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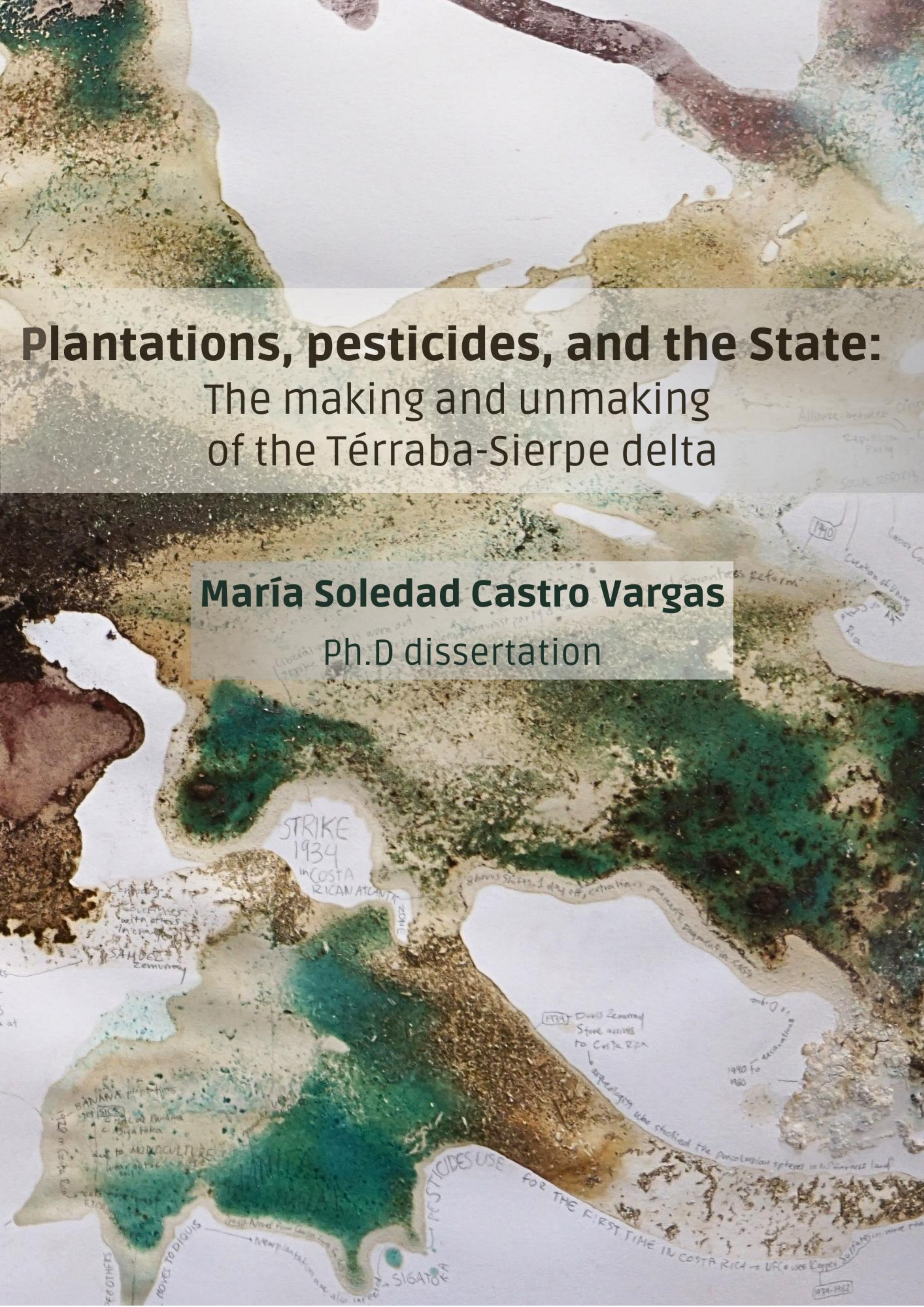
Pesticides, plantations and the State: The making and unmaking of the Térraba-Sierpe delta

Maria Soledad Castro-Vargas



Plantations, pesticides, and the State:

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María Soledad Castro Vargas

Ph.D dissertation

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PhD Dissertation

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Acronym list

1,2-dibromo-3-chloropropane (DBCP)
1,3-dichloropropene-1,2-dichloropropane (DD)
Agri-business multinationals (ABMs)
Agricultural Development Institute (INDER in Spanish)
Agricultural Services Development or ASD
Centre for Research and Policy Studies of the University of Costa Rica (CIEP-UCR in Spanish)
Centre Specialized in Organic Agriculture at the National Learning Institute (CEAO-INA)
Chamber of Agriculture and Livestock Inputs (CIA in Spanish)
Cooperative for the Commercialization of Oil Palm Producers in the Osa Peninsula (OSACOOP)
Dichloro-diphenyl-trichloroethane (DDT)
Dominican Republic, Central America Free Trade Agreement (CAFTA-DR)
Inter-American Institute of Agricultural Sciences (IICA in Spanish)
Inter-American Technical Service for Agricultural Sciences (STICA in Spanish)
International LabourOrganisation (ILO)
International Monetary Fund (IMF)
Ministry of Agriculture and Livestock (MAG in Spanish)
National Council for Scientific and Technological Research (CONICIT)
National Chamber of Agriculture and Agribusiness (CNAA in Spanish)
National Front of Sectors Affected by Pineapple Production (FRENASAPP in Spanish)
Non-governmental organizations (NGOs)
Organization for Economic Development and Cooperation (OECD)
Participatory Action Research (PAR)
Pesticide Residue Analysis Laboratory (LAREP)
Pineapple Research Institute (PRI)
Persistent organic pollutants (POPs)
Regional Institute for the Study of Toxic Substances from the National University (IRET-UNA in Spanish)
Research and development (R&D)
State Phytosanitary Service (SFE in Spanish)
System of Conservation Areas (SINAC in Spanish)
Tax Credit Certificates (CATs in Spanish)
Térraba-Sierpe Wetland (HNTS in Spanish)
United Fruit Company (UFCo)
United Nations (UN)
UN Food and Agriculture Organization (FAO)
US Environmental Protection Agency (EPA)

