Revista de Biología Tropical, ISSN: 2215-2075, Vol. 71 (S1): e54853, abril 2023 (Publicado Abr. 30, 2023)

SUPPLEMENT

REVISTA DE Biología Tropical

https://doi.org/10.15517/rev.biol.trop..v71iS1.54853

Applying the SES Framework to coral reef restoration projects on the Pacific coast of Costa Rica

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Received 07-X-2022. Corrected 14-II-2023. Accepted 26-II-2023.

ABSTRACT

Introduction: Global and local stressors have led to rapid declines in coral reef health. The high rates of coral degradation have motivated restoration initiatives worldwide. Evaluation of these initiatives has provided valuable information regarding coral restoration techniques and limitations faced by projects. However, most of the literature is focused on evaluating metrics related to fragment survival rate and growth, leaving a gap in understanding how social aspects such as governance structure affect project outcomes.

Objective: The present research applies the Social-Ecological Systems Framework to identify social and ecological factors contributing to the success of three coral reef restoration projects in Costa Rica.

Methods: Data was gathered from 50 semi-structured interviews with project members, volunteers, tour operators, fishers, and related community and government organizations that were analyzed using the categories determined by the Social-Ecological Systems Framework**.**

Results: Despite each case's specific ecological and governance characteristics, research results show that three main steps have contributed to project success. First, the importance of locals having a positive perception of coral reef and project benefits; second, the use of network structure to obtain adequate financial and human resources and third, the importance of compliance with a regulatory framework to create enabling environments for reef restoration.

Conclusions: Results show no universal solutions for coral reef restoration projects. Project managers must understand the ecological and social context of the restoration site to boost the benefits that reef restoration projects can provide, such as an increase in local stewardship, income generation, and the creation of more resilient communities.

Key words: reef restoration; Costa Rica; social-ecological systems; governance.

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RESUMEN

Aplicación del marco SSE a proyectos de restauración de arrecifes de coral en la costa del Pacífico de Costa Rica.

Introducción: Los factores de estrés globales y locales han llevado a una rápida disminución de la salud de los arrecifes de coral. Las altas tasas de degradación de los corales han motivado iniciativas de restauración en todo el mundo. La evaluación de estas iniciativas ha proporcionado información valiosa sobre las técnicas de restauración de coral y las limitaciones que enfrentan los proyectos. Sin embargo, la mayor parte de la literatura se centra en la evaluación de métricas relacionadas con la tasa de supervivencia y el crecimiento de fragmentos, lo que deja un vacío en la comprensión de cómo los aspectos sociales y estructura de gobernanza, afectan los resultados del proyecto.
Objetivo: La presente investigación aplica el Marco Conceptual de Sistemas Socio-Ecológicos para identificar los factores sociales y ecológicos que contribuyen al éxito de tres proyectos de restauración de arrecifes de coral en Costa Rica.
Métodos: Los datos se recopilaron a partir de 50 entrevistas semiestructuradas con miembros del proyecto, voluntarios, operadores turísticos, pescadores y organizaciones comunitarias y gubernamentales relacionadas que se analizaron utilizando las categorías determinadas por el Marco Conceptual de Sistemas Socio- Ecológicos.
Results: A pesar de las características ecológicas y de gobernanza específicas de cada caso, los resultados de la investigación muestran que tres pasos principales han contribuido al éxito del proyecto. Primero, la importancia de que los locales tengan una percepción positiva de los arrecifes de coral y los beneficios del proyecto; segundo, el uso de la estructura de la red para obtener recursos financieros y humanos adecuados y tercero, la importancia del cumplimiento de un marco regulatorio para crear entornos propicios para la restauración de arrecifes.
Conclusiones: A pesar de las características ecológicas y de gobernanza específicas de cada caso, los resultados de la investigación muestran que tres puntos principales han contribuido al éxito del proyecto. Primero, la importancia de que los locales tengan una percepción positiva de los arrecifes de coral y los beneficios del proyecto; segundo, el uso de la estructura de la red para obtener recursos financieros y humanos y tercero, la importancia del cumplimiento de un marco regulatorio para crear entornos propicios para la restauración de arrecifes.

Palabras clave: restauración arrecifal; Costa Rica; sistemas socio ecológicos; gobernanza.

INTRODUCTION

Coral reefs cover 0.2 % of the earth's surface; however, almost 50 % of coral reef live coverage has been lost in the last 30 years (Burke et al., 2011; Souter et al., 2020). Loss of coral coverage decreases ecosystem services such as recreational use, tourism development, fish biomass production, and coastal protection, causing direct effects on the livelihood of people living near coastal zones (Eddy et al., 2021; Moberg & Rönnbäck, 2003).

The global decline in coral reef ecosystem services has motivated restoration initiatives worldwide (Edwards & Clark, 1999). Reef restoration initiatives started in the 1960s with artificial reefs when coral reef degradation became more visible, and laws for protecting marine habitats were introduced (Rinkevich, 1995). In the early 2000s, efforts started eradicating invasive species and outplants from nurseries (Goergen et al., 2020). In 2016, emphasis was given to increasing efficiency and scale using micro-fragmentation and larval propagation. During this last wave, efforts have been accompanied by the commercialization of initiatives for touristic purposes (Meyers, 2017). Evaluation of projects conducted in the previous 60 years has helped identify the importance of site selection, accessibility (Quigley et al., 2022), water quality, eradication or control of threats (Shaver et al., 2020), public support (Frey & Berkes, 2014), adequate human and financial resources (Wenger et al., 2017), effective governance (Cinner et al., 2012), and straightforward legal mandate (Christie & White, 2007) as factors for influencing effective restoration initiatives.

Ecological restoration can be defined as the process of assisting in the recovery and management of the ecological integrity of an ecosystem (Van Diggelen et al., 2001). Suding et al., 2015 argue the following four fundamental principles should be met: 1) increasing ecological integrity, 2) benefiting and involving society, 3) long-term sustainability, and 4) the past should inform initiatives. These principles can be used as pillars for evaluating project performance. However, most of the coral reef restoration literature is focused on evaluating only the ecological aspects of projects (Bayraktarov et al., 2019). The most common indicators for project success are coral colony-level metrics related to corals' survival rate and growth (Hein et al., 2017). There is a knowledge gap in understanding the social and economic factors that impact the restoration project's performance. Factors such as the influence of livelihoods, governance, local capacity building, and community participation on project efficiency and sustainability are not usually considered (Hein et al., 2017; Kittinger et al., 2012).

Some studies have assessed social factors; for example, Hein et al. (2019) evaluated vital stakeholders´ perspectives on coral reef restoration efforts in four restoration projects in Thailand, Maldives, Florida Keys, and the US Virgin Islands. Their findings show most common limitations to restoration success are lack of technical capacity, no connection between the project and local actors, the scale of threats outweighs solutions, lack of partnerships, and lack of science behind efforts. Boström-Einarsson et al. (2020) reviewed 362 cases evaluating restoration knowledge related to methods, success, and failures. The primary limitations identified relate to poor project design, lack of experimental control, short temporal scale, and lack of appropriate and constant monitoring. Human and coral reef interactions positively and negatively impact coral reef restoration, making it necessary to analyze reef restoration from a social-ecological perspective (Uribe-Castañeda et al., 2018). Very often, social and ecological aspects are seen as separate elements, ignoring interactions between different cultural, political, social, economic, ecological, and technological components (Gunderson et al., 2010). Oversimplifying these interactions and applying one-size-fits-all solutions to ecosystem management have led to failures such as a lack of stakeholder involvement, capacity to control degradation causes, or long-term sustainability (Wyborn & Bixler, 2013).

Yeemin et al. (2006) highlighted that the prevention of causes of degradation should be prioritized before starting restoration projects to reduce the costs of restoring large areas. Also, projects in limited demonstration areas are easier to manage for different purposes, such as education, tourism, or research. Trialfhianty & Suadi (2017) assessed projects in North-west Bali, analyzing the relationship between community perception and participation in restoration activities. They found that the level of community participation depends on how related their livelihood is to coral reefs and the importance of local leadership as bridges between science and local awareness. Community participation is assessed in several studies; Kittinger et al. (2016) showed that projects that increase community awareness, participation, and shared responsibility achieve long-term results. Notably, Kittinger et al. (2016) found that restoration projects helped develop a skilled workforce, improve economic benefits through job creation, increase the capacity of community organizations to act on threats to reefs and watersheds, revitalize Native Hawaiian cultural practices, and innovate on using invasive algae as compost for farmers. Hein et al. (2019) found that community participation is retributed through jobs, education, stewardship, and increasing recreation opportunities.

