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Sensing a Changing Tide: Community-Based Monitoring and Collaborative Governance in Mexico's Small-Scale Fisheries

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Abstract

This article examines how small-scale fishing cooperatives on Mexico's northern Pacific coast integrate technologies into community-based marine governance. Drawing on ethnographic research with cooperatives in Baja California Sur, it asks how oceanographic sensors are used, adapted, and made meaningful in citizen science and co-constructed governance practices, and what that reveals about empowerment and blue justice in coastal communities. Sensors enable cooperative members, particularly the cooperatives' technical experts, to assess oceanographic conditions, better understand phenomena like harmful algal blooms and hypoxia, and make collective decisions about fishing practices and management of fishing areas. These technologies do not operate in isolation but complement existing community monitoring systems and embodied knowledge of the ocean, supporting deliberation that draws on plural forms of knowledge. We also describe the challenges, material and less tangible, that the cooperatives encounter, from lost equipment to the limits of translating local data into regulatory influence. Considering these developments through citizen science and blue justice, the article shows how co-constructed monitoring infrastructures supported by scientists and civil society organizations open new avenues for community epistemic agency, support locally led knowledge production and adaptive management, and unsettle persistent inequalities in whose knowledge counts. It therefore contributes to debates on participatory environmental governance in small-scale fisheries and its limits in uneven ocean governance regimes.

Keywords

blue justice; citizen science; cooperatives; environmental monitoring; marine governance; Mexico; small-scale fisheries

1. Introduction

Across the world, coastal communities are being confronted with new constellations of environmental pressure, regulations, and conservation initiatives that promise sustainability yet often reproduce inequalities in access to marine resources, decision-making, and knowledge (Berkes & Franz, 2025; Ojea et al., 2020). In this context, blue justice has emerged as a framework for interrogating who benefits and who bears the costs of social, ecological, and governance transformations, and whose knowledge, livelihoods, and political projects are recognized or marginalized (Bennett et al., 2021; Blythe et al., 2023). Small-scale fisheries (SSFs) in Mexico illustrate these tensions sharply. They are crucial to food security, local economies, and marine conservation, yet operate in a landscape marked by climate change, regulatory shifts, and uneven implementation of conservation policies.

On the Pacific coast of the Baja California Peninsula, fishers organized in cooperatives have long practiced forms of co-management and self-governance, developing local institutions and monitoring practices to steward key species such as abalone and lobster (Basurto et al., 2012; Cota-Nieto et al., 2018). The fishers are increasingly integrating different technological devices into their practices, which aid them in navigation, measuring water quality parameters such as temperature, PH, and oxygen levels, identifying and tracking marine life, and monitoring catches. This article explores how SSFs on the Peninsula's Pacific coast use new technologies to make sense of the changing conditions in their fishing areas and employ new forms of knowledge into environmental decision-making with different actors. It focuses on a citizen science project that promoted the use of sensors by fishing cooperatives, supported by marine scientists from academic institutes and a civil society organization (CSO), to measure, collect, analyze, and use water quality data in their fishing areas.

This article asks how the sensors are used, adapted, and made meaningful in everyday governance practices in Baja California Sur, and what it reveals about empowerment and blue justice in ocean communities. We trace how cooperative members manage technologies, practices, and information to make sense of the conditions in their fishing areas; how cooperative technicians act as intermediary agents between sensor data and the knowledge and priorities of members and leaders; and how sensors are contributing to new decision-making processes and adaptive strategies. The analysis draws on science and technology studies (STS) and environmental anthropology and contributes to debates on the role of citizen science in environmental governance and the co-production of knowledge and power in marine socioecologies.

The article reveals how technologies form part of shifting processes of collaborative marine governance, where co-constructed monitoring infrastructures supported by scientists and CSOs enable communities to navigate environmental change while advancing locally-led knowledge production, adaptive management strategies, and new practices.

2. Context of SSFs and Collaborative Governance in Baja California Sur

2.1. Socioecological Importance of SSFs

SSFs in Mexico are critically important for supporting food security, livelihoods, and socioecological systems (Espinosa-Romero et al., 2014). They account for an estimated 40% of total catch of local species and employ

320,000 fishers directly alongside administrative, processing, and/or surveying roles (Comisión Nacional de Acuacultura y Pesca [CONAPESCA], 2024). Most people involved in SSFs live in rural coastal communities with their way of life and livelihood deeply entangled with the ocean and its condition (Salgueiro-Otero et al., 2022). As conditions in the Pacific Ocean place increasing pressure on marine organisms and coastal communities, SSFs face rising socioenvironmental vulnerability, making adaptation central to the sustainability of the fishery system, the socioeconomic wellbeing of the communities, and the resilience of the marine-coastal ecosystems they are part of (Espinoza-Tenorio et al., 2022; Micheli et al., 2024). SSFs are well-placed to address these challenges, and those in Baja California Sur have unique qualities that make them well-equipped to do so.