SUMMARY

This dissertation examines the making and unmaking of the delta Térraba-Sierpe in the southern Pacific of Costa Rica to explain why and how pesticide-contaminated waterscapes have been and continue to be produced in Costa Rica. The research combines approaches and methods from political ecology and tropical ecotoxicology to study the intersection of pesticides and plantations in waterscapes, and is divided into four chapters: (1) Regulation by impasse: Pesticide registration, capital, and the State (2) Pesticides and ecological regimes: A view from Costa Rica, (3) The making of the Térraba-Sierpe waterscape: thinking within and beyond the plantation and, (4) Tracking pesticides from upstream river waters to wetland fauna in the Terraba-Sierpe National Wetland: An ecotoxicology study of *Anadara tuberculosa.*

Chapter two studies a two-decade long effort to reform the country's pesticide registry system. It demonstrates that the registry's gridlock, far from signalling regulatory failure, is a mechanism to maintain irresolutely valid registrations of old active ingredients. Chapter three reconstructs the chemicalization of Costa Rican agriculture from the vantage point of pesticide legacies and contemporary use in the South Pacific region. It argues that more than inputs, pesticides serve as stabilizing agents for an ecological regime that depends upon the surpluses that they marshal: as byproducts of extractive industries, as compounds that externalize harms, and as biocides that tap organisms' susceptibility. The chapter exposes how the susceptibility of monocrops to pathogens, and the erosion of these target organisms' susceptibility to pesticides, creates a patchwork of biotechnical and chemical fixes. Chapter four traces plantation extensions over time, in the legacies of the banana enclave in Palmar Sur, and space, through the effects of upstream plantations on the delta's socio-ecological relations. It analyses how the United Fruit Company (UFCo), over the course of its decades-long occupation, converted the delta through hydrological infrastructure for drainage and irrigation. This ruined and largely abandoned water infrastructure has conditioned the spatial dynamics of successive land uses, in oil palm plantations and smallholder land occupations, and has increased the magnitude of floods due to climate events. The chapter shows how the interaction between plantation legacies and the effects of contemporary plantations impacts the livelihoods of local populations living along the Térraba river and its delta. Chapter six, included in Appendix 1, analysis the presence and distribution of pesticide residues in water and sediment in the Térraba Sierpe Wetland and the potential biochemical responses due to environmental exposure in the bivalve mollusk *Anadara tuberculosa*. Results make evident the presence of pesticides in the Térraba river waters and the northern Térraba-influenced wetland area, with diuron, carbendazim, diazinon and ethoprophos appearing at the highest concentrations. Considering the geographical distribution of these substances and their use in pineapple cultivation, the findings suggest a plausible association between this agricultural activity and the observed impact on the wetland aquatic environment.

Overall, the thesis argues that the pesticide-contaminated waterscape of the Térraba-Sierpe delta is produced as a confluence of the chemicalization of agriculture developed in Costa Rica over the long twentieth century, the legacies of the plantation and its expanded boundaries, a frayed pesticide regulatory regime shaped by sedimented histories, i.e. regulation by impasse, and its interaction with global networks of pesticide production and distribution, and by the dispersion of pesticides from agricultural lands to aquatic ecosystems.

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JUEGOS PERVERSOS

Soy una silla.
Soy una persona buscando una silla.
Una silla que reniega de su condición.
Una persona que lidia con la contradicción
del juego de las sillas
en el que no sabemos qué pasa
cuando acaba la música.

Soledad Castro-Vargas

WICKED GAMES

I am a chair.
I am a person looking for a chair.
A chair that denies its condition.
A person who deals with the contradiction
of the game of musical chairs
where we don't know what happens
when the music stops.

Soledad Castro-Vargas

Introduction

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This chapter includes insights from the conference paper :

Food regimes as chemical regimes: Pesticides and agrarian transformations in Costa Rica, by Soledad Castro-Vargas (presenting author) and Marion Werner. Silent Springs: Global Histories of Pesticides and our Toxic World, Rachel Carson Center, LMU Munich, Germany. October 17, 2022.

1.1 Introduction

> Hope and despair are as entangled as the synthetic twine or mecate on the soil. We have been engaged for years in these conversations that precede us. "Like life itself," I repeat, when internal contradictions seem to overcome us. Julian, the coordinator of the Finca Chánguena land struggle, and a worker on a nearby oil palm plantation, speaks with frustration. We just came from a meeting at the old banana packing house. For the past few weeks, we have been discussing the challenges of agriculture in the former banana plantation plots, *parcelas* in Spanish. An agronomist specialized in agroecology has been supporting a process of grassroots education, which seeks to strengthen the self-sufficiency of the *parcelas* through pesticide substitution. Both he and Julian point out that we have spent years in trainings, workshops, and meetings, but they do not see changes. Julian elaborates on the challenges of smallholder agriculture and why some *parcelas* have been abandoned. We are swamped by the humidity, we continue to talk in the gloom of the night. Anahí, also from the land struggle movement, points out the internal tensions of the movement and questions the collective commitment towards agrarian transformation from plantation logics to agroecology. I have participated in these discussions for a long time, again and again, trying to understand why there seems to be no escape from industrial agriculture. It feels like an eternal present, seeking to get to the core of the problem, to build collective solutions. Why is this so penetrating and pervasive?

This dissertation stems from long-standing collective reflections, as the vignette illustrates, with an underlying intention to understand how Costa Rica developed tropical agriculture production highly dependent on pesticide use. It adopts a multidisciplinary framework, which draws upon political ecology and environmental sciences, i.e. ecotoxicology. On one hand, political ecology has studied how power and economic dynamics shape socio-natural relationships (Perreault et al., 2015). On the other hand, ecotoxicology has studied contaminant exposure and its effects on the biosphere, to understand how chemicals behave and how they affect living organisms (Gagné, 2014; Sparling, 2016). By engaging with both disciplines through different theoretical frameworks, I examine the making and unmaking of the Térraba-Sierpe delta in the southern Pacific of Costa Rica in order to explain why and how pesticide-contaminated waterscapes have been and continue to be produced in Costa Rica.

I address the aforementioned through four different research questions:

1.What is the relationship between regulatory struggles over pesticide registration in Costa Rica and the global pesticide complex?

2.What work do pesticides do for capital accumulation in and through plantations, and how does past use condition present livelihoods in the southern Pacific region?

3.How do past and present plantations shape the waterscape of the Térraba-Sierpe delta, including effluent flows, sediments and pesticide residues? How do these plantation waterscapes (re)make subjects and territories in the delta?