Financing restoration projects is complex and limited, one of the biggest impediments to scaling up interventions (Bayraktarov et al., 2019). Most of it has been in-kind or NGO sector financing (Goreau & Hilbertz, 2008). Recently, the private sector has been increasingly funding restoration activities, especially hotels and dive operators (Bottema & Bush, 2012; Meyers, 2017; Okubo & Onuma, 2015). Understanding how governance structure and types of financing influence project outcomes is relevant for decision-making. Bottema &

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Bush (2012) analyzed private sector-led marine conservation. Their results highlight the private sector's ability to create awareness both in tourist and local communities, generate income, and the capacity to support financial restoration activities. When government support is lacking, other reef users need help to guarantee compliance; for this to occur, trust is required. In their study, the private sector gained legitimacy by investing in education and employment programs. In the same direction, Okubo & Onuma (2015) analyzed commercial restoration projects in Okinawa, where diving tours have incorporated restoration activities. Results show it is appealing to tourists and creates environmental awareness. However, they highlight that this commercial project lacks long-term ecological integrity emphasis.

The Social-Ecological Systems Framework (SESF) is a diagnostic tool that allows to deepen the analysis of social and ecological interactions affecting coral reef restoration performance. A *framework* is a comprehensive structuring tool that depicts an empirical situation. The SESF was explicitly created to understand social-ecological systems (Schlüter & Madrigal, 2012), allowing us to assess which variables across the ecological and social realm influence human behavior causing different outcomes in particular resource systems throughout time (Ostrom, 2007). For achieving a holistic perspective, the framework distinguishes eight categories for analysis: 1) social, economic, and political settings, 2) resource systems, 3) resource units, 4) governance, 5) actors, 6) interactions, 7) related ecosystems, and 8) outcomes. These categories are subdivided into second-tier variables identified in the literature to be relevant for common pool resources management (Ostrom, 2007; Ostrom, 2009). These variables supply a common language for comparing cases by analyzing each case's ecological, economic, social, and policy characteristics and outcomes (Delgado-Serrano & Ramos, 2015; Ostrom, 2007).

The SESF has helped to determine factors influencing sustainable management in coastal and marine ecosystems (Basurto et al., 2013; Leslie et al., 2015; Partelow et al., 2018; Schlüter & Madrigal, 2012; Torres-Guevara et al., 2016). Fewer studies have been made regarding applying the SESF to coral reef management; most refer to Marine Protected Areas (MPAs) containing coral reefs. For instance, Cinner et al. (2012) used the framework to measure the success of coral reef co-management across five countries. Their results show that successful co-management is related to critical institutional designs, knowledge of human agency in the ecosystem is high, and people have a history of being involved in co-management. Palomo & Hernández-Flores (2019) applied the framework to a marine natural protected area in Mexico by analyzing the key elements to achieve sustainable use in multiple resource systems such as coral reefs. Findings show that governance systems within a community change depending on the type of economic activity performed by the population, and governance complexity is related to the equity level of the actors. It also highlighted how community-based governance helped people get skills in conservation and increase stewardship.

Some studies have not applied the SESF directly but have linked social and ecological data to understand how these interactions influence outcomes and have helped identify relevant variables for understanding human-coral reef dynamics. Pollnac et al. (2010) evaluated 56 marine reserves in the Philippines, the Western Indian Ocean, and the Caribbean, finding that fish biomass was influenced by human population density and compliance with rules. Cinner et al. (2016) evaluated 2 500 reefs worldwide; their results show that bright fish spots were linked to high dependence on marine resources, levels of local engagement, marine tenure, cultural taboos, and beneficial environmental conditions. On the other side, dark spots were linked to intensive capture, storage capacity access, and recent environmental stress events history. Conclusions from this study highlight the importance of strengthening participation and property rights in fisheries. These results help identify what social variables have been influential in other cases. Rogers et al. (2015) evaluated how the structure of coral reef communities may change in the future due to climate change and overfishing by considering structural complexity and primary productivity. Their findings show that the efficacy of management depends on biophysical characteristics and reef state, making marine reserves more effective with high structural complexity and restoration more effective for low complexity reefs.

This study aims to contribute to the knowledge of coral reef restoration projects through a social-ecological perspective by applying the Social-Ecological System Framework to identify the main social and ecological factors contributing to the successful outcomes of three restoration projects on the Pacific coast of Costa Rica. The research analyzes the role of perception in increasing local participation, the enabling conditions that allow access to technical and financial capacity, and how compliance with the existing regulatory framework contributes to project success. Emphasis is given to the influence of different governance structures on projects' successful outcomes by comparing projects led by an NGO, co-managed by the community and technical government institution and co-managed by a local university and a private tourism developer.

MATERIALS AND METHODS

Study Area: Three study cases from the Pacific Coast of Costa Rica, part of the ETP were chosen to analyze social and ecological enabling conditions for success (Fig. 1). They share ecological characteristics related to topography, oceanographic dynamics strongly influenced by low latitude trade winds, and inter-annual climate variation associated with ENSO. The Northern part of the coast has a dry tropical forest with a dry season from December to April when the upwelling season

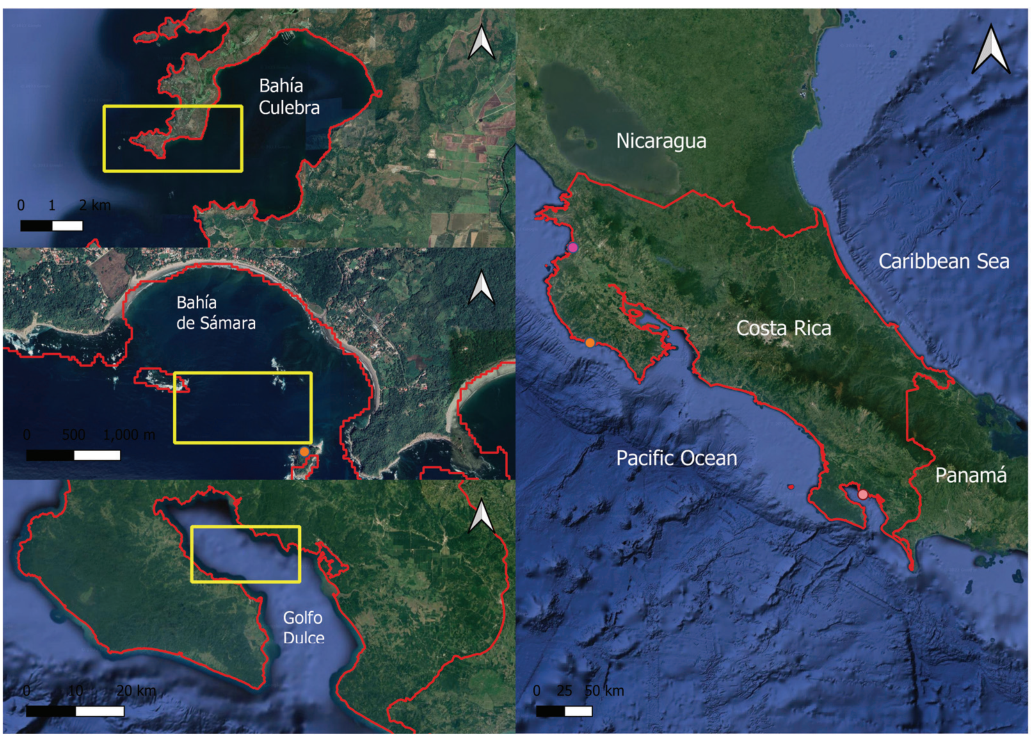

Fig. 1. Location of three coral reef restoration projects working areas (Bahía Culebra, Sámara, and Golfo Dulce. (Google Satellite, n.d.)

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occurs; meanwhile, the southern part has tropical rainforest, with rain all year round, which decreases from December to April. High mountains in the central and southern areas prevent coastal upwelling (Cortés & Jiménez, 2003). Also, reefs in the ETP are built by a few coral species and have a discontinuous distribution (Reyes-Bonilla et al., 2020).

Regarding social and economic aspects, the Pacific Coast has experienced economic growth through tourism due to the country's political stability and infrastructure development, such as airports and roads (Honey et al., 2010). The following sections briefly describe the location where projects are being conducted and the project history and results. Table 1 summarizes the project description and results.

Bahía Culebra: The bay has an extension of 7 km, located inside the Papagayo Gulf (10.619357 °N - 85.655315 °W) in the northern Pacific of Costa Rica. The bay has seasonal upwelling from December to April, having colder and nutrient-rich waters and decreasing water temperatures (Alfaro & Cortés, 2012). Bahía Culebra is characterized by having rare and unique coral communities and reefs. Pocilloporid corals are the primary reef builders in shallow waters, and *Pavona clavus*, *Psammocora* spp., and *Leptoseris papyracea* are primarily found in deeper waters. Branching corals such as *Pocillopora damicornis* and massive such as *Pavona clavus* account for 42 % and 30 % of live cover, respectively (Cortés & Jiménez, 2003). Jiménez (2001) states dominance of species in the bay might be influenced by coral thermal tolerance and exposure to cool upwelling waters during the dry season. Corals in this area have been affected by siltation, fishing, and touristic activities, El Niño, extraction for the aquarium trade, macroalgal proliferation, and red tides (Cortés et al., 2010).