2.2. Cooperative Organization and Co-Management

The SSFs described in this article are situated along the Pacific coast of the Baja California Peninsula, in the states of Baja California Sur (Punta Abreojos, La Bocana, Bahía Asunción, Bahía Tortugas, Natividad Island) and Baja California (Cedros Island), in an area that falls within the El Vizcaíno Biosphere Reserve (Figure 1). The SSFs in this area catch a great variety of fish, crustaceans, and mollusks, but green and pink abalone and spiny lobster are the most economically significant (Cota-Nieto et al., 2018). The SSFs are organized into fishing cooperatives, which have been foundational to the existing coastal communities and the collaborative management of resources (Álvarez et al., 2018). The cooperatives collaborate with each other and with CSOs, universities, and government agencies to monitor, protect, and manage the marine

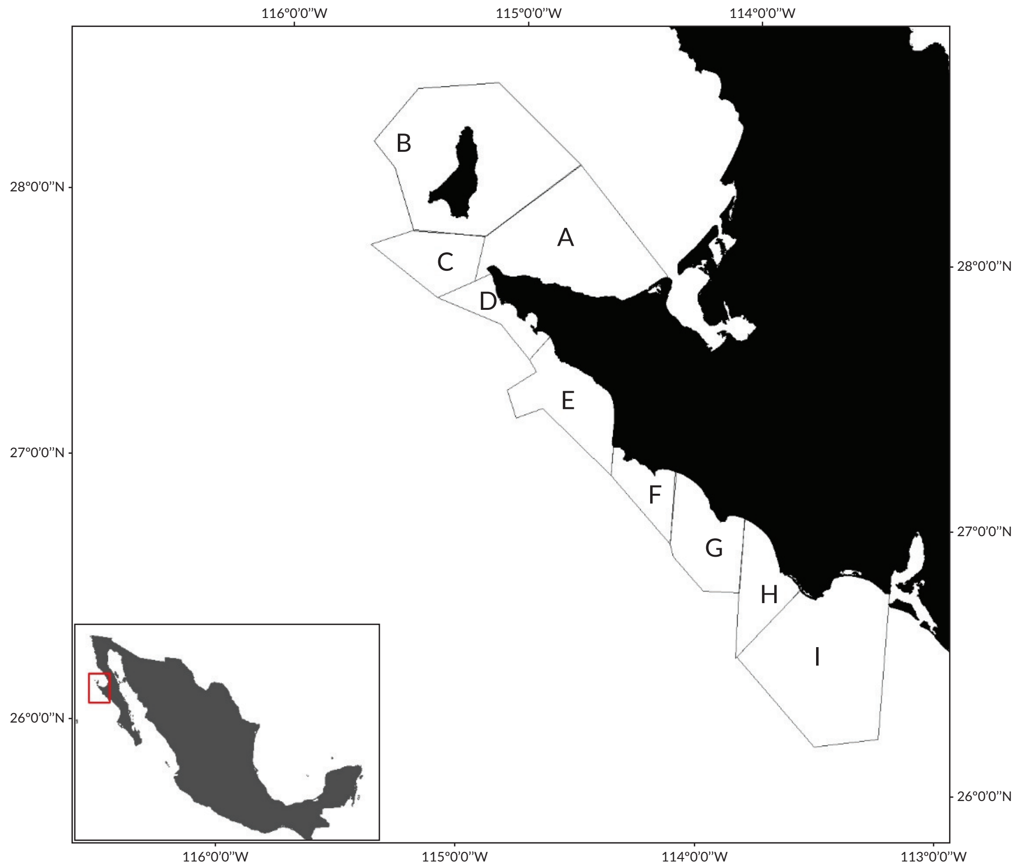

Figure 1. Map of the El Vizcaíno area in Baja California and Baja California Sur, with the cooperative fishing concessions. Map provided by Comunidad y Biodiversidad (COBI).

ecosystems of which they are part. Eleven of the cooperatives in Baja California Sur and neighboring Baja California form the Regional Federation of Fishing Industry Cooperatives of Baja California, or FEDECOOP, which represents around 1,500 members with stewardship obligations in return for reliable incomes and additional benefits such as disaster payment and retirement plans.

Adaptation, innovation, and transfer of (technological) knowledge have been a leading thread in Baja California Sur's fishing communities, and co-management approaches have historically been encouraged (Zepeda-Domínguez & Espinoza-Tenorio, 2018). Since the 1920s, access to Mexican fisheries has been regulated through a permit and concessions system (Basurto et al., 2012). In the 1930s and 1940s, several of the region's cooperatives started managing more controlled fishing practices triggered by declining abalone catches due to overexploitation, which led to the development of internal rules, surveillance mechanisms, and bottom-up management practices. Over time, they strengthened internal organization and formalized consensus-based decision-making structures, such as assemblies, internal surveillance boards, and the division of fishing territories within their concessions (Álvarez et al., 2018). The participatory management system now includes inter-institutional collaboration, evaluation actions, and the monitoring of fisheries (Finkbeiner & Basurto, 2015; Micheli et al., 2024).

Since the 1960s, the fishers have been responsible for the management of the cooperatives in a form of self-governance in which the communities design management proposals and collaborate with state agencies, scientific institutions, and later CSOs (Basurto et al., 2012; Fulton et al., 2019). However, in this co-management model, final management decisions are in the hands of the federal fishing agency CONAPESCA (Espinosa-Romero et al., 2014). The cooperatives are assigned concessions with exclusive fishing rights, and given autonomy by CONAPESCA to manage fisheries in these areas within the existing national norms and regulations. In practice, the areas are open-access, and there is illegal, unreported, and unauthorized (IUU) fishing activity taking place with fishers coming in from other areas (Cisneros-Montemayor et al., 2013). This affects the fisheries and their chances to recover, as well as the ability to carry out sustainable fishing measures. It also limits knowledge of the amount and species caught, preferred seasonal timing of fishing, and tools used (Cuevas-Gómez et al., 2021).