4.What are the current levels and distribution of pesticide residues in water and sediment in the Térraba Sierpe wetland and the potential biochemical responses due to environmental exposure in *Anadara tuberculosa*?

I approach these questions by taking up different perspectives, which I refer to as lenses. Each lens has its own implicit scalar bias and, consequently, its own pitfalls. Whether it is the trap of territorial thinking through the nation-state (Agnew, 1994), the challenges to ground historical approaches (Edelman and León, 2013), an excessive abstraction (Nagar et al., 2002), or the inherent fallacies in frameworks to assess the effects of environmental contamination (Boudia and Jas, 2014; Liboiron, 2021), each approach carries its tensions and limitations. However, the exercise is not to dismiss them, but rather to navigate through them and gain a comprehensive understanding by examining each lens in relation to the others.

Lens I: Power geometries and regulations

Lens II: Human/nature relationships

Lens III: The production of space

Lens IV: Biochemical interactions

The introduction at first instance brings a background to locate Costa Rica in the pesticide complex, followed by a presentation of the study area, a description of the methodology employed, and my positionality as a researcher. Finally, the introduction concludes with a summary of the chapters that are organised around the respective research questions.

1.2 Background

Pesticides: definition and general characteristics

The term "pesticide" refers to active ingredients intended to kill or control unwanted organisms or agricultural pests, as well as to modify the behaviour or physiology of pests

Table 1. Types of pesticides according to their target organism

Type of pesticide	Target Organisms
Acaricide	Mites, ticks, spiders
Microbiological	Bacteria, viruses, other microbes
Avicide	Birds
Fungicide	Fungi
Herbicide	Plants
Insecticide	Insects
Molluscicide	Snails, slugs
Nematicide	Nematodes
Piscicide	Fish
Rodenticide	Rodents
Sanitizer	Microbes

Source: Sparling (2016).

or crops during production or storage . Pesticides encompass chemical substances as well as biological agents like viruses or bacteria. While some pesticides can be toxic to both plants and animals, they are specifically designed to be more harmful to a certain group (Sparling, 2016). Pesticides can be categorized in multiple ways, including the organism(s) they target for control or eradication (Table 1) or by the type of molecules that compose them (Stenersen, 2004). In terms of molecular composition, pesticides can be either inorganic or organic. Inorganic pesticides consist of naturally occurring compounds such as sulphur and copper, while organic pesticides are complex chemical compounds with a carbon backbone in their molecular structure, often bonded to heteroatoms like oxygen, phosphorus, sulphur, chloride, and fluorine. Organic pesticides can be further classified based on their chemical functional groups (Karasali and Maragou, 2015), such as organochlorines, organophosphates, triazines, ureas, carbamates, chloroacetanilides, pyrethrins, and pyrethroids (Karasali & Maragou, 2015) (Table 2). The majority of pesticides used in contemporary agriculture are synthetic organic compounds.

Costa Rica in the Pesticide Complex

Much of the critical social science literature on pesticides in the English language builds upon the influential work of journalists Weir and Shapiro (1981), who popularized the idea of pesticide circulation in the global economy as a “circle of poison.” In the long decade following Rachel Carson’s Silent Spring, organochlorine pesticides banned by the newly constituted US Environmental Protection Agency (EPA) continued to be exported to Latin America and the Third World. The “circle” was completed via the export of tropical products with high levels of banned pesticide residues to the US. Through the “circle of poison” heuristic, Weir and Shapiro helped to catalyze “an extended geography of concern” weaving pesticide flows through a world systems-type core-periphery model of development (Galt 2008: 787). Their investigative work informed legislation in the US Congress, new EPA regulations, a United Nations (UN) resolution on hazardous exports,

Table 2. Organic pesticide main functional groups description.

Type	Description
Azoles	Fungicides that inhibit fungal enzyme, disrupt cell walls, and stop fungal growth. Persistent in soil and sediments, detectable in vegetable residues. Some may pose health risks as human carcinogens or endocrine disruptors.
Carbamates	Diverse group including herbicides, fungicides, and insecticides. Applied to soil as preemergence to control weeds in horticultural crops. Inhibit acetylcholinesterase enzyme, blocking the action of acetylcholine neurotransmitter. Examples include mancozeb, carbofuran, aldicarb, oxamyl, and methomyl.
Neonicotinoids	Widely used systemic insecticides derived from nicotine synthesis. They persist in plant tissues and can bioaccumulate when applied to seeds. Common examples: imidacloprid, thiamethoxam, clothianidin, acetamiprid, thiacloprid, dinotefuran, nitenpyram.
Organochlorines	Insecticides classified into three types: DDT analogues, benzene hexachloride (BHC), and cyclodiene compounds. They are persistent organic pollutants (POPs), known for their toxicity and bioaccumulation potential. Widely used in the 1940s, banned in many countries during the 1970s due to their persistence and harmful effects on human health. Semi-volatile, long-range transport from warmer to colder regions.
Organophosphates	Broad spectrum compounds, highly soluble esters of phosphoric acid. Applied extensively for their effectiveness, fast degradation rates, and low persistence. High acute toxicity to bees, wildlife, and humans. Inactivate acetylcholinesterase, affecting nerve function. Examples include parathion, malathion, chlorpyrifos, diazinon, dichlorvos, phosmet, and azinphos-methyl.
Pyrethrins and pyrethroids	Insecticides commonly utilized in households, mosquito control, and agriculture. Their usage has risen as a result of the decreased use of organophosphate pesticides due to their high acute toxicity. They can be either botanical extracts or synthetic pesticides. Some exhibit neurotoxic effects by disrupting the nervous function of target insects, leading to paralysis. Examples include bifenthrin, cyfluthrin, lambda-cyhalothrin, and cypermethrin.
Phosphonoglycine	Glyphosate, a broad-spectrum contact herbicide, is widely used for post-emergence weed control. Glyphosate is the most extensively utilized herbicide globally, initially developed by Monsanto and after patent expiration made available by other companies. Its formulation includes various salts and mixtures, posing challenges in assessing its toxicity.
Triazines	Widely used herbicides for pre-emergence and post-emergence weed control in crops like corn, wheat, barley, sorghum, and sugar cane. Also used outside of agriculture (e.g., railways, roadside verges). Can be used combined with other pesticides and some are persistent. Examples include cyromazine (insecticide), simazine, and atrazine (possible human carcinogen).
Ureas and substituted ureas	A herbicide group with various subcategories. Phenylurea herbicides can be selective or nonselective, commonly applied in significant quantities. Sulfonylurea herbicides are selective and inhibit acetolactate synthase, a crucial enzyme in the biosynthesis of branched amino acids. They are used at low doses to control broadleaf weeds in cereals, with low acute and chronic toxicities. Benzolureas, introduced in the 1970s, are substituted ureas that act as insect growth regulators. Representative examples include diuron, linuron, and isoproturon.