The bay's economic development intensified in the '90s due to the Polo Turístico Golfo de Papagayo (PTGP), which promotes sun, sea, and sand tourism. The PTGP is managed by the Instituto Costarricense de Turismo (ICT), which grants concessions to investors. Main touristic activities in the bay include sport fishing, diving, snorkeling, and water ski rides (Jimenez, 2001; Sánchez-Noguera, 2012).

The restoration project started as a coral gardening pilot in 2019. It is managed by a private-public partnership between Sistema Nacional de Áreas de Conservación (SINAC), CIMAR, German Corporation for International Cooperation (GIZ), Península Papagayo, and RCCR. In 2020, the project was officialized

Table 1

Summary of project relevant information took from interviews with project´s members. Data was taken during fieldwork conducted from February to June 2022.

Organization	Culebra Reef Gardens	Asociación Proyecto Corales	Raising Coral Costa Rica
Location	Bahía Culebra, Guanacaste	Sámara, Guanacaste	Golfo Dulce, Puntarenas
Managed by	Private sector and Academia	Community and Government institutions	NGO
Funded by	International cooperation, Private and public sector (University) funding	Personal donations, citizen science events, public sector (Govt institution) funding	International cooperation and personal donations
Starting Date	2019	2017	2016
# of transplanted corals	265 transplanted 4,000 for growing in structures	600 transplanted	1600 transplanted
% survivance	83.20 %	64 %	90 %
Species	*Pocillopora* spp., *Pavona clavus, Pavona gigantea, Porites lobata*	*Pavona gigantea, Psammocora stellata, Porites lobata , Pocillopora elegans*	*Pocillopora* spp., *Pavona frondifera Pavona gigantea, Psammocora stellata*

to implement an in-situ coral gardening program and promote responsible touristic activities in reefs and nurseries in Bahía Culebra. CIMAR's role is to lead ecological monitoring and provide technical knowledge. Meanwhile, Península Papagayo contributes by managing volunteers to clean the structures. Both organizations make financial contributions to the project. In the case of CIMAR, they contribute US$76 000 per year, including equipment, staff, and materials. The relationship between both actors is ruled by a cooperation agreement of three years which will be evaluated by the end of the period. Project goals are to transplant 5 000 corals in 5 years, recover 30 % of coral cover, increase biomass and fish diversity by 50 %, establish a responsible tourism program with three local enterprises, create environmental awareness in the local community, propose marine spatial planning for productive activities related to coral reefs in the zone. The project covers around 0.09 ha in Güiri-Güiri, Islas Pelonas y Playa Blanca. Two hundred sixty-five coral fragments have been transplanted, and 4 000 fragments of *Pocillopora* spp. are meant to stay in the spider and A structures that are already growing. The project has 83.2 % of coral survival.

Sámara: Sámara (9.869220° N - 85.515304° W) is located in the Nicoya canton in the Guanacaste Province. The estimated population for 2022 is 4 685 habitants (Instituto Nacional de Estadística y Censos [INEC], 2011). The primary income sources are tourism, fishing, and agriculture (CREST, 2013). Unlike other areas of the Guanacaste Province that follow a high-volume tourism strategy with resort-type hotel infrastructure, Sámara has small and medium infrastructure focused on ecotourism. The Refugio Nacional de Vida Silvestre (RNVS) Isla Chora is located in Sámara Bay. The bay has a 3 km extension. Most popular touristic activities include snorkeling, diving, kayaking, dolphin, whale, and turtle watching, horseback riding, and sport fishing. The region has a small *Pocillopora* or *Porites lobata* reef patch (Cortés & Jiménez, 2003); however, these reefs have been affected due to gravel and clay sedimentation carried by the Mala Noche and Lagarto rivers (Armstrong et al., 2010). In addition, anthropogenic and natural threats have reduced live coral cover to 5 % (C. Perez, personal communication, February 21st, 2022).

In 2016, the Ministry of Environment and Energy (MINAE) requested the Instituto Nacional de Aprendizaje (INA) to evaluate the feasibility of conducting a coral reef restoration project in Samara Bay. The feasibility analysis allowed to determine sites for the nursery near RNVS Isla Chora and transplant sites in Cangrejal. The project started officially in 2017 when INA approached local tour operators and tour guides to participate in coral gardening training to create a group of local volunteers.

The project is co-managed by Asociación Proyecto Corales Sámara and INA. Asociación Proyecto Corales is a community organization with seven active volunteers, mainly from the tourism sector. INA provides technical knowledge and performs ecological monitoring. The project cost for Asociación Proyecto Corales is around US$28 000 per year, including equipment, nursery materials, and transportation. This money is collected from volunteer donations, local businesses' material donations, and a citizen science monthly event in partnership with tour operators. INA has funded around US$12 547 (Perez Reyes, 2021), including the working hours of 3 INA staff members, equipment, and materials. The project is working in approximately 0.04 ha and aims to transplant 10 000 fragments with the help of the local community. Until February 2022, the project transplanted 600 fragments with a 64 % survival rate.

Golfo Dulce: One of four tropical fjords in the world (Quesada-Alpízar et al., 2006), Golfo Dulce (8.612352° N, - 83.291639° W) is in Puntarenas Province, between Golfito and Osa cantons (Fig. 1). Results from the demographic census made in 2011 estimate population between both Puerto Jimenez and Golfito would be 24 703 habitants in 2022

(INEC, 2011). Historically, the economy near Golfo Dulce was dictated by agriculture and gold mining. Nowadays, rice, livestock, tourism, commerce, artisanal, commercial, and sport fishing account for the most significant activities in the zone (Román & Angulo, 2013).

Golfo Dulce covers an area of 750 km^2. The gulf is surrounded by two National Parks, a forest reserve, and a Marine Area for Responsible Fishing (AMPR) (Fargier et al., 2014). Tidal forces, wind, freshwater entry into the system, upwelling subsurface water, and basin topography influence water mixing and circulation in the gulf (Morales-Ramírez, 2011). Coral reefs and communities found in the gulf can be divided into two main groups: the ones located in the inner section of the gulf and those from the outer area (Cortés, 1990). Most common species found were *Porites lobata, Pocillopora damicornis* and *Psammocora stellata*. The inner gulf has low coral diversity (1-8 %) and high topographic relief. Meanwhile, the outer gulf has a higher live coral coverage (29-46 %) and low topographic relief (Cortés & Jiménez, 2003).

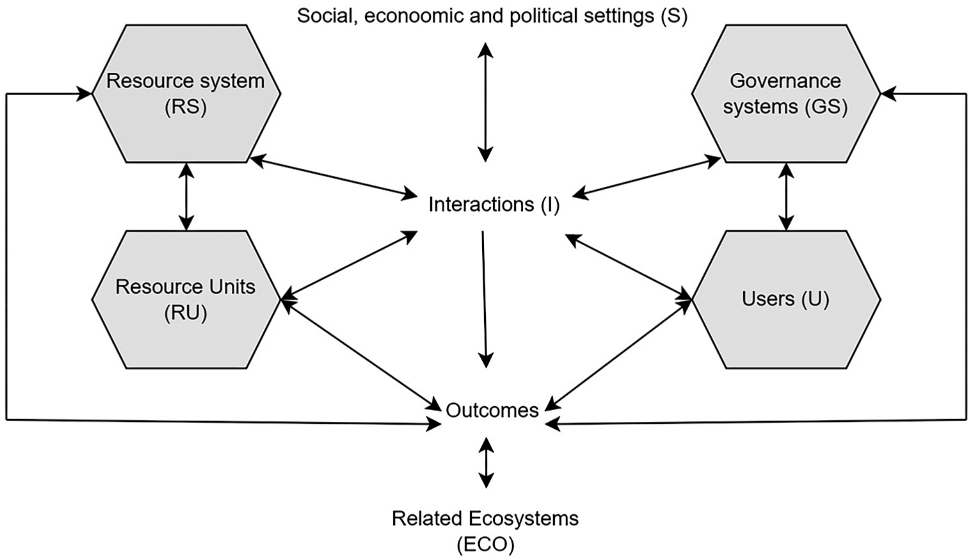
The restoration project started as a research initiative of two coral reef experts, with access to funding and technical knowledge for conducting the project. One of the coral reef experts was linked to the Costa Rica University (UCR) and the Centro de Investigación en Ciencias del Mar y Limnología (CIMAR), which facilitated access to local marine experts. The restoration initiative began in 2015 as part of a master's thesis (Villalobos-Cubero, 2019). In 2016, NGO Raising Coral Costa Rica (RCCR) was created in partnership with UCR, and in 2019 the NGO got its independent status. The cost of implementing the project for RCCR is around US$100 000, which includes day of work payment for volunteers, equipment, materials, and transportation. 84 % of funds come from international cooperation, 15 % from personal donations, and 1 % from citizen science events (RCCR, 2021).