In the early 1980s, when intensive fishing led to the depletion of lobster and abalone fisheries, the cooperatives sought assistance from research institutes and CSOs, which undertook systematic studies of fisheries ecology and proposed sustainable management strategies. Collaboration promoted the exchange of information and co-management between cooperatives, government, research institutions, and CSOs, and eventually the cooperatives began contributing to the formulation of official policy instruments for abalone and lobster fisheries, such as a minimum legal catch size for lobster (Álvarez et al., 2018). Seasonal closures (*vedas*), quotas, and official bylaws with specific regulations for each fishery began to be broadly implemented in the 1990s (Cota-Nieto et al., 2018; Espinosa-Romero et al., 2014). For abalone, a minimum legal fishing size was established and each season's catch quota is set by the Mexican Institute for Sustainable Fisheries and Aquaculture Research (IMIPAS), CONAPESCA's scientific arm. For lobster, defining the quota was left to the cooperatives as a component of the co-management scheme. The cooperatives use their historical catch records to determine the optimal quota and to define the lobster fishing seasons (Interview TE2; TE5; TE7). As discussed below, the fishers have observed modifications in lobster behavior, which together with water temperature inform the quotas they set.

2.3. Data Needs and Existing Monitoring and Conservation Collaboration

The cooperatives in the El Vizcaíno region have practices and structures in place for collective governance and have gathered experience in maintaining and restoring the health of fish populations and ecosystems. However, public participation from fishers and CSOs in decision-making regarding fisheries management and marine conservation faces political and operational challenges (Zepeda-Domínguez & Espinoza-Tenorio, 2018). Despite some consultation roles in policy-making processes, top-down policies in Mexico have disenfranchised small-scale fishers, and the lack of socioeconomic information at the local level has limited the development of integrated public policies for fisheries (Finkbeiner & Basurto, 2015). While communities can manage their own concessions, the national norms, laws, and policies that frame these decisions have been based on data gathered by formal research institutions which may not be specific to the area (Espinosa-Romero et al., 2014; Fulton et al., 2019). At times, there are also tensions between conservation and fisheries management objectives (Senko et al., 2014).

Fishing communities in Baja California Sur have long contended with pressures from overexploitation and environmental phenomena. Recently, these pressures have been compounded by warming sea temperatures, ocean acidification, and harmful algae blooms, resulting in hypoxia, fish die-off, declining fish populations, biodiversity loss, and changing reproduction patterns (Ojea et al., 2020; Salgueiro-Otero et al., 2022). Data can help cooperatives, allied CSOs, scientists, and government agencies understand conditions and underlying processes, and inform ways to protect and restore marine life and adapt their practices. Knowledge and technology exchange has been shown to be a key adaptation strategy for more resilience to the increased pressures, as communities co-develop solutions that respond to environmental variability through innovation and shared decision-making (Fernández-Rivera Melo et al., 2024). Researchers from academic and governmental scientific institutes have been collecting and analyzing data in the Pacific Ocean near the coast of the Baja California peninsula, which have been used to inform fisheries management and marine biodiversity conservation, including on a cooperative level. However, there are still many data gaps, and data generated by scientific institutes have not always been accessed or used by the fishers (Fulton et al., 2019).

To obtain more location-specific and fine-grained data and improve the understanding of underlying conditions of phenomena affecting marine life in the cooperative fishing areas, several monitoring and data collection initiatives are underway, often with a citizen science or community-based monitoring component. These include visual surveys by diving, biodiversity monitoring (Précoma-de la Mora et al., 2020), and mobile applications which fishers use to log their catches. Another is the Oceanographic Monitoring Network (Red de monitoreo oceanográfico); here we focus on that initiative and its impact.

2.4. Framework and Methodology

2.4.1. Conceptual Framework: Citizen Science & Blue Justice

The study examines the impact of an oceanographic monitoring pilot framed as a citizen science project. Citizen science is defined as research and monitoring conducted by non-specialists—individuals who have not received scientific training, at least not relevant to the project—in collecting, categorizing, transcribing, or analyzing data (Bonney et al., 2014). Increasingly common in environmental monitoring, citizen science has been used to generate data in understudied areas, foster public engagement, and inform management and policy (Chandler et al., 2017; Cigliano et al., 2015; Hidalgo-Ruz & Thiel, 2013). However, as critical scholarship notes, not all initiatives redistribute epistemic authority or address structural inequalities; some instead rely on unpaid labor to feed expert-driven systems without shifting decision power (Eitzel et al., 2017; Piña-Romero et al., 2022). And as citizen sensing scholarship has pointed out, regulators frequently contest community-gathered data as collected through sub-standard instruments, prompting arguments for valuing "just good enough data" on terms other than regulatory compliance (Gabrys & Pritchard, 2018). We are interested in collaborative or co-creative forms of citizen science that aim to enhance empowerment and epistemic agency by enabling citizens to actively reconfigure the methods, practices, and interpretations of marine knowledge production. We therefore approach citizen science not only as producing data but also as a way of using, maintaining, and reworking the technologies integral to it, and examine to what extent the devices and their upkeep are themselves objects of local design and improvisation.