Source: Karasali & Maragou, 2015; Sparling, 2016 and some new regulatory standards in pesticide-importing Third World countries.

Over the next decade, researchers continued to focus on problems associated with pesticide use in the global South, but scholars highlighted important discrepancies in the “circle of poison” framework. For one thing, Green Revolution programs promoted the use of pesticides and fertilizer throughout Latin America and newly decolonized countries both for exports and domestic production. State credit and extension programs promoted pesticides as part of food self-sufficiency policies (Thrupp 1990; Wright 1990; Galt 2014). While some banned compounds were imported from the US in line with the “circle of poison” thesis, these compounds were also formulated domestically by parastatal companies and transnational subsidiaries as part of import-substitution industrialization policies. Pesticides were woven into the fabric of Costa Rican farming early on, adopted both by small farmers, the targets of these self-sufficiency programs, along with traditional export plantations (Edelman 1999). Indeed, according to the 1963 agricultural census, 38% of vegetable farms (for domestic consumption) used insecticides, 44% employed fungicides and 46% applied herbicides (Table 3.3., Galt 2014).

As structural adjustment policies were imposed on much of Latin America in the 1980s, parastatal pesticide firms, along with state marketing boards and public agricultural credit facilities, were dismantled (e.g., Murray and Hoppin 1992; Thrupp et al. 1995). The subsequent shift towards “non-traditional” exports such as off-season vegetables and higher-value tropical fruits (e.g., fresh pineapple) was largely organized through arms-length global commodity chains. Pesticides and seeds for these arrangements were supplied by multinational buyers, while the production risks were absorbed by farmers (Little and Watts 1994: see also McMichael 2013). The mapping of pesticide use, regulation, and trade onto a rigid north-south, consumer-producer dualism became more difficult to substantiate with this shift. It is not that the “circle of poison” no longer existed,[1)] but rather that it could not diagnose the changing political-economic dynamics shaping pesticide use. As Wright initially noted in Mexico, non-traditional exports were subject to (limited) residue testing at the point of import. Residue testing by regulators in import markets created direct and effective economic incentives for farmers to transition from the use of highly residual organochlorine insecticides, to more acutely toxic, but less residual organophosphate and carbamate insecticides (see also Grossman 1998). What ensued was described by Barling and Lang (2005) as regulatory dualism: more intensive pesticide use for domestic consumption and less intensive use for exports that were subject

[1)] See Public Eye’s 2020 https://www.publiceye.ch/en/topics/pesticides/banned-in-europe to importer residue controls and thus direct economic sanction (Arbona 1998; Williamson 2003; Galt 2008).[2)] Costa Rica in this period continued its pattern of intensive pesticide use. In a widely cited study, Schreinemacher and Tipraqsa found Costa Rica to have the highest use intensity of all 50 countries evaluated (24.3 kg a.i./ha), followed by Colombia and Mexico (2012).[3)] Although the authors attributed the high figure to the large proportion of cultivated land dedicated to pesticide-intensive monocrop plantations (principally pineapple and bananas), Galt's study of national vegetable production found that domestic production also significantly drove demand (2014).

Given the dynamic nature of these regulatory, trade and development shifts, Galt argued for conceptualizing these political economic dynamics as "the global pesticide complex." The term seeks to capture the pesticide economic and ecological lifecycle, including "where specific pesticides are developed and manufactured, where they are traded and sold, where they are used, where they move and where they settle and degrade or persist… within international, national and subnational pesticide and food regulation

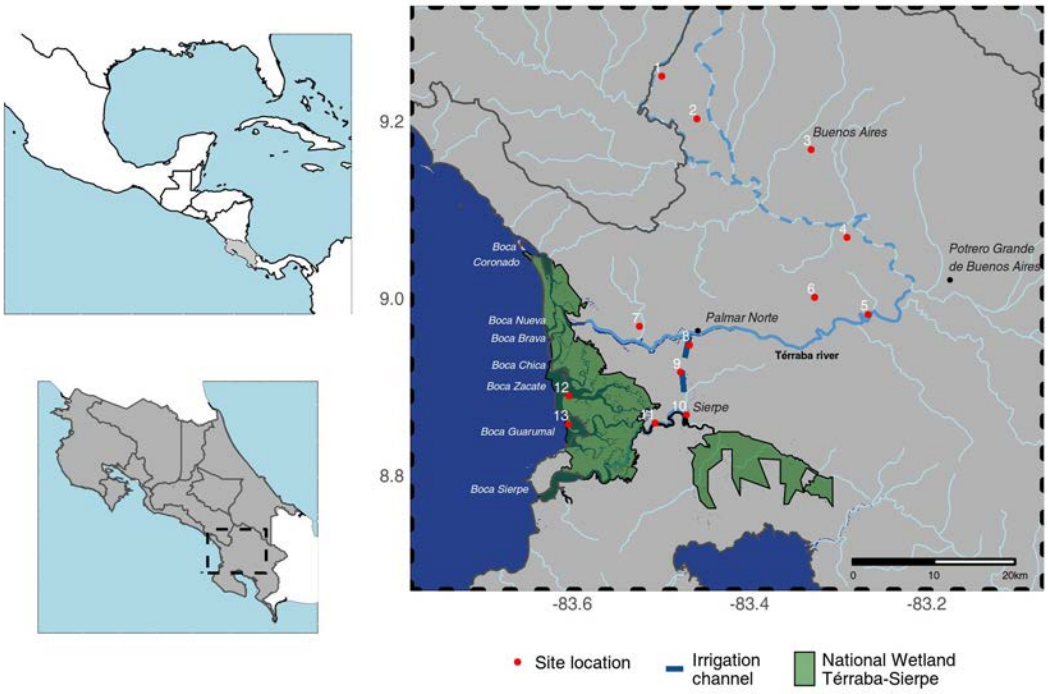

Figure 1. Main interview locations: 1) Longo Mai. 2) Volcán. 3) Buenos Aires 4) Térraba. 5) Rey Curré 6) Boruca. 7) Ciudad Cortés. 8) Palmar Sur. 9) Finca 2-4. 10) Sierpe. 11) Ajuntaderas 12) Isla Zacate 13) Boca Guarumal.