RCCR intervenes approximately 0.5 ha in Golfo Dulce. Objectives are defined annually; for 2022, the goal is to transplant 2 000 corals. One thousand four hundred corals have been transplanted with a 90 % survival. RCCR has three major restoration sites in Playa Nicuesa, Mogos, and Sandalo. The NGO structure is vertical, with two project managers specializing in marine biology and coral reef restoration and seven local coral gardeners.

Method: This research follows a qualitative approach by comparing three case studies using the SESF as a diagnostic tool (Fig. 2) (McGinnis & Ostrom, 2014; Ostrom, 2007). The diagnostic process means asking a series of questions on a specific system and elaborating on more specific questions based on the responses provided by previous questions, allowing it to go from general to particular (Frey & Cox, 2015).

SESF facilitates the diagnosing task because it orders a set of variables that have been proven relevant for understanding resources' sustainable use (Ostrom, 2009). First-tier variables help design the general questions, and then second-tier variables can be chosen depending on the system's characteristics and the information provided through the data collection.

The case selection method used was most similar cases (Seawright & Gerring, 2008), which requires the identification of key variables of interest that should be similar across cases and variables that should vary meaningfully (Nielsen, 2016). For this study, similar variables are successful ecological outcomes with survival rates above 50 % (Harriot & Fisk, 1988), projects that have been sustained for more than 18 months, and similar ecological characteristics for being part of the ETP. This similarity, especially regarding ecological variables, allows us to focus on the impact of varying variables such as governance structure or being surrounded by touristic poles, land protected areas, or no special management zone may have on project success with the aim of understanding if governance structure is an influential variable for successful outcomes in coral reef restoration.



Related ecosystems (ECO) ECO1 Climate patterns ECO2 Pollution patterns ECO3 Flow into and out of local SES	**Governance systems (GS)** GS1 Government organizations GS2 Nongovernment organization GS3 Network structure GS4 Property rights systems GS5 Operational rules GS6 Collective-choice rules GS7 Constitutional rules GS8 Monitoring and sanctioning processes	**Resource systems (RS)** RS1 Sector RS2 Clarity of system boundaries RS3 Size of resource systems RS4 Human constructed facilities RS5 Productivity of systems RS6 Equilibrium properties RS7 Predictability of system dynamics RS8 Storage characteristics RS9 Locations
Social, economic and political settings (S) S1 Economic development S2 Demographic trends S3 Political stability S4 Government resource policies S5 Market incentives S6 Media organizations	**Users (U)** U1 Number of users U2 Socioeconomic attributes of users U3 History of use U4 Location U5 Leadership U6 Norms/social capital U7 Knowledge of SES U8 Importance of resource U9 Technology used	**Resource Units (RU)** RU1 Resource unit mobility RU2 Growth or replacement rate RU3 Interaction among resource units RU4 Economic value RU5 Number of units RU6 Distinctive markings RU7 Spatial & temporal distribution

Fig. 2. Social-Ecological Systems Framework including first and second-tier variables (taken from DeCaro & Stokes, 2013).

Data collection: Data was collected using semi-structured interviews and participant observation. Interviews followed a diagnostic procedure (Cox, 2011; Ostrom, 2007) consisting of broad semi-structured questionnaires designed for each actor group based on the SESF first and second-tier variables (Fig. 2) to ensure the information during cases would be comparable for the analysis. Using second-tier variables allows for identifying more specific details of the resource system management. Also, a literature review from similar studies helped identify relevant questions for designing the interview protocol. Questions were divided into 1) project data which included questions regarding motivation to start the project, goals, criteria for species and site selection, number of transplanted fragments, survival rate,

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Table 2
Semi-structured interviews were conducted during field research to identify relevant SESF variables for successful project outcomes.

Study area	Total interviews	Project Members/volunteers	Fisherman	Tour operators	Hotels	Community or govt. organizations
Samara	20	4	4	6	3	3
Bahía Culebra	11	1	1	6	1	2
Golfo Dulce	19	4	3	6	2	4
Total	**50**					

monitoring schedule, and actors involved. 2) Perception segment included questions on reef benefits, reef state, significant threats, time living in the community, knowledge about project existence, project benefits and limitations, and conflicts between reef users. 3) The technical knowledge, financial capacity, and social capital section included questions on the quantity of cleaning and monitoring activities performed per month, type of funding, key partners, how project information is shared with different stakeholders, the number of training sessions received and by who, how decision making is made, level of trust in different actors, participation in community organizations. 4) Regarding rules compliance, questions were directed to the application of the AMPR, touristic pole, or the lack of management and what benefits or challenges they identified from the type of management in each zone. Data regarding ecological systems and socioeconomic context was mainly obtained from management plans, monitoring reports, thesis, and published articles.

All primary data was collected between February 2022 to June 2022 through 50 semi-structured interviews in Spanish (Table 2). Following literature related to coral reef restoration projects (Frey and Berkes, 2014; Hein et al., 2017; Kittinger et al., 2016; Okubo & Onuma, 2015), individuals were chosen based on their proximity to sea-related activities and the information they could provide due to their role in the community or workplace.

Sampling was done according to the type of actor. For critical informants, who included project members and representatives of community and government institutions, purposive sampling was selected (Bernard, 2006; Maxwell, 2014). Information from interviews was triangulated with other data-collecting methods, such as field notes taken during field work. Data was collected until reaching saturation point (Bonde, 2013), which refers to the point where no new data appears, and concepts of the theory are well developed. This saturation point was determined during the field work. People outside the projects have little knowledge on coral reef and most information shared was similar thus no new or relevant data was acquired after four to five interviews. Most of the information regarding the projects is centralized in project managers. Due to the homogeneity and level of experience of the people interviewed, we reached the saturation point with 50 interviews.

Data was also collected through participant observation, mainly by participating in restoration activities, watching people interact with restoration sites, and living in each community for at least three weeks, providing the perception of the daily reality of each project. Bahía Culebra has a smaller sample than the other two sites due to the project's characteristic of being remotely located in a private complex and because its focus is not a community project. This may represent limitations to the study specially regarding the generalization of perceptions regarding reef and project benefits.

Data analysis: Data was analyzed by applying qualitative content analysis using MAXQDA software (VERBI Software, 2021). The analysis consisted of classifying data from interviews using systematic coding classification that allowed the identification of themes and patterns (Hsieh & Shannon, 2005). First, transcribed interviews were analyzed, and relevant data based on the research questions were highlighted. Afterward, deductive category application (Mayring, 2000) was used by applying SESF first and second-tier variables to determine coding schemes and the relationship between codes. Partelow´s (2018) definitions and indicators of SESF variables were used as a codebook. Data that could not be coded using SESF first and second-tier variables were highlighted and labeled either as a new category or subcategory. In the case of perception-related questions, codes are derived directly from data. Data was triangulated by gathering information from different sources to validate their context (Creswell, 2014). Data was segmented by cases, involving constant comparative techniques (Strauss & Corbin, 1990). Once all data was coded, a list of the frequency of codes was developed. The text was analyzed to identify their positive or negative impact on projects' ecological outcome of more salient variables. Information regarding positive or negative impact was crosschecked with previous studies of collective action theory (Olson, 1965; Ostrom, 2009; Poteete & Ostrom, 2014) and coral reef restoration research (Cinner et al., 2016; Frey & Berkes, 2014; Kittinger et al., 2012; Kittinger et al., 2016; Okubo & Onuma, 2015; Yeemin et al., 2006). Afterwards, comparison tables were developed depicting how each variable was present in each case.

RESULTS

Results show that despite peculiarities to each case, they follow similar routes for success. Three main factors were present in all cases: (1) Role of positive perception of benefits from coral reefs and restoration projects; (2) Role of network structures to achieve adequate human and financial resources; and (3) Role of compliance with regulatory frameworks.

The coding process with variables shown in Fig. 2 displays that these three main factors were possible due to the interaction of the following SESF variables: network structures (GS3), constitutional choice rules (GS7), leadership/entrepreneurship (U5), norms, trusts, social capital (U6), investment activities (I5), knowledge of SES (U7), information sharing (I2), operational choice rules (GS5), monitoring activities (I9), location (RS8), economic value (RU4), the importance of resource dependence (U8), predictability of system dynamics (RS6), distinctive characteristics (RU6), history or past experiences (U3), (S5) markets (Fig. 6). Variables were chosen due to the frequency of

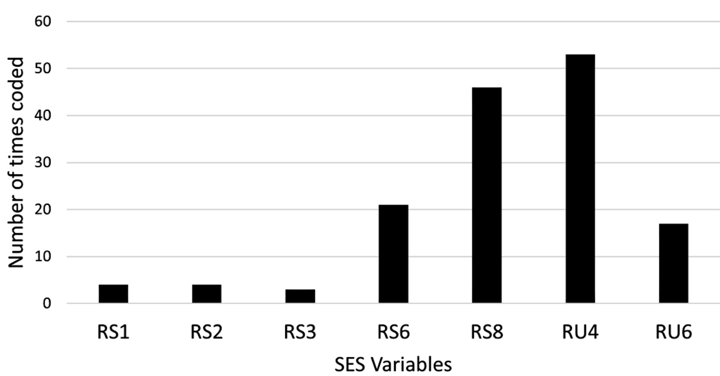

Fig. 3. Graph representing the frequency of codes related to Resource System and Resource Units set of second-tier variables identified during the analysis of the interviews.