Community-based monitoring is closely related to, and can be understood as a form of, co-creative citizen science (Eitzel et al., 2017; Tengö et al., 2021). Community-based monitoring is "monitoring of natural resources undertaken by local stakeholders…in relation to aims and objectives that make sense to them" (Danielsen et al., 2014, p. 15). Co-creative citizen science and community-based monitoring involve community members not only in data collection but also in problem definition, research design, analysis, and the use of data for environmental management (Danielsen et al., 2014; Tengö et al., 2021). Such integral involvement can be a powerful approach for equity and justice, as those living most closely with the environmental conditions in question shape the objects and parameters of inquiry and mobilize knowledge to address locally salient issues, fostering inclusivity, ownership, the integration of experiential knowledge, and social learning (Cigliano et al., 2015). The knowledge generated through such monitoring can also benefit community-based environmental governance, grounded as it is in local knowledge and proximity to place (Turnhout, 2024). Community proximity enables early detection of environmental change. Being in and on the water often, fishers might be the first to notice changes such as fluctuations in sea level and temperatures as well as in the amount and health of fish, altered migration patterns, and the appearance or disappearance of species. In the context of SSFs, this creates opportunities for co-constructed, plural monitoring, where multiple ways of knowing and sensing the sea coexist and jointly inform governance.

Questions of recognition, meaningful involvement, and fair treatment of coastal people in relation to how ocean and coastal resources are accessed, used, managed, and enjoyed are deeply entwined with blue justice. Blue justice concerns distributional, procedural, recognitional, and epistemic dimensions of fairness in ocean governance, including who has access to resources, who participates in decision-making, and whose ways of knowing are considered legitimate (Blythe et al., 2023). In this case, questions of blue justice are intertwined with the socioecological history of cooperatives and communities in Baja California Sur, the increasing pressures on the marine and coastal ecosystems, and the often top-down imposition of regulations (Finkbeiner & Basurto, 2015; Salgueiro-Otero et al., 2022). Reading the Oceanographic Monitoring Network through blue justice and co-creative citizen science makes it possible to analyze empowerment beyond capacity-building to consider shifts in epistemic authority, infrastructural control, and the terms on which marine futures are imagined and governed.

2.4.2. Methods

This article is based on two kinds of research and data. The first draws on active involvement in the Oceanographic Monitoring pilot throughout its course from 2017 to 2024. The second is organized around participant observation and semi-structured interviews with members, technical experts, and administrative leaders of seven cooperatives located in the El Vizcaíno area involved in the oceanographic monitoring project, as well as with divers and researchers who helped train the technical directors. Participant observation focused on the sensor maintenance and retrieval, data interpretation, restoration and conservation activities, as well as deliberative processes such as assemblies. The interviews addressed the role of environmental technologies in cooperative management and decision-making, knowledge creation and use regarding ecological conditions and fisheries, the possibilities the sensors might offer and challenges that might arise from their use, and the ways in which sensor data intersected with other forms of knowledge and monitoring. Eleven interviews were conducted with technical experts and management members of the cooperatives at the end of the pilot period, and four with supporting CSO staff during the pilot's last year, alongside informal conversations during ethnographic fieldwork. The study's ethical protocol and data management practices were appraised and approved by the ethical review board of the International Institute of Social Studies of Erasmus University Rotterdam. We opted for an anonymization method that would protect the individual participants while acknowledging their work and their role as epistemic agents and community leaders, referring to them as TE (technical experts), DI (members of the cooperative management), or C (CSO staff) in listing interviews.

The article draws on vignettes, snippets of material-discursive practices we collected in our fieldwork, to illustrate how sensing practices unfold in concrete situations, and unpacks how these practices relate to broader governance and questions of empowerment. The vignettes reflect some of the central themes that emerged from the data analysis. Fieldnotes, visual materials (photographs, videos), and the transcribed recordings from the interviews were collected in ATLAS.ti, after which the transcribed data were coded and patterns discerned through inductive thematic analysis. Aided by the fieldnotes, patterns in the codes were used to identify themes such as material infrastructures, epistemic intermediaries, and plural ways of knowing, which were then linked to community-based monitoring and blue justice.

3. Piloting Community-Based Monitoring by Fishing Cooperatives

3.1. The Oceanographic Monitoring Network

In 2006, in a collaboration between fishers and researchers from the CSO Comunidad y Biodiversidad (COBI) and international universities, monitoring started around Isla Natividad, an island off the El Vizcaíno coast with its own cooperative (Micheli et al., 2012). This was related to the establishment of two marine reserves within the cooperative's fishing area. In 2008 and 2009, fishers around Isla Natividad reported a massive die-off event of green and pink abalone and other benthic organisms. It was known that the region had current patterns involving upwelling of deep, cold water rising toward the surface, which can result in significant drops in oxygen concentrations that lead to hypoxic conditions (Interview C2). However, at the time there was not enough information available to fully understand the drivers of the die-off events (Interview C1). After the mortality occurrences around Isla Natividad, monitoring results showed that abalone inside the reserves were more abundant, larger, and produced 40% more eggs than in the fishing areas, suggesting that marine reserves could buffer some of the negative environmental impacts of the hypoxic conditions (Micheli et al., 2012).