[2)]In this case, one point that Galt (2008) raises is the problem of assuming that industrial countries' pesticide regulations are homogeneous, on the one hand, and that they are more stringent than middle- or low-income countries, on the other (p. 792). These assumptions do hold for older-generation pesticides like heptachlor and others now regulated through the Stockholm and Rotterdam conventions, but not for the many pesticides that have come into circulation since.

[3)]The calculation of pesticide use is highly contentious in the country, even among different state institutions. The Ministry of Agriculture (MAG in Spanish) estimates use intensity at 11.50 kg a.i./ha while the Ministry of Environment (MINAE in Spanish) recently published a figure nearly three-fold higher, 32.56 kg a.i./ha (Servicio Fitosanitario del Estado, 2020; Vargas, 2019). The country has not reported pesticide use to the UN FAO, which manages the global use database since 2014.

frameworks" (2008: 786). Galt's formulation signalled the need to pay more attention to agrochemical capital off-farm, and associated dynamics of regulation, in contrast to the bulk of political ecology and rural economy studies that focused on on-farm practices.

The conceptual shift to analyzing pesticides from the perspective of the dynamics of capital accumulation could not be more timely and inspires the present inquiry. A number of major changes over the last quarter century have transformed the broad contours of the pesticide complex. When Weir and Shapiro wrote Circle of Poison, the majority of pesticides were produced and used in North America (35% of global market), Western Europe (20%), Japan (12%) and Eastern Europe and the Soviet Union (11%) (WHO 1990). So-called developing countries represented just 20% of the market, and Brazil had the outsized share of that proportion (35%) (Ibid.). Between 1965 and 1985, the WHO estimated a three-fold increase in pesticide use from one to three million tons (Ibid: 26). The macro-geographies of the industry have since changed dramatically and pesticide use has continued to skyrocket. I sketch two, related reasons for this change here. First, China (and increasingly India) adopted industrial policies to facilitate the expansion of its agrochemical industry, first as a subcontractor to large agri-business multinationals (ABMs), then as a producer of generic active ingredient (a.i.) and finally as an investor and driver of R&D and proprietary formulations.[4] This last position was consolidated with the takeover of Swiss-giant Syngenta by state-owned ChemChina during the same period (2016-2019) that Bayer's acquisition of Monsanto was approved. This corporate consolidation at the top of the industry reflects the second explanation key for restructuring: the rise of generics and the associated declines in monopoly profits and new active-ingredient discoveries (see Shattuck 2021; Clapp 2021; Werner et al. 2022). In 2000, global agrochemical sales of patented or proprietary formulations accounted for 70% of the market (UPL 2017). By 2018, 76.6% of agrochemicals on the global market were generic products; only 15.7% were patented (PMD, various years).[5] The ChemChina and Bayer acquisitions responded to these changing market pressures. Along with the merger of Dow and Dupont (leading to the launch of Corteva), the result was a more consolidated industry with a reduced top-tier of four firms (ChemChina, Bayer, Corteva and BASF) down from six. As a result of these shifts in ownership, together with the preponderance of generics, the first billion-dollar generic ABMs emerged, creating a second tier to the industry, headquartered in Australia, Japan, the US and also China, India, and Israel (the latter part of ChemChina's Syngenta group).

[4] Pesticides are formulated from active ingredients and various co-formulants, which can include surfactants (to reduce surface tension), emulsifiers and dyes. In the general pesticide commodity chain, active ingredient production is more capital-intensive and thus its production is more concentrated in fewer countries, and has higher barriers to entry (even before we consider intellectual property rights). Formulation often uses easily acquired commodity chemicals and processes, and therefore has low barriers to entry. While agribusiness multinationals' production was once largely vertically integrated from R&D to a.i. production to formulation, like other industries, the commodity chain has been restructured and relocated over the last two decades in light of the changes described here. For more on this restructuring process, and its relationship to glyphosate (the world's most widely used herbicide) in particular, see Werner, Berndt and Mansfield (2022).

[5] Proprietary off-patent products, defined as products for which the company that held the patent still accounts for more than 90% of the sales, accounted for 7.7% of the market (PMD, various years).

Global estimates of pesticide use are notoriously inaccurate, but even relying upon incredibly flawed official data, Bernhardt et al. (2017) estimate that pesticide use has increased three-fold, while trade (likely a more accurate measure of use than official use data) has increased six-fold since 1970 (to 2015). As in the rest of Latin America and the global South more widely, the surge in generic production has lowered prices for corporate plantations and smallholders alike. This phenomenon has been well-documented for herbicides in particular, dubbed by Haggblade et al. (2017) as the "herbicide revolution in developing countries."[6] These global changes are reflected in Costa Rica, which has shifted its position in these protean supply chains, and hosts a growing formulation industry that benefits in part from Chinese and Indian capital (Castro-Vargas & Werner, 2022). Indeed, since 2009, the country has become a net exporter of agrochemicals for the first time in its history, a trend that has continued for the subsequent decade. This new position of the country as a producer and exporter is not unrelated to its long-time, largely underappreciated role as a significant regional center for the development of practices, innovations and technologies for monoculture agro-exports (Ramírez Cover, 2020). In the past decade, plantation agriculture has expanded, spurred by foreign investment, state

Table 3. Wetlands' classification in Costa Rica.