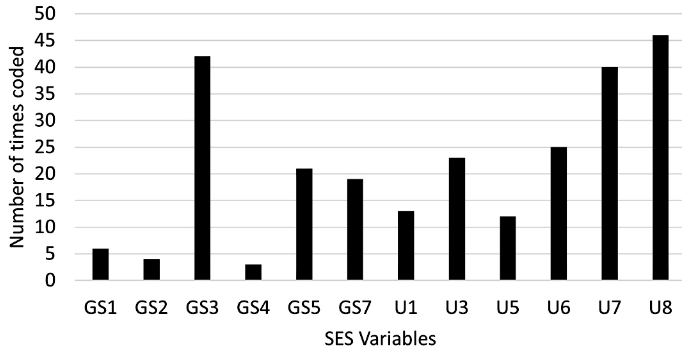

Fig. 4. Graph representing the frequency of codes related to the Governance system and Actors set of second-tier variables that were identified during the analysis of interviews.

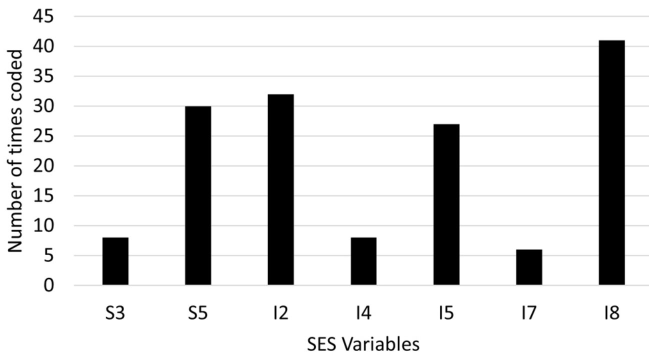

Fig. 5. Graph representing the frequency of codes related to Social, Political, and Economic Settings and Interactions set of second-tier variables identified during the analysis of the interviews.

their appearance as relevant factors during the coding process, as shown in Fig. 3, Fig. 4, and Fig. 5, and their relationship with collective action and coral restoration literature.

Role of positive perception of benefits from coral reefs and restoration projects: During the interviews, people were asked to mention up to three benefits they perceived from coral reefs and restoration projects. Results regarding the perception of benefits from these two elements show that in all three study cases (Fig. 7, Fig. 8), people positively perceive coral reefs as home to marine biodiversity, justifying that without corals, there would be no fish, lobsters, or turtles in the zone. The second, most important benefit identified was tourism attraction, which seems to relate to the first option because the perception is that people are attracted to coral reefs due to the number of animals they can see, as expressed by a key informant in Golfo Dulce and a tour operator in Bahia Culebra.

Golfo Dulce Key Informant 1: *"They are the marine ecosystem engineers; where there are coral reefs, we see life and food."*

Bahía Culebra Tour Operator 3: *"it´s a huge touristic attraction, locals like it, and foreigners come from all over the world to dive here, and that is really good for us; more corals, the better."*

There is a difference between results from Sámara and Golfo Dulce compared to Bahía Culebra mainly because fewer people were interviewed in this zone than in the other two

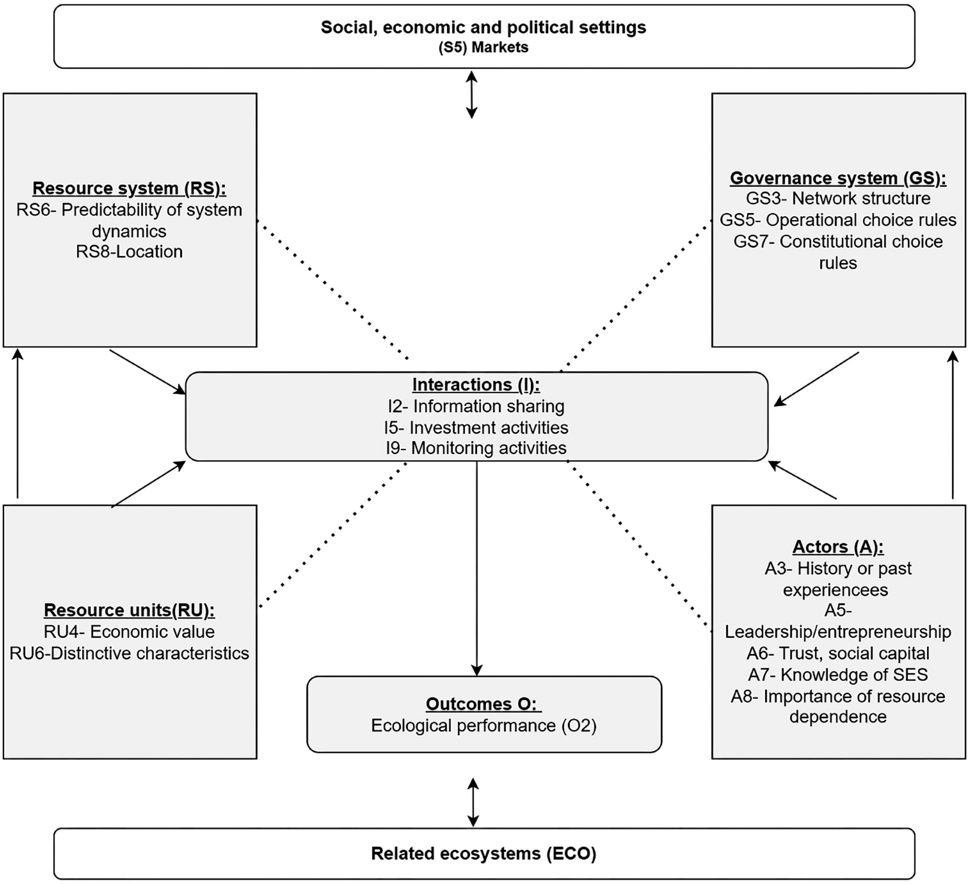

Fig. 6. Adaptation of the SESF diagram showing how the salient variables interact to produce a positive perception of benefits, obtain adequate financial and human resources, and achieve enabling environment for coral reef restoration.

due to less community involvement. Also, the perception of most interviewees was that Papagayo gulf did not have many coral reefs.

Results from reef benefits are aligned with those perceived as project benefits. When asked about project benefits, restoring marine biodiversity was the most mentioned. A volunteer from RCCR expressed how changes are becoming noticeable in a short period. ***Golfo Dulce Volunteer 1:*** *"The change in a variety of fish, seahorses, and lobsters that we now see is big. In places where everything was dead before, after 4 or 5 months, we start to see a change."*

Income generation was the second most mentioned benefit. Again, it is perceived directly and indirectly, as explained by a key informant from Sámara. ***Sámara Key Informant 2****: "We are seeing jobs being created just to receive this type of tourism; people now come to the city and have one more tourist activity to do, so hotels, restaurants, tour operators, and everyone benefits from it*.

This positive perception motivated people to support project activities. However, there is a difference in motives to participate in the project between the groups interviewed, which is caused by the type of economic activity performed by the individual. People related to touristic activities were more willing to contribute to the project since they perceived short-term benefits from their contribution due

Revista de Biología Tropical, ISSN: 2215-2075 Vol. 71 (S1): e54853, abril 2023 (Publicado Abr. 30, 2023)

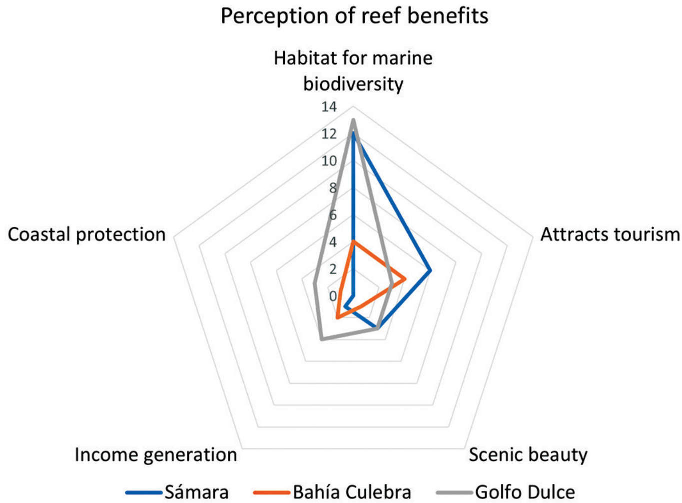

Fig. 7. Results from interviews regarding reef benefit perception in Sámara, Golfo Dulce, and Bahía Culebra.