This convinced the fishers and scientists of the value of monitoring and the potential use of more data on the oceanographic conditions in the fishing areas, spurring interest in developing more systematic monitoring across FEDECOOP cooperative areas (Interview C2). Fishers also started to see and understand the potential benefits of marine reserves, including for adaptation to environmental changes. In 2017, COBI, Stanford University, the Monterey Bay Aquarium Research Institute, the University of Georgia, and the FEDECOOP fishing cooperatives started an oceanographic monitoring initiative in the fishing areas of all 11 FEDECOOP cooperatives. During the Oceanographic Monitoring Network pilot, members of the cooperatives would be trained in the use of robust, relatively low-cost, and easy-to-use sensors. They would also be trained to interpret the sensor-registered data and receive support from the scientists and an interdisciplinary team from COBI that would offer logistical assistance of the sensor retrievals and installments. After the pilot period, the sensors would eventually be monitored and managed by the cooperatives.

The fishing cooperatives started using the sensors in September 2017. At the beginning of the pilot, workshops organized by COBI and its scientific partners trained the cooperatives' technical experts on how to use, install, retrieve, and maintain the sensors, and a manual was created for the technical experts to refer to during and after the training (Villaseñor-Derbez et al., 2017). Each cooperative received two sensors. For the sensors to work optimally, it was recommended that the sensors be placed 12 to 14 meters below the surface and 1 meter above the seabed, in locations ecologically and operationally significant to the cooperatives. The manual offered a design for the anchor that should hold the sensor in place, but every cooperative was free to design its own anchor adapted to local conditions, if it kept the sensor anchored and retrievable. Because there is marine traffic in the area and surface buoys could become entangled, the sensor locations were not marked with buoys. However, the geographic position and underwater references were recorded for each sensor to facilitate its location. While scientists and CSO staff played central roles in this initial phase, the project was designed with the aim of eventual cooperative autonomy in operating the network (Interviews C1; TE10).

The sensor, the miniDOT logger, is a commercial instrument manufactured by Precision Measurement Engineering. It is easy to use and maintain and consists of relatively few components that can be separately replaced, although the parts are specifically designed by the manufacturer. The miniDOT is a submersible logger that records dissolved oxygen (DO) and temperature measurements in water through a fluorescence method. DO refers to the amount of oxygen present, an essential indicator of water quality. As cold water can hold oxygen more effectively than warm water, temperature is closely linked to DO. Water temperature influences many biochemical phenomena, acting as the driving force behind events like the formation of dead zones or harmful algal blooms. Algal blooms known as red tides have become more frequent and represent a major environmental concern for the cooperatives (Interview C2). Rising water temperatures can accelerate metabolic rates within ecological systems and their inhabitants, while reduced temperatures can slow them down. Temperatures affect the speed of reproduction of marine organisms, therefore influencing, for example, when lobsters or abalone are developed enough to be fished without interrupting reproductive cycles (Interview TE5).

The miniDOT measures DO and temperature every 10 minutes, and data are recorded to an internal SD card. To access the data on the SD card, the sensor needs to be retrieved and connected to a computer. About every six months since the first placement of the sensors in September 2017, the sensors have been retrieved, the data downloaded to a computer before the sensor was cleaned, its batteries replaced, and then placed again in its anchor location. A typical sensor maintenance and data upload procedure can be seen in Figure 2.

Figure 2. Sensor maintenance and data upload procedure once the sensor has been retrieved: (a) the sensor retrieved, (b) taken out of its protective case, (c) connected to a computer for (d) downloading data, (e) placed back in the case and covered in bright tape, and (f) dated.

The pilot lasted seven years, an unusually long period for a citizen science project. As part of this monitoring network within the FEDECOOP cooperatives, a WhatsApp group was formed to maintain communication between cooperative technicians and Stanford and COBI personnel to resolve doubts and concerns that occurred. This communication channel also served as an alert system for phenomena, so that technicians could notify each other when they saw or recorded red tide events, low oxygen levels, or anomalies reported by the sensors, which helped to identify whether these phenomena were local or regional. After seven years of piloting the oceanographic monitoring by the cooperatives, in September 2024 the pilot ended and a transition into a new phase began. The monitoring and the sensor retrieval and maintenance, which until then had been led by the CSO and university researchers, would now be in the cooperatives' hands.

3.2. Material Infrastructures of Community-Based Monitoring

Maintaining the Oceanographic Monitoring Network requires significant material resources, coordination, and labor that are often invisible in celebratory accounts of citizen science. Retrieving a single sensor for data download and maintenance entails organizing a dive team, preparing boats and diving equipment, traveling to the deployment site, conducting one or more dives to locate the sensor, and then cleaning, downloading, and re-deploying it. The following vignette describes one such retrieval procedure that took place in September 2024, when a team from COBI visited the cooperatives for a final round of supportive dives to retrieve and maintain the sensors, to reflect on needs with the cooperatives, and to formally hand over care of the sensors to the cooperatives:

> Looking for the Sensor
>
> It had been 10 minutes since the divers had immersed themselves in the ocean for a third time, and from the small boat we had once again watched how the oxygen bubbles became smaller and dispersed as the divers went deeper and started moving around in the water. We scanned the surface, eagerly waiting for the divers to emerge with good news. They had been moving in circles that moved ever further from the boat, looking to find the sensor that had been detached from its anchor. Without the sensor, it would be impossible to upload the information on water temperature and DO levels it had been logging in this location, a strategic location for the fishing cooperative. The sensor had been missing for a year and a half, and sensor batteries typically last two years. With the dives generally done every six months, if the sensor wasn't recovered now, it and the data it had recorded in the last year and a half were likely to be lost forever. The cooperative's technical expert had saved the GPS points for the location when placing the sensor, but when he returned to the location pinpointed by the coordinates, there was no sign of the sensor nor of its anchor. On this last attempt to recover the sensor, divers from COBI assisted him. The technical director had brought an additional GPS locator to ensure the other locator wasn't off. They tried triangulating the position in different ways. For every dive, two divers—a COBI team member with a COBI colleague or with the cooperative technical expert—went underwater looking for the sensor, while the other divers and boat crew tried to keep an eye on the divers' location, guiding the captain to stay close. The wind was just a faint breeze and the sea was calm, underwater visibility was clear, but so far, it had not helped.
>
> Suddenly, a small inflatable orange buoy broke the surface some meters to the right of where we had been looking. "There they are!" The bubbles around the buoy became increasingly obvious until, two minutes later, the divers' heads emerged. "We found the anchor. But no sign of the sensor."
>
> Back on the boat, freed from their diving kits, the divers deliberated what could have happened to the sensor. It could have become dislodged from the anchor by a current, a fish, or even fishing gear, including the nets of fishers who had entered the area without permission. The divers had scoured the bottom in a wide circle, and if it was not in one of the likely places, it could be anywhere. After three dives that day and two previous searches, they decided to call off the search and move on to the second sensor location. Luckily, the other sensor was found easily.

The story of the lost sensor reminds us that oceanographic sensing is not a frictionless act of data capture but relies on infrastructure, resources, and efforts put in by the cooperatives and scientists. The search had required four divers, including the cooperative's technical expert, the boat, a captain and two additional crew members, the satellite phone, GPS trackers, and complete diving kits, including oxygen tanks. Lobster season was about to begin, and the search for the sensor, even though this one had been placed relatively close to the beach and was only a short boat ride away, took several hours. To recover the device, the technician and other cooperative members had to set aside half a day and pause the seasonal rush of lobster cage repairs, trap building and placing, and other forms of monitoring. And now, this sensor was considered definitively lost, meaning data loss, wasted time and effort, and the costs of its replacement.

The vignette also reveals infrastructural fragility and how the location of the sensor, in this case, became a material contingency. Despite all the deliberations that went into the choice of location, considering the relevance for the measurements but also the accessibility of the sensors and the chances they stay in place based on water movement, currents, swell, temperature, visibility, and presence of fish and vegetation, the sensors can drift, break, or get stolen. This translates into epistemic uncertainties and financial burdens for cooperatives and CSOs, who must decide whether and how to replace lost equipment. Finally, the technical expert's remark that the sensor could have been dislodged by nets cast too close to the seabed, perhaps by fishers from outside of the cooperatives who entered the area without permission, laid bare some of the frictions with other fishing operations they had no control over taking catch. The missing sensor thus also registers something the device itself could not measure: the limits of the cooperatives' control over their own concession.

3.3. Technical Experts as Intermediaries and Epistemic Innovators

Within each cooperative, the technical experts play a pivotal role in enabling and sustaining the oceanographic monitoring practices. They manage the sensors and their data while integrating this information with existing knowledge and attitudes of cooperative members and administrators. These technical experts are members of the communities, many of whom pursued university degrees in marine biology, oceanography, marine engineering, or related fields (Interviews TE1–10; DI1). Some received support from parents or family members, but in some cases the cooperatives offered financial support, actively contributing to capacity development. After receiving their degrees, they returned to their home communities to use the acquired knowledge and skills in the management of fishing practices and conservation. Many of them dive and use their skills in the oceanographic monitoring project, but also on many other occasions, such as biodiversity registration by visual observation. Besides the ecological knowledge and the skills to dive, the technical experts understand the technical requirements of, and data generated by, the sensors and are attuned to cooperative politics and community priorities. They align with the cooperative administration and general members and guide decision-making. They collaborate with CSO and academic scientists as well as with government actors such as CONAPESCA, who is responsible for managing, regulating, and promoting the development of the fishing sector, and its research branch IMIPAS. Working across worlds that do not readily translate into one another, the technical experts move knowledge between them and work out how the categories of one can be made to answer to the concerns and requirements of the other.

The activities of the technicians are diverse. They often lead monitoring activities beyond the sensors, including biodiversity surveys and the systematization of documenting catch and effort data. They care for young abalone in nurseries, work on conservation planning, or train young community members, including women. Their work also entails translating sensor registrations (and other datapoints) into interpretations that make sense to cooperative members, preparing visualizations or summaries for assemblies, and advising leadership on how to incorporate data into decisions about quotas, seasonal openings, or proposed marine protected areas (MPAs).

Technicians are knowledge brokers as well as custodians of the sensors. They are active participants in citizen science and agents of technological adaptation, who innovate in the design of anchors, draw connections between sensor data and visual underwater observations, tailor sensor placement to local bathymetry and currents, develop strategies for integrating sensor readings with other indicators, and strategically mobilize data in negotiations.

3.4. Co-Constructed Monitoring and Decision-Making

The cooperative fishers have long monitored the sea with their bodily senses and tuned their practices to seasonal rhythms and embodied cues: reading the color and temperature of the water, the force of the current, the direction of the swell, the clouds on the horizon, abundance of the kelp, the sounds of arriving migratory birds (Interviews TE4; TE5; TE6). This local ecological knowledge has long underpinned adaptive strategies such as moving fishing activity, adjusting gear, or modifying the timing of catch seasons. Sensory and experiential modes of ecological attunement persist, but they increasingly operate alongside digital technologies, such as GPS devices, smartphones, and sensors. These devices do not replace older forms of knowing but rather become enmeshed with them.