Wetland system	Definition
Fluvial	Aquatic environments contained in drains that periodically, permanently or temporarily keep water moving.
Estuary	Deep-water habitats influenced by tides, often semi-enclosed by land, where oceanic water is mixed with freshwater from inland sources (e.g., mangroves, marshes, estuaries).
Marine	Coastal areas exposed to oceanic water flows, including marine extensions up to the posterior limit of marine coral reefs or, in its absence, up to 6 meters deep at low tide.
Lacustrine	Aquatic habitats occurring in natural or artificially dammed depressions, categorized as lakes (over 2 meters deep) or lagoons (less than 2 meters deep). They may feature various types of vegetation, including emergent plants, floating plants, mosses, and lichens. Water salinity can be tidal or non-tidal, with freshwater having a salinity equal to or less than 0.5 parts per million (ppm) (coastal lagoons).
Palustrine	Non-tidal wetlands characterized by varying vegetation cover, such as trees, shrubs, emergent vegetation, mosses, and lichens. The depth in depressions does not exceed two meters, and salinity derived from ocean salts does not exceed 0.5 ppm (e.g., yolillales, freshwater flooded forests, swamps).

Source: Proyecto Humedales de SINAC-PNUD-GEF, 2018.

[6] To give the reader a sense of this change, in 2000 China and Ethiopia used less than 1 kg a.i. per hectare of herbicide in agriculture. This figure rose to 20-25 kg a.i. per hectare by 2015 (Haggblade et al. 2017).

export promotion policies, and domestic innovations in agronomic sciences (Leon 2021; Picado Umaña 2012); agrochemicals are at the heart of this story, as this dissertation will explore.

1.3 Study area: The Térraba-Sierpe delta

The Térraba-Sierpe delta is a coastal floodplain formation characterized by meandering channels and islets defined by mangrove vegetation, created by the sediments of Térraba river and Sierpe river (Acuña and Quesada, 2008).Its area of influence extends to the upper basin of the Térraba and Sierpe rivers (Bogantes, 2017).The Térraba river is the largest watershed in Costa Rica, with a 160 km course that flows into the Pacific Ocean; it is navigable 22 km upstream from its estuary (Montoya et al., 2012; Rojas, 2011). It constitutes the main river of the basin, originating in the middle watershed of the General river and Coto Brus river and covering an area of 5079 km^2(Rojas, 2011).

river deltas are distinctive coastal features formed through the accumulation of sediment near the mouths of rivers. The development of these landforms is the result of complex interactions among fluvial processes, sediment transport, and coastal dynamics, including waves and tides. As sediment gradually accumulates over time, expansive and dynamic landscapes emerge at the river's terminus (Syvitski, 2008; Syvitski and Saito, 2007). From an ecological perspective, studying deltas requires recognizing their embeddedness and interconnectedness within larger environments. Deltas are open systems that are intricately linked to and dependent on various environmental elements, such as the atmosphere, drainage basin, and coastal ocean (Burger et al., 2012; Day et al., 2016).

This study engages in a dialogue that combines these ecological principles such as expanded boundaries, interconnectedness, and embeddedness with a relational understanding of space and place (Christophers et al., 2018). In this regard, the study area extends beyond the physical boundaries of the delta itself, encompassing diverse locations such as Ministry offices in San José, an agrochemical warehouse in the distant town of Pérez Zeledón, or a village situated near a pineapple plantation, in the middle basin of the Térraba river. To conduct my research, I divided my fieldwork between San José, the capital of Costa Rica, and the Southern Pacific Region (for more details, see next subsection). Within the Southern Pacific region, my primary base was the town of Sierpe, strategically located between the terrestrial delta and the mangroves, which provided valuable observations and insights for my analysis. Additionally, I had the opportunity to stay in other towns along the Térraba river and, to a lesser extent, the Golfo Dulce area, allowing me to gain diverse perspectives on the production of the waterscape (see Fig. 1).

In this section, to enhance the readability of the dissertation, I will first provide a general context for the Southern Pacific region, followed by a characterization of the Térraba-

Sierpe wetland from an ecological perspective and land use dynamics. In Chapters 3 and 4, I will delve into its history and related human and ecological relationships in greater detail.

The Southern Pacific region

Costa Rica is territorially divided into three types of subnational entities: provinces, composed of cantons, and districts, as stated in the Political Constitution (Costa Rica, 1949). It has seven provinces, 82 cantons, and 484 districts. At the provincial level, there are no separate governing bodies; however, the cantons are administered by municipal governments. The country is also organised into six socio-economic regions, a political and economic subdivision, namely: Central Region, Chorotega Region, Central Pacific Region, Southern Pacific region or Brunca Region, Atlantic Huetar Region and North Huetar Region (Alvarado Salas, 2003).

The South Pacific region is located in the southeastern part of the country. It includes the Pérez Zeledón canton in the province of San José, and the cantons of Buenos Aires, Corredores, Coto Brus, Golfito, and Osa in the province of Puntarenas. Is delimited by Panamá to the east, the Pacific Ocean to the south, the provinces of Cartago and Limón to the north and the provinces of San José and Puntarenas to the west. In an area of 9,528.54 km^2, it covers around 18.6% of the national territory (Fallas Hidalgo et al., 2006). The