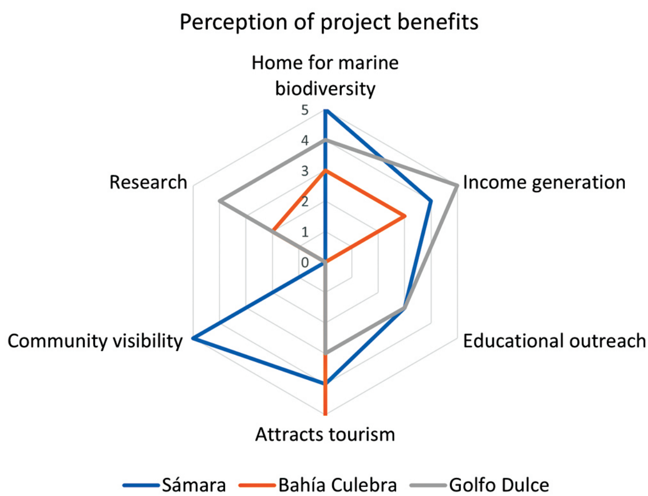

Fig. 8. Results from interviews regarding project benefit perception in Sámara, Golfo Dulce, and Bahía Culebra.

to the possibility of generating income from the project as a touristic attraction, which gave them a higher *economic value* perception. On the other side, fishers who perceived benefits related to the increase of marine biodiversity see it as a long-term benefit that did not cause a significant motivation to participate in restoration activities, as expressed by a fisher from Golfo Dulce. ***Golfo Dulce Fisher 1:*** *"I know the project will benefit because more corals mean more fish, but the problem is the change takes time. It could be months or years until we see the number of fish we used to have, and I need money and food to take back home. I can´t just take a day off work. I live from what I earn every day, and, in the sea, we never know if it´s going to be a good day but not going to fish is not an option."*

Projects have also conducted educational awareness campaigns to reach locals and tourists about the importance of reefs, causing an impact on the perception of corals and project benefits. Most of these educational outreach activities target youth from schools and social media. *The location* also influences perception, and collective action in three ways: (1) Projects were in sites of easy access to communities, as in the case of Sámara, or in the area of influence of local businesses, as in the case of the hotels in Golfo Dulce and the private developer in Bahía Culebra, it was easier for people to perceive benefits and stewardship was increased. (2) Accessibility to restoration sites also reduces transaction costs related to transportation. (3) All three projects were in zones with no previous conflict between reef users.

In the case of Sámara, in the beginning, the project faced sabotage from local fishers because of a lack of communication of project objectives and benefits from the project to the local community. Fishers feared the project would take their fishing rights in the area. The problem was solved with meetings to inform about project goals, how it would benefit fishers regarding the provision services of reefs, and by defining in conjunction restoration site in which the project would not be affected, and fishers could continue with their activities. A fisher, a member of the Samara fisher association, gave an example. ***Sámara Fisher 2:*** *"They focus mainly on tourism, which is fine, but they should not leave out the fishers. For example, where they wanted to make the nurseries was a place on the fishing route. So, I told them no, you could not put it there because you will affect us; you must use common sense. They probably would have set up the project there if they had not invited me to the meeting, which could have caused conflicts. We know it is a good project, but it must be good to everyone, not just a few."*

Interviews with project volunteers in Sámara and Golfo Dulce showed that the duration of living in the community is essential for increasing collective action. People who lived in the community where restoration took place and knew how coral reefs changed through time were more willing to contribute. When asked about what will motivate them to participate in the project, we saw that people with a negative perception of the reef state due to local threats, such as sewage water or sedimentation (Fig. 9), were more willing to participate than those that had a common perception and perceived global threats, such as climate change because they saw their actions could not stop the original problem. This difference in perception of the reef state and threats was one of the most significant contrasts between local actors interviewed in Sámara and Golfo Dulce, projects with greater community participation. For instance, a member of the local water organization in Sámara told us about how teak plantations damaged corals and the actions they have been conducting to reduce this type of threat. ***Sámara Organization 2:*** *"I have lived in Sámara all my life, and I saw how we have been losing our reefs, especially 30 years ago when the teak plantations started. We are doing our best to restore the riparian buffer and help give better conditions for corals to survive. I also participate in the project because it´s important for our community."*

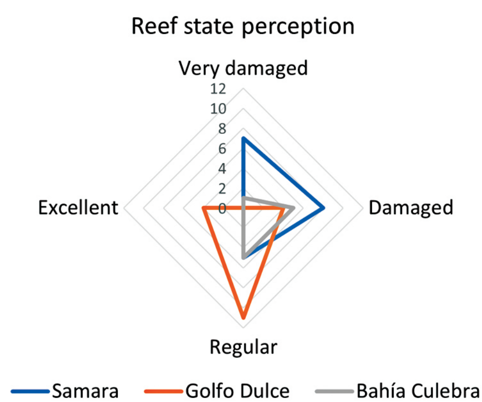

Fig. 9. Results from interviews regarding reef state perception.

In Sámara, reefs are mostly perceived as very damaged (Fig. 9). People interviewed in Golfo Dulce considered reef stats primarily regular. In Bahía Culebra, perceptions were

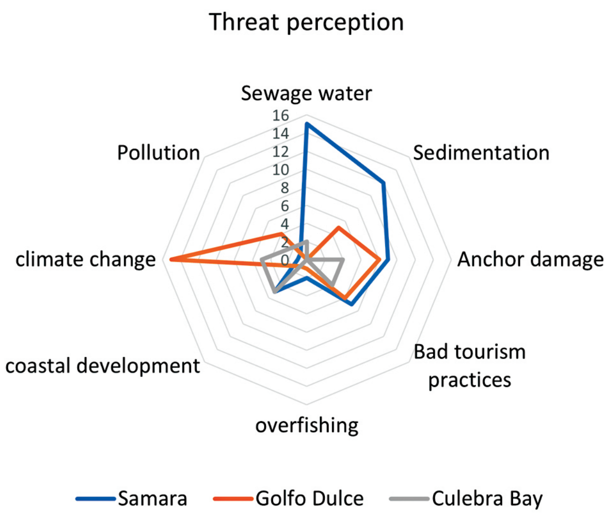

Fig. 10. Results from interviews regarding the perception of significant threats to coral reefs.

divided between regular and damaged. However, in Bahía Culebra, when we asked about the coral reefs' state or benefits, most people said the zone doesn't have coral reefs or just some small patches. They did not seem to recognize them as an essential ecosystem in the area.

In the case of Golfo Dulce, the primary threat perceived is climate change (Fig. 10), as explained by this tour operator ***Golfo Dulce Tour Operator 3****: "It´s difficult because Golfo Dulce is very protected, and we can see coral reefs are in a good state. We have events such as El Niño and red tides that affect them, but there is nothing we can do; that´s nature and climate change. I don´t participate directly in project activities, but I help corals by keeping tourists from damaging them during our tours."*

Role of network structures to achieve adequate human and financial resources: Project members were asked about limitations they perceived from restoration projects; project funding and access to a workforce with diving skills were among the most mentioned. Estimations done by RCCR show that certifying someone in diving and coral gardening costs US$1 200. To balance costs and scale up their actions, all three projects relied on partnerships between local and external actors to obtain adequate human and financial resources. These partnerships were possible due to two main factors; first, positive perception of *economic value* from local businesses such as tour operators, private developers, and hotels that motivated them to participate in restoration activities. Second, *trust and social capital* were built through previous social and institutional interactions, allowing organizations to have a good reputation between the community and their partners. For example, in Asociación Proyecto Corales, most active project members have participated in other community organizations, such as the local development organization, which has allowed them to individually create a good reputation in the community that has an impact on the association. Península Papagayo performs social outreach activities focused on education and employment for the community, allowing a rapprochement between the community and the project. In the case of Golfo Dulce, RCCR has focused on educational outreach activities and providing jobs to locals.

Also, external actors, such as CIMAR and INA, were also relevant in the three cases to obtain technical knowledge and access adequate human resources. These external actors were trusted due to their historical presence as community public education service providers.

Technical knowledge transferred from external actors to local actors has allowed the building of local capacities, which has helped increase the number of volunteers as coral gardeners. Coral gardeners work differently depending on each project. For example, in Sámara, coral gardeners do not receive payments; in Golfo Dulce, they receive a US$35 per day of work retribution; in Bahía Culebra, gardeners are composed of CIMAR and Peninsula Papagayo staff. To reduce costs and still access the skilled workforce, projects have implemented volunteer programs in which people pay and access equipment, training, or supervision from project members. People participating in these volunteer programs are either members of the diver community in Costa Rica or tourists. Costa Rica's reputation of being an ecotourist destination with well-known diving spots (Valverde-Sanchez, 2018) is an advantage projects have when implementing these types of volunteer programs. These programs have been strengthened through *information sharing*, especially on social media. Social media has also been used to report on project results and crowdfunding. Information sharing has been possible due to network structures enabling trust ties to exchange information. For example, science-related actors and local businesses at a group level have shared technical and community knowledge to design projects adapted to the context of each place. At the individual level, we have a network of divers and tour operators that allow volunteer coral gardening activities. Trust at group and individual levels has been maintained due to the shared motivation of restoring marine biodiversity.

