDG 11: Sustainable Cities and Communities, SDG 12: Responsible Consumption and Production; SDG 13: Climate Action and SDG 14: Life Below Water).

As the understanding of wastewater impacts on tropical coastal ecosystems is essential for developing effective management strategies, we studied the biogeochemical and physical processes behind it. The aim of this research was to understand the environmental impact of wastewater discharge from the Santa Marta outfall (SMO) and its interaction with natural upwelling phenomena in the Santa Marta Coastal Area (SMCA) in the Colombian Caribbean. To achieve this research, we applied an experimental approach and mathematical modeling.

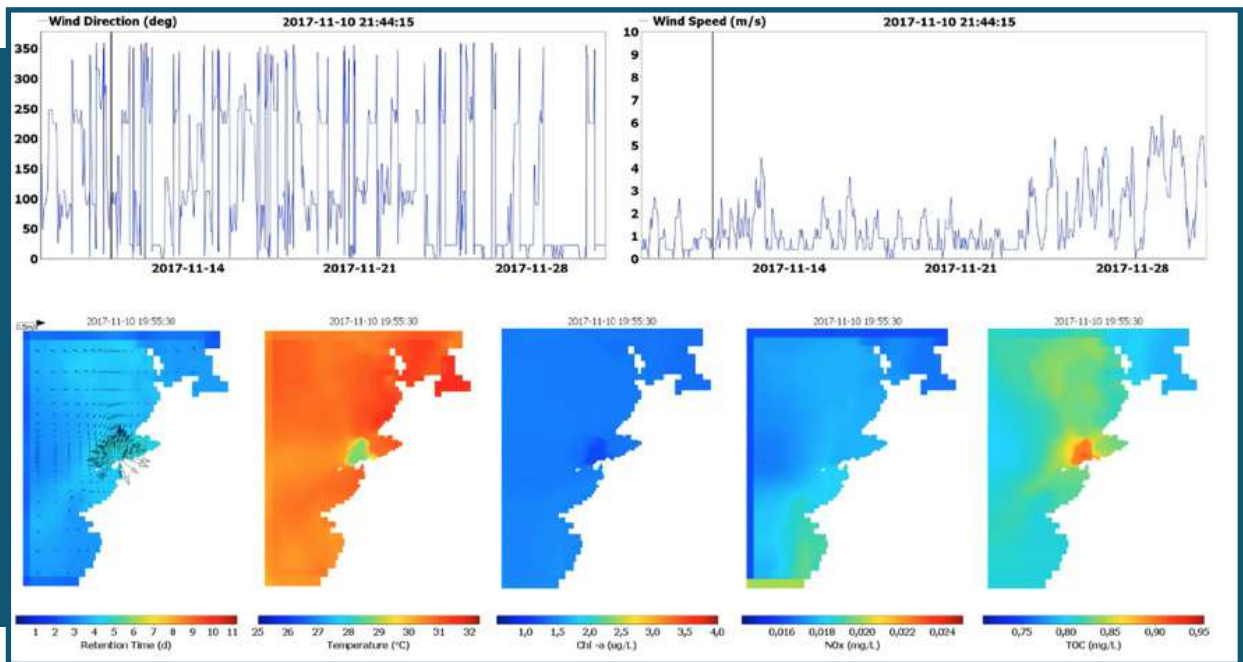
The experimental work focused on the sediment because it represents the ecosystem compartment with a higher accumulation capacity of impacts. The changes in the sediment were traced by using advanced techniques to measure sediment features and benthic metabolism (e.g. $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, denitrification, nitrogen fixation, etc.) at two stations close to the wastewater discharge and two control stations. On the contrary, the changes in the water column are more difficult to evidence in coastal areas due to short residence times and high dilution capacities. In the second approach, we applied a complex coupled 3D hydrodynamic-ecological mathematical model (AEM3D) in the SMCA to trace and predict the changes of nutrient and phytoplankton concentrations in the water column.



Sampling of sediment cores for biogeochemical analysis in the laboratory. - Photo: Diana Marcela Arroyave Gómez

We have found that the combination of these different approaches (experimental and modeling) allows us to determine the environmental impact of a sewage outfall in a coastal marine ecosystem with highly variable and complex hydrodynamics. The sediments allowed us to trace the outfall's spatial impact around 1800 m away, whereas the model showed the stimulation of phytoplankton growth near the outfall plume over short time periods during the upwelling season. Furthermore, the sediments revealed a pronounced organic impact in the proximity of the wastewater discharge, altering the biogeochemical dynamics of the sediments and the habitat of benthic organisms.

Our results suggest that combining the experimental and modeling approaches to study wastewater impact on marine ecosystems is increasingly important due to the rising anthropogenic pressures on coastal areas and watersheds, and ongoing global changes affecting the climate, wind patterns, water temperature, and mixing rates. Understanding the synergy of several physical, chemical and biological processes is essential to develop effective wastewater management strategies in coastal areas that contribute to achieving the SDGs.



Results of simulations of the physicochemical, hydrodynamic and biological variables (water residence time, temperature, chlorophyll-a and nutrients) with the 3D hydrodynamic-ecological mathematical model (AEM3D).

Associated publications:

Arroyave Gómez DM, Bartoli M, Bresciani M, Luciani G, Toro-Botero M (2021) Biogeochemical modeling of a tropical coastal area undergoing seasonal upwelling and impacted by untreated submarine outfall. *Marine Pollution Bulletin*, 172: 112771 doi.org/10.1016/j.marpolbul.2021.112771

Arroyave Gómez DM, Gallego Suárez D, Bartoli M, Toro-Botero M (2020) Spatial and seasonal variability of sedimentary features and nitrogen benthic metabolism in a tropical coastal area (Taganga Bay, Colombia Caribbean) impacted by a sewage outfall. *Biogeochemistry*, 150:85–107 doi.org/10.1007/s10533-020-00689-0