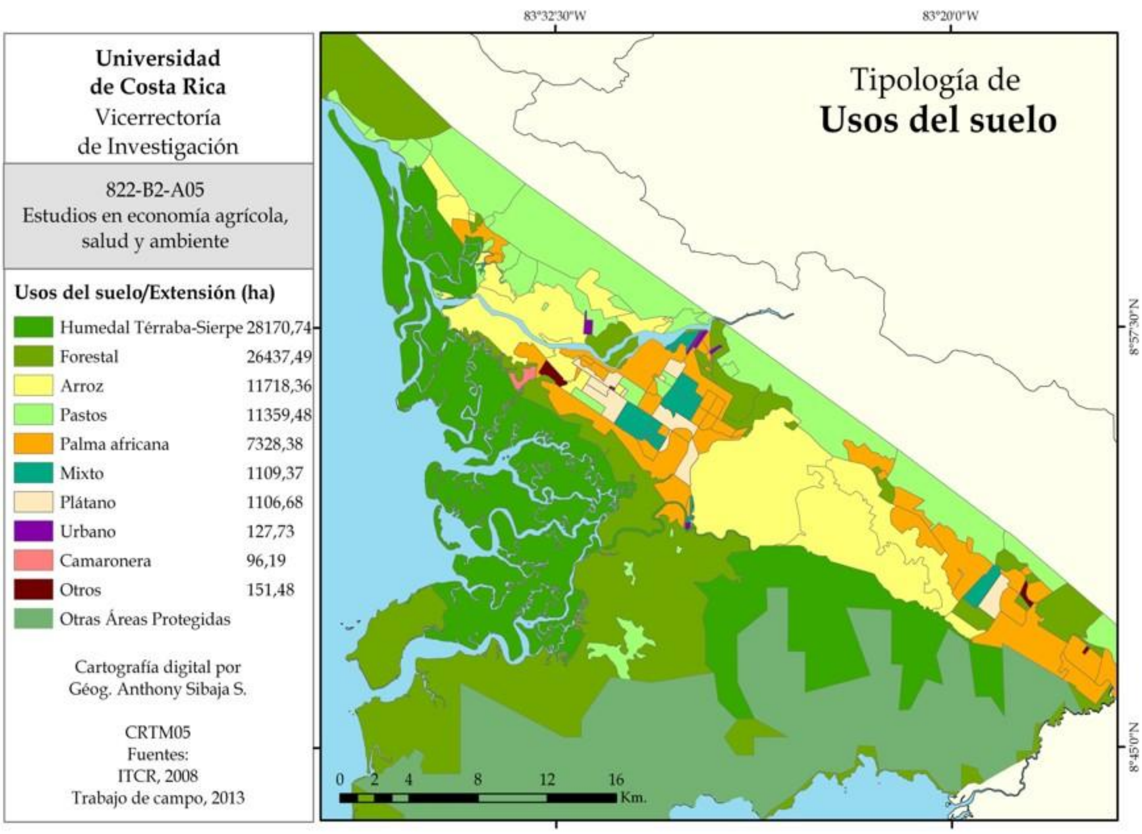

Figure 2. Land use coverage of HNTS wetland. Source: Universidad de Costa Rica

Table 4. Pesticides used in rice, banana, palm oil and pineapple crops.

Crop	Pesticide	Application mode
Rice	Herbicides: 2,4-D propapil, pendimetaline, butaclor, imazapic.	Plane/manual
	Fungicides: mancozeb, carbendazim	Plane/manual
	Insecticides: dimetoato, triazophos, cypermethrin, imidachlorpid, pyrethroids	Plane/manual
Banana	Fungicides: mancozeb, agricultural oils, tridemorf, conazoles (fenbuconazole, tebuconazole etc.) azoxiestrobin, trifloxiestrobin (up to 40- 50 times per year)	Plane
	Insecticides- nematicides: terbuphos, etoprophos, fenamiphos, cadusaphos, (2-3 times per year)	Manual pump, around banana plant, bags
	Insecticides: clorpiriphos, bifenthrin	Bags
	Fungicides post-harvest: imazalil y thiabendazol	Packaging plant
Oil palm	Herbicides: paraquat, diuron y glyphosate. Insecticide: carbaril	Manual pump, spray-boom
Pineapple	Insecticides: diazinon, etoprophos, carbaril	Spray-boom, manual pump
	Herbicides: ametryne, bromacil, diuron, paraquat (post-harvest), glyphosate.	Spray-boom, manual pump
	Growth regulator: etephon (even three times per cycle).	
	Fungicides: fosetil, mancozeb, metalaxyl, triadimephon, carbendazim	Spray-boom, manual pump
	Post-harvest fungicide: triadimephon	Packaging plant

Source: Castillo et al., 2013; Corporación de Desarrollo Agrícola Del Monte, 2016.

region has a highly irregular topography, including mountainous terrain highlighted by the Talamanca mountain range, as well as valleys such as the General Valley and the Coto Brus Valley, and large plains like the Térraba-Sierpe Delta. Due to its topography, orographic orientation, and air and marine currents, the region experiences a diverse humid tropical climate (MIDEPLAN, 1987). In some locations, it can rain all year round, but in others, there is a more differentiated pattern between dry and rainy seasons (Rojas, 2011).

This region is renowned for its exceptional biodiversity, particularly in the Osa Peninsula, recognized as one of the most biodiverse places in the world, hosting 2.5% of terrestrial plant and animal species (Gutierrez et al., 2019). Its marine biodiversity is also outstanding, making it an important area for fishing activities (Friedlander et al., 2022). The area's ecological prestige has turned it into a focal point for both public and private conservation initiatives, with 28 protected areas including six national parks (Alfaro et al., 2022; Carter et al., 2020; Morales-Aguilar and Fernández-Montero, 2022). However, despite these conservation efforts, the well-beingof the local inhabitants has not seen significant improvement (Hunt et al., 2015).

Approximately 7.2% of the national population resides within the confines of this geographic area, with the Osa canton exhibiting the lowest population density. Moreover, the region grapples with notable socioeconomic challenges, characterized by the highest rates income-based poverty. Although during the pandemic, specifically in 2020, these indicators apparently improved, it is believed that this was due to state aid transactions. Recent statistics from 2021 indicate an overall poverty threshold of 33.5%, with extreme poverty standing at 10.2% (Morales-Aguilar and Fernández-Montero, 2022).

Six distinct Indigenous Peoples, including the Bribri, Cabécares, Bröran, Ngäbes, and Bungles, inhabit a total of twelve Indigenous Territories (INEC, 2013). These indigenous peoples have been struggling for a long time for the recognition of their self-determination and autonomy by the Costa Rican state, which has neither approved the Law on Indigenous Autonomy (the bill is from 1995) nor assumed its responsibility to guarantee their right to territory, which is non-transferable and inalienable according to the International Labour Organisation (ILO) Convention No. 169 (Baltodano-Calvo et al., 2018).[7] As a result of this, they have undertaken multiple land recoveries of certain parts of the territory that were occupied by non-indigenous people (Mora Calderón and Solis Aguilar, 2020). Moreover, the Indigenous Peoples Ngäbes and Bungles often move between Costa Rica and Panamá (Muñoz-Zuñiga, 2014). Owing to its proximity to the Panama border, significant migratory flows characterize the region, which also serves as a pivotal transportation nexus for various commodities (Fallas Hidalgo et al., 2006).

The delta as a protected conservation area

The wetland known as Térraba-Sierpe wetland (HNTS in Spanish) is a protected area managed by the System of Conservation Areas (SINAC in Spanish) under the Ministry of Environment in Costa Rica. It has held protected status since 1994 and spans

Figure 3. Workshop in Finca Chánguena: Evelyn, a parcelera, explaining her personal timeline, which included evictions and how she decided to participate in land struggles.

[7] The State of Costa Rica ratified the "Convention concerning Indigenous and Tribal Peoples in Independent Countries" of the International Labour Organisation (ILO) in 1992. Article 7 of the country's constitution states that international conventions have authority over national legislation, so that the right to territory recognised by this convention should be protected by the Costa Rican state.

approximately 33,030.8 hectares. The wetland is nationally recognized as one of the most important in Costa Rica and has also gained international recognition as a RAMSAR site since 1995 (Picado, 2015). Despite its protected status, Térraba-Sierpe wetland faces significant challenges in its management. Various factors contribute to these weaknesses, including the non-enforcement of the management plan, a lack of human and economic resources, the absence of pollution monitoring and control, and the ongoing tension between agricultural land use and conservation interests (Contraloría General de la República, 2011).

From an ecosystem perspective, the Térraba-Sierpe wetland exhibits two distinct hydrological systems. One is influenced by the Río Grande de Térraba watershed in the north, creating an intertidal estuarine wetland with a landscape classified as a forest flooded by tidal influence. The other system is associated with the Sierpe river watershed, characterized by a permanent and extensive marsh area (Mora, 2013). It boasts the largest mangrove coverage in Central America. According to Costa Rica's legislation (Decree Nº 35803-MINAET, based on RAMSAR Convention categorization), the Térraba-Sierpe wetland is classified into five wetland types: marine, estuarine, lacustrine, riverine, and palustrine (Proyecto Humedales de SINAC-PNUD-GEF, 2018; Ramsar Convention Secretariat, 2016) (see Table 3). These classifications provide a framework for understanding the diversity of aquatic habitats within the Térraba-Sierpe wetland and their ecological significance.

Within the Térraba-Sierpe wetland, there are seven mouths, namely Boca Coronado, Boca Nueva, Boca Brava, Boca Chica, Boca Zacate, Boca Guarumal, and Boca Sierpe (Fig.1). As Picado has determined (2015), the salinity values in the wetland exhibit spatial and temporal variations influenced by several factors, including rainfall patterns, atmospheric phenomena such as El Niño or La Niña, and changes in the area's geomorphology. In the northern zone, the Térraba river plays a significant role, resulting in two distinct estuarine conditions depending on the flow season. During the low flow season from December to April, the estuary displays characteristics of a partially mixed estuary. However, during the intermediate and high flow season from May to November, it transitions into a salt-wedge estuary. Moving towards the central area, the marine influence becomes more pronounced, leading to a vertically homogeneous or well-mixed estuary. There, the freshwater and saltwater mix more uniformly throughout the water column. In the southern part of the wetland, the estuary experiences a partially mixed condition, due to a balanced state between the contributions of the Sierpe river and the tidal regime. The combination of these factors creates a distinct estuarine environment in the southern region. Thus, the Térraba-Sierpe wetland showcases a range of estuarine conditions across its different zones (Picado, 2015).

Regarding the composition, structure, and distribution of mangroves, there is a discernible pattern in the Térraba-Sierpe National Wetland, where species are distributed in zones from the coast to the mainland and from the estuaries to the interior (Lizano, 2015). In the estuarine sector of the wetland, several mangrove species have been recorded, including *Rhizophora racemosa* (red mangrove), *Pelliciera rhizophorae* (black mangrove), *Rhizophora mangle* (red mangrove), *Laguncularia racemosa* (white mangrove), *Avicennia* spp. (black mangrove), and *Conocarpus erectus* (button mangrove) (Fig. 7). Among these species, *R. racemosa* and *P. rhizophorae* exhibit the highest relative abundance, accounting for 45.44% and 39.92%, respectively. Conversely, *R. mangle*, *Avicennia* spp., and *L. racemosa* have lower abundance and frequency, suggesting localized clustering (Barrantes and Cerdas, 2015). Mangroves possess specific characteristics that render them vulnerable to changes or modifications, such as temperature fluctuations, wind patterns, tides, variations in water salinity, shifts in freshwater inputs, rainfall, sediment dynamics, and primarily, geomorphological aspects (Acuña-Piedra and Quesada-Román, 2017).

The sediment composition within the HNTS estuarine sector exhibits a correlation with the presence of mangrove species. Sludge and sandy sludge substrates comprise 49% and 39% of the area, respectively. Consequently, fine sediments constitute approximately 88% of the substrate, with the remaining 12% being coarse-grained, specifically sandy with variations of sludge or gravel. Additionally, the HNTS has recently experienced changes in its geomorphology owing to sediment dynamics and local sea level rise (Lizano, 2015). These factors contribute to the ongoing change of the wetland.

Figure 4. Sampling campaigns carried out in the Térraba-Sierpe Wetland. Top-left: Mollusc extraction in the mangrove forest. Top-right: Access to the sampling site during low tide. Bottom-left: Water characteristics measurement. Bottom-right: Water sampling with Niskin water sampler.

Land use in the delta

The land use patterns in the delta exhibit highly dynamic changes, changing at a faster rate than the research on the subject. Despite the fact that the majority of the delta is classified as a protected area, the surrounding zones are primarily dedicated to agricultural activities. Plantations of oil palm, rice, and banana not only surround the protected area but also frequently invade it or lead to land use conversion (e.g. Fig. 2 includes a glimpse of land use in 2013)(Cortés Muñoz and Montero Solís, 2021; Fundación Marviva, 2019). Between 2008 and 2016, approximately 1,310 hectares were drained, resulting in a shift in land use to livestock, rice, and palm oil production (Camacho et al., 2017). These plantations employ diverse pesticide technological packages that can easily reach the wetland waters through leaching and runoff. Table 4 provides more detail on the pesticides used on each crop.

Furthermore, as elaborated in Chapter 3 and Chapter 4, Palmar Sur was once part of the United Fruit Company's banana enclave (1934-1984) in the Southern Pacific. After the enclave, two processes of land occupation occurred as part of broader agrarian struggles (Mora Calderón, 2022). Consequently, the wetlands currently encompass protected areas, agricultural plantations, and small plots or *parcelas* (averaging around three hectares) (see Figure X below). Additionally, the wetland's mangrove area is inhabited by *piangüeros/as* (shellfish gatherers) who rely on the extraction of the bivalve mollusk *piangua* (*Anadara tuberculosa*) as their primary livelihood activity (Bogantes, 2017).

Upstream of