External actors have contributed to backing restoration efforts with science. This helped establish *operational choice rules* regarding the site, species selection, and monitoring activities, contributing to more efficient projects. For example, scientific knowledge transferred by external actors allowed them to know about season and weather variability, *giving predictability of system dynamics* to determine rules for restoration sites and activities such as choosing nursery sites without the presence of coralivorous fish, sandy bottom, good water quality, presence of live coral coverage, selecting species that have had a presence in or near the restoration site, choosing structures that fit in *distinctive characteristics* of each species cleaning restoration sites at least twice a month, and monitor changes in fish biomass.

Most of the scientific knowledge external actors have comes from official guides established by international coral reef organizations based on international reef restoration experiences. Also, projects had two and half year's experimental phase, where tests regarding the correct type of species with specific structures were made. In the case of Bahía Culebra, knowledge of how to start the project was transferred from RCCR through a partnership.

Role of compliance with regulatory frameworks: Costa Rica banned trawling fishing in 2013 (Sentence No. 2013–10540, 2013). Project members and fishers identified this fishing method as one of the most extensive threats corals had and perceived that the prohibition helped improve the environment for coral reefs. In general, interviewees highlighted compliance with this legal framework and a positive perception of its effects on marine biodiversity. ***Sámara Fisher 1:*** *"I have been living here for more than 40 years, and I remember when I was a kid, my father would capture many fishes, and with time, the quantity of fish decreased. Trawlers were the worst thing that happened to the seas; they destroyed everything. Now we see a change, but still, more time is needed to see a difference. We as fishers, must fight for the sea, the government wanted to allow trawlers again, and we fought against it because we know how bad it is."*

In 2019, MINAE, through decree N° 41774, established the promotion of restoration and conservation initiatives for recovering coral reef ecosystems. This decree is the first regulatory framework in Costa Rica to address coral reef restoration projects by stipulating the creation of a multilevel governance structure to facilitate cooperation for restoration initiatives and creating an official restoration protocol

(Sistema Nacional de Areas de Conservación, Sociedad Alemana de Cooperación Internacional [SINAC-GIZ], 2020). This protocol gives the guidelines for submitting a restoration project, including the rules that a biologist or natural resources manager must lead each project proposal. In addition, projects must last a minimum of two years to guarantee at least one year of monitoring. Finally, research departments approve restoration proposals from the Conservation Area where the project belongs. Key informants from Sámara and Golfo Dulce shared insights into how they have contributed and benefited from this legal framework:

Golfo Dulce Key Informant 1: *"Due to our experience in coral restoration, the governmental conservation institution ordered us the design the official coral restoration protocol for Costa Rica. There we stated biological differences between the Pacific and Atlantic coast corals, specified rules for starting a project, and how to monitor them."*

Sámara Key Informant 1: *"I am in charge of assisting with the Coral Council meetings. When the project started, we received technical assistance through this committee."*

As seen before, water quality is an essential element for effective coral reef restoration. Our study shows the relationship between regulatory framework aiming to reduce deforestation and positive water quality. Golfo Dulce is surrounded by National Parks, Forest Reserve, and an AMPR and is the only place to achieve natural regeneration rates in coral reefs. Fournier et al. (2019) evaluated anthropogenic impacts from plantations near the Coto Colorado river, which covers 95 % of the agricultural area and drains into the gulf. Their results show the importance of the 2100 ha of mangrove to cushion the impact of land-based pollution. Another study by Cortés (1990) demonstrates that corals have natural regeneration rates; for example, at Punta Nicuesa, Cortés (1990) reported a 45.9 % increase in live coral cover in 1985/1988. Alvarado et al. (2015) report an 83.4 % live coral cover for the same zone. The project Manager from RCCR also says their monitoring shows natural regeneration rates and greater resistance to stress events such as changing water temperatures.

Golfo Dulce Key Informant 2: *"There is not much being done by the government to protect the oceans; it´s still something new, but we can´t deny national parks have helped reduce deforestation and provide a good environment for corals."*

In Bahía Culebra, the legal document establishing rules in the Touristic Pole is the Management Plan approved in 1995 by the ICT board, which includes regulations on the conservation of protected areas, reduction and control of possible pollution sources, wastewater, and solids recycling, among others. An employee from one of the hotels in the PTGP highlighted compliance with the management plan.

Bahía Culebra Hotel 1: *"Our business complies with requirements to operate in the touristic pole. We treat 100 % of the water we use, and none is thrown to the sea; we reuse it to water our golf camps."*

DISCUSSION

To our knowledge, this is the first study to use the SESF applied to coral reef restoration projects. SESF proved relevant to studies that aim to explain how sustainable outcomes are achieved because it connects real issues related to the system of interest to the decision-making process at multiple levels. Our results show that even though projects have differences in governance structures, they have followed similar paths for achieving successful outcomes. This path must include three critical enabling conditions for achieving successful restoration: (1) Positive perception of benefits both from coral reefs and projects to achieve collective action; (2) Network structures to get adequate financial and human resources; (3) The importance of compliance with an existing regulatory framework to create enabling environments for projects development and coral reef ecology.

Perceptions can be used as evidence for assessing environmental outcomes to understand stakeholders´ conception of social and ecological outcomes of a specific initiative and the social acceptability of conservation or restoration governance (Bennett, 2016). Our study found that positive perceptions of coral ecosystem services and project benefits influenced collective action to restore the coral reef. In the three projects, we found a positive perception of both coral and project benefits related to resource dependence, the high economic value of reefs, duration of living in the community, knowledge of the human agency, project location, and information sharing. Studies made in México and Indonesia about perceptions of coral reefs and restoration projects show wealth (Cinner & Pollnac, 2004) and local leadership involvement, degree of interaction with the project, and overall project results (Trialfhianty & Suadi, 2017) also influence perceptions.

Depending on the group of reef users being studied, the resource's type, use, and governance vary (Palomo & Hernández-Flores, 2019). Tour operators and fishers in the three cases seemed to positively perceive coral reefs and project benefits. However, the willingness to participate in the project was greater among tourism-related actors than among fishers. The main difference is that fishers' positive perception is related to increasing fish biomass which is a long-term benefit that doesn't seem to compensate for using their time to contribute to the project because of economic reasons. Cinner & Pollnac (2004) used Maslow's hierarchy of needs to show the relation between wealth and involvement in environmental activities in a coastal community in Mexico. Wealthier residents were able to meet basic needs and have more economic security for contributing to environmental conservation, which is related to a fulfilling sense of belonging. In our research, tourists-related actors were more willing to participate because they perceived the short-term benefits of restoring coral reefs. Diedrich (2007) found similar results with a positive correlation between tourism and coral reef conservation awareness in Belize.

Analyzing the type of governance structures and motivations to start a restoration project matters because it affects project design, stakeholder participation, monitoring, and long-term ecological integrity. Even though the three cases have different governance structures, they all share similarities of being projects with a biotic rationale, which means their main goal is to recover lost aspects of local diversity (Clewell & Aronson, 2006). These types of inspiration seem to be a tendency in the region, as shown by Bayraktarov et al. (2020) review of coral reef restoration projects in Latin America, where 42 % of projects have biotic motives, followed by an 8 % with idealistic and pragmatic reasons.

Reviews of projects implemented in the Caribbean, Western Atlantic, and Indonesia highlight the importance of partnerships for having adequate scientific, logistical, technical, institutional, and interpersonal skills (Johnson et al., 2011; Lamont et al., 2022). In the case of Latin America, Bayraktarov et al. (2020) showed that NGOs and foundations are the most common type of project leaders. They establish partnerships with universities, conservation management bodies and regulators, local associations, national and international business partners, international environmental NGOs, tourist operators, private donations, international grant schemes, and local community groups. These partnerships are established mainly to fill funding gaps and provide a skilled workforce. Goreau & Hilbertz (2008) highlight that NGOs or foundations financed by international cooperation grants are the most common governance structure for reef restoration projects. Hesley et al. (2017) and Lirman & Schopmeyer (2016) identified the dependence on grants as the main cause of long-term failure of coral restoration led by NGOs because these funds usually last between 1-3 years. In that perspective, the fact that RCCR primary mission is working with coral restoration helps to focus all resources on this work, unlike the other case studies where organizations leading do not deal exclusively with coral reef restoration or depend totally on volunteer work. However, if we evaluate long-term performance, RCCR may have a more significant challenge in maintaining stability than the other two cases because their central workforce depends on the payment workers receive. They will also have to reduce critical activities such as continuous monitoring if they fail to diversify funds other than grants.