Sensor data have become one important element in cooperative decision-making, particularly in deliberations around seasonal openings and the designation or justification of MPAs. For instance, when considering the start of the lobster season, cooperatives have historically relied on cues such as water temperature, catch rates in pre-season sampling, and visual assessments of reproductive status (Interviews TE3; TE6). The cooperatives increasingly consult sensor data in these decisions. And they sometimes use the data to obtain permission from IMIPAS to start fishing before the decreed opening of the season on October 1st. This timing matters economically, since the Mexican cooperative to first start selling lobsters sets the seasonal price, which is furthermore influenced by the price of lobster caught near Australia, where the season opens on September 1st. A conversation between the technical expert, cooperative members, and COBI scientists demonstrated how significant the water temperature is for the decisions to start the catch season: During a visit in the last week of September, they were hotly debating the water temperature and the status of the lobsters they had sampled. In the weeks leading up to the season, the cooperatives monitor water and sample some lobsters to gauge the advancement of the reproductive cycle. From linking sensor water temperature data trends to lobster size and reproductive development from the previous years, they corroborated the older observations that if the water is cold, the female lobsters are slower to develop and release their eggs. As the technical expert summarized, the water was cold, the traps they had set out for sampling were mostly empty, and one female lobster that was found still carried all her eggs. The expert and cooperative administration decided to postpone the starting date.

Similarly, in communities affected by recurring harmful algal blooms, sensor data have been used retrospectively to make sense of unusual marine organism mortality events, strengthening local understandings of how environmental conditions interact with fishing practices. These interpretations are then mobilized in dialogues with state agencies, and in some cases used to argue for or against proposed management measures (Interviews TE5; TE7).

The sensor data also play a role in collective deliberations, such as in the design of MPAs, demonstrating how citizen science can empower communities to claim epistemic authority in marine planning processes often dominated by external scientific and governmental actors. This is pivotal because, as one of the technical experts explained, “Establishment of MPAs is one of the tools available for local communities to combat the effects of large-scale environmental impacts, including climate change, on ocean ecosystems” (Interview TE8). One of the cooperatives held an assembly to begin the deliberation process on establishing a reserve or a no-take zone. Its technical expert had been spearheading efforts to promote biodiversity and conservation, including implementing an MPA in the cooperative’s fishing area. In the assembly, the cooperative members agreed that documenting the traditional knowledge of local fishers and incorporating it into adaptation strategies was critical for fostering dialogue between scientific and local knowledge systems amidst environmental change. But they also welcomed how new technologies, skills, and knowledge were being integrated into their practices, and found the new types of data insightful. This was especially true for younger generations, though older members were also supportive. Some said the data confirmed what they had already known, such as the effects of *vedas* or no-take zones, and put it in black and white, which might be “the only way to convince the authorities” (Interview TE2).

Sensor data inform decisions, yet they rarely stand alone. As witnessed in assemblies and daily activities, choices about when and where to fish, closing an area for seasonal recovery, or where to monitor next emerge from collective deliberation among all cooperative members, sometimes with advice from CSO or university scientists, as they weigh sensor records alongside fish behavior, underwater observations, and traditional knowledge. Data visualizations that the technical experts bring in are interpreted, contested, and re-situated within histories of past crises, memories of earlier abundance, and projections about future risks and opportunities.

Such deliberations point to citizen science manifesting as a practice of collective environmental governance. The cooperatives use these tools to act autonomously and are increasingly influencing state institutions. The MPA discussed above has since been established through a deliberative process led by the technical expert. Sensor data alongside other sources have informed that process, and the outcome was settled by a consensus negotiated between immediate livelihood needs and longer-term conservation commitments. In May 2026, after years of skepticism about the scientific validity of the data coming from the cooperatives, state research institute IMIPAS sent the FEDECOOP cooperatives an official request to provide data from the oceanographic monitoring project, to be used as scientific evidence in institutional analyses of oceanographic conditions in the Pacific.

4. Discussion

4.1. Empowerment as Epistemic and Infrastructural Control

The Oceanographic Monitoring Network has contributed to empowering the Baja California Sur SSFs not only by building technical skills but by expanding cooperative capacities to generate, interpret, and strategically deploy environmental knowledge. Read against the distributional, procedural, recognitional, and epistemic dimensions of blue justice set out above (Blythe et al., 2023), the monitoring aimed to create conditions where cooperatives share in benefits and risks, participate meaningfully in decisions, have their claims recognized, and see their knowledge treated as authoritative within marine governance. Through training and practice, technicians and other cooperative members have acquired competences in operating sensors, handling data, and relating quantitative records to their own ecological observations. They might be the ones that have and can further enable what Tousignant (2018), writing on toxicology in postcolonial Senegal, calls the capacity to do epistemic things: to produce more data, understand the data already produced, and further develop and/or adapt technology to their own needs. This epistemic agency supports more informed local deliberations and strengthens cooperatives' positions in negotiations with state agencies and conservation organizations. Where citizen sensing initiatives often struggle to have their data accepted on regulators' own terms, the IMIPAS request for the cooperatives' records treats them as scientific evidence. Several features of the pilot appear to have made this possible. An unusually long support phase of seven years and continued accessible contact with scientists through the WhatsApp group, as well as inter-cooperative communication, allowed technicians to calmly learn to use the devices and interpret their outputs. This appears to have contributed to the integration of sensor data into decision-making at community level, to the continuation of monitoring, and to the institutional acknowledgment of the data.