Besides motivation, the three study cases share the involvement and funding of activities from the public sector through external actors such as the local university or technical learning government institution. These external actors have enabled science efforts backing restoration activities, which has allowed projects to have experimental phases to determine what species and structures work best for the specific ecological conditions in the zone and provide continuous monitoring. This testing phase is present in the three cases. It has allowed the projects to use small-scale pilot projects to demonstrate success and build relationships with key stakeholders to contribute to scaling up. A review of restoration projects in Thailand recommends pilot projects as a good management practice for successful restoration (Yeemin et al., 2006). Nonetheless, it is not the case in many projects, as shown by the Boström-Einarsson et al. (2020) review, where 60 % of projects out of 362 lack standardized monitoring, with the median of projects performing less than 18 months of monitoring. Also, external actors have had an essential role in building local capacities through the implementation of workshops on coral gardening and providing educational benefits to local communities (Bottema & Bush, 2012; Hein et al., 2019; Okubo & Onuma, 2015).

However, external science-related actors alone could not perform all the work. Transferring knowledge is essential to success because it builds local capacities, increasing local stewardship (Hein et al., 2019). It´s the case in Sámara, where the project is being co-managed by community and government institutions. The local organization makes decisions regarding cleaning or fundraising activities; meanwhile, the public sector institutions support technical decisions and monitoring. We found that past experiences, trust, social capital, and benefit perception influence community involvement. These variables depend on who is leading the project and the history of the restoration site. Sámara is being led by locals who participate in other community organizations, allowing trust and social capital to be developed (Pretty, 2003). Similar results regarding the importance of social capital and trusted leaders have been found in projects evaluated in Indonesia by Frey & Berkes (2014) and Partelow & Nelson (2020). In the case of the local community interviewed in Bahía Culebra, they were less likely to participate in the restoration project because: (1) They perceived Península Papagayo as a powerful actor that already had all the resources needed to conduct the project, (2) It´s their responsibility to compensate for the damage caused by the building of the touristic pole, and (3) Locals feel excluded from possible benefits that could be obtained from the project due to difficulty accessing restoration sites.

Bottema & Bush (2012) analyzed private restoration initiatives conducted in Indonesia and found similar challenges in getting acceptance and participation from locals. They recommend state support for private initiatives to create lasting institutional arrangements. In Golfo Dulce, the project started as a research initiative, and project managers are not locals, affecting community participation. Also, past experiences of exclusion in the decision-making process of land and marine regulations (National Parks and AMPR) (Fargier et al., 2014) have left local groups, such as fishers associations, suspicious that more conservation activities will affect their property rights. RCCR has been working since 2019 to address the lack of information about the project goal and increase community involvement through local workshops and educational outreach activities with schools. Strengthening local communities' governance, such as property rights, seems to have an impact on coral reef conservation (Cinner et al., 2016)

The private sector, through tourism-related businesses, has also been critical for funding and scaling up restoration activities. Meyers (2017) highlights the positive use of tourism to get a skilled workforce and funding for restoration. However, well-planned commercial projects may positively impact coral reef restoration (Westoby et al., 2020). Okubo and Onuma (2015) research on Okinawa commercial projects presents three significant problems derived from profit-driven projects. The first has to do with the use of fragments from natural coral colonies that are already deteriorated and the effect it may have on natural processes corals are having. Second is the need for genetic or species diversity to be used. For example, projects tend to use *Acropora*, which has a commercial interest because of its beauty and faster growth rates. The third increase in market restoration activities could cause scarcity of donor fragments, increasing costs of restoration, which could increase poaching and thus lead to even more deterioration. The level of involvement of the private sector varies in each case for our study. For example, in Bahía Culebra, there is an agreement to co-manage the project between the local university and private developer, and responsibilities between both sides are established under a written agreement. In Sámara, we identified private touristic-related owners participating from the local community organization and donating equipment, hotel rooms, and their time as volunteers. Also, Sámara partnered with a local tour operator for the citizen science event. Finally, in the case of Golfo Dulce, private support comes mainly from "house reefs" (Liburd & Becken, 2007). In the three cases, decision-making is not profit-driven; instead, decisions are managed by science-related actors to improve ecological integrity by using lessons learned from other projects' best practices in scientific or grey literature and through experimental phases.

Private partnerships are mainly used to establish volunteer programs through citizen science. Volunteer programs help projects obtain funding and a skilled workforce, which is more difficult for reef restoration than shore-based activities such as mangrove restoration because diving or boating skills are less common (Hesley et al., 2017). The main difference in volunteer programs between projects is that funding from the private sector in Bahía Culebra covers most of the expenses from volunteers compared to the other two, which allows for a more constant list of volunteers for Bahía Culebra.

Results from our study highlight the importance of compliance with regulatory frameworks to reduce coral causes of degradation. All official restoration guides state that effective restoration must first control the causes of degradation (Goergen et al., 2020; Quigley et al., 2022; Shaver et al., 2020). Coral reef restoration should complement other conservation strategies, such as sustainable fishing practices and marine spatial planning (Lirman & Schopmeyer, 2016). Good water quality is critical for choosing restoration sites (Goergen et al., 2020; Shaver et al., 2020). In Golfo Dulce, good water quality is possible due to the protection of forests surrounding the gulf through the declaration of national parks and forest reserves. The existence of mangrove forests in the zone (Fournier et al., 2019) goes up to 2 100 ha. A study in the Caribbean supports incorporating habitat diversity, including mangroves and seagrass meadows, to reduce threats to coral reefs (Mumby et al., 2004). In the case of Sámara, almost all the mangrove forest has been deforested, so sedimentation from teak plantations in the mountains directly affects coral reefs. Besides that, sewage water is not being treated, thus affecting water quality.

Sánchez-Noguera et al. (2018) present a study from 2010-2011 on water quality in Bahía Culebra. Using the geometric average of FC/100ml, Bahía Culebra obtained < 1.8, corresponding to excellent water quality classification. The study concludes that Bahía Culebra has a high degree of sanitary quality in its coastal waters, which has been constant over time. In Bahía Culebra, the regulatory frameworks contributing to water quality come from the Touristic Pole Management

Plan, which determines wastewater and solids recycling rules. However, the study highlights the importance of monitoring and access to information regarding compliance with the Management Plan.

There is a global gap in environmental policies for coral reef restoration projects (Westoby et al., 2020). Nevertheless, regulatory frameworks play a crucial role in translating scientific knowledge into basic restoration standards, mobilizing financial resources, and enabling environments for cooperation. For example, coral reef restoration legislation in Costa Rica is still in the initial phase but has effectively facilitated best practices and knowledge to restoration stakeholders.

Regarding long-term sustainability challenges, we identified global ones, such as changes in the predictability of system dynamics due to climate change, which could affect survival rates. For projects to be prepared for these challenges, technology like underwater temperature sensors and constant in-field monitoring is necessary to understand how corals react to stress events and what species or fragments are more resilient so they can be used as donors. National challenges include narrowing university or technical learning government institutions' funding, which could broadly compromise the ecological monitoring of the restoration programs, especially in Bahía Culebra and Sámara. Projects must communicate their results in social and economic terms for high-level decision-makers to understand the importance of funding this activity. Relevant metrics could include the number of jobs created or the revenue gathered through tourism or restoration activities.

Finally, at the local level, we found the challenge of reducing local causes of degradation, which requires interinstitutional coordination between the community, private sector, and government through marine spatial planning. Other challenges are more context- or governance-dependent; for example, science or NGO-led initiatives typically guarantee ecological integrity but fail to create local stewardship. For community and NGO-led initiatives, it's important to diversify their funding. For all three projects, monitoring and researching which techniques or species are working better for their specific environmental conditions and the importance of sharing these results with the entire restoration community are essential. Also, for scientific purposes, the country should standardize the results reporting (Goergen et al., 2020; Shaver et al., 2020), contributing to making projects more comparable and knowledge regarding the best techniques or structures for growing corals or species resilience to stress events would be available for the reef restoration community to learn of. The three projects evaluated in this study have differences in the number of corals transplanted, and the coral genus used that can influence the overall survival rate. That is why we included other aspects, such as project durability and local involvement, to determine project success and not focus only on ecological outcomes but overall project performance. Also, all three projects continue to be implemented and thus are evolving continuously to solve the different challenges faced. The results shown here are statical; they reflect a specific period of each project. Coral reef restoration initiatives are still recent in Costa Rica; findings from this study contribute to providing insights for future restoration project design and implementation strategies that can reduce transaction costs hence making projects more cost-effective and appealing to a more significant number of stakeholders, especially during these times when the United Nations declared the Decade on Ecosystem Restoration (2020-2030) (Fischer et al., 2021).

Ethical statement: the authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgements section. A signed document has been filed in the journal archives.

ACKNOWLEDGMENTS

The authors are grateful to the communities and project members from Asociación Proyecto Corales Sámara, Raising Corals Costa Rica and Culebra Reef gardens that shared their time and knowledge with us. Furthermore, the present research would not have been possible without the funding of the German Academic Exchange Service (DAAD) and support from the Tropical Agricultural Research and Higher Education Center (CATIE) and the Leibniz Center for Marine Tropical Ecology (ZMT).

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