Empowerment in this context is also infrastructural (Star & Ruhleder, 1996). The capacity to sustain monitoring depends on access to boats, diving equipment, computers, and connectivity, as well as on institutional arrangements that allocate time and resources for monitoring amid other cooperative activities. Existing infrastructures, such as cooperative governance structures, long-term partnerships with CSOs, and prior monitoring programs made it possible to integrate sensors into local practices (Espinosa-Romero et al., 2014; Micheli et al., 2012). Without these foundations, the use of sensors alone would not have produced meaningful empowerment.

From a blue justice perspective, this highlights that technical interventions must be evaluated in relation to the broader socio-technical systems into which they are introduced. In Baja California Sur, cooperatives with stronger organizational capacity and external support are better positioned to benefit from citizen science, raising questions about how to ensure that communities with less resources are not left behind. The long history of co-management, the strong role of cooperatives with the capacity to support (technical experts as) intermediaries, and long-term collaboration with CSOs particular to this case are all key preconditions for the forms of citizen science and epistemic agency described here (Cota-Nieto et al., 2018).

4.2. Fragility, Dependence, and Limits of Citizen Science and Technologies

The missing sensor vignette illustrates how fragile the material basis of citizen science can be. Sensors that drift away, corrode, or malfunction can erase long periods of monitoring, while the costs and logistics of replacement may be prohibitive for some cooperatives. Dependence on external funding or technical support for equipment procurement and repairs can undermine the long-term sustainability and autonomy of community-led monitoring (Fulton et al., 2019; Geise & Ureta, 2025). These conditions not only threaten monitoring, but shape what gets registered in the first place. Where sensors can be placed, how often they are retrieved, and which periods go unrecorded follow from the materiality of the coastline and the resources at hand; so that, reminiscent of what Tousignant (2018) outlined, the resulting datasets register the conditions in which they are produced as much as the conditions of the ocean.

The translation of sensor data into policy influence is not guaranteed and not necessarily a linear process (Finkbeiner & Basurto, 2015). While cooperatives may use data to argue for quota adjustments or to justify local management measures, final regulatory decisions often remain in the hands of federal agencies that may prioritize other interests or draw on different data sources (Espinosa-Romero et al., 2014). Even if recognized, citizen-generated data may still be valued instrumentally where they align with pre-existing agendas and sidelined when they challenge them (Cigliano et al., 2015; Danielsen et al., 2014). These dynamics underscore that increased knowledge, skills, and technological capacity alone cannot resolve structural injustices in ocean governance. Instead, advancing these aspects should be understood as one arena of struggle among many, where communities seek to reshape knowledge infrastructures and governance relations yet continue to face constraints rooted in broader political-economic structures.

4.3. Plural Monitoring and Negotiating Multiple Ways of Knowing

The Oceanographic Monitoring Network exemplifies a form of plural, co-constructed monitoring in which multiple ways of sensing and knowing the sea coexist and intersect, sometimes in tension, often in synergy (Turnhout, 2024). Sensors have become one voice among many in cooperative deliberations, their authority mediated by embodied experiences, social relations, and institutional context. These negotiations have implications for blue justice. When cooperatives successfully assert that their data and interpretations should be taken seriously by regulators, they contest hierarchies that historically devalued local knowledge in favor of centralized expert models (Espinosa-Romero et al., 2014; Finkbeiner & Basurto, 2015). When the cooperatives design marine reserves grounded in both sensor trends and community priorities, they enact visions of marine conservation that foreground relational responsibility rather than top-down control.

5. Conclusion

This article has examined how small-scale fishing cooperatives in Baja California Sur integrate technologies into community-based monitoring and marine governance practices, and how these practices relate to empowerment and blue justice. It has provided insights into how the Oceanographic Monitoring Network functions as a form of citizen science, in which cooperative members and technical experts actively shape the aims, methods, and interpretations of environmental sensing.

By situating sensor use within a long-standing history of cooperative co-management, collaborations with scientists and CSOs, and rich repertoires of local ecological knowledge, the article has highlighted how epistemic agency and empowerment are co-produced with material infrastructures, social relations, and institutional arrangements. Technical experts emerge as key intermediaries and innovators who bridge scientific and community worlds, while the labor and fragility of sensing underscore the material and political work required to sustain citizen science.

For blue justice, the case shows both potential and limits. Accessible sensing technologies, when embedded in cooperative structures and collaborative networks, can strengthen community control over knowledge, bolster claims in negotiations with state agencies, and support more just and adaptive forms of marine governance. At the same time, structural inequalities in resources, regulatory power, and recognition constrain how far citizen science can go in transforming broader ocean governance regimes.

For marine social sciences and STS, the experiences of Baja California's fishing cooperatives invite further attention to the everyday practices through which communities integrate environmental technologies, negotiate multiple ways of knowing, and struggle for more just futures in rapidly changing oceans.

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Conflict of Interests

AHV is employed by Comunidad y Biodiversidad (COBI), the civil society organization involved in creating the Oceanographic Monitoring Network discussed in this article. MG and SU declare no competing interests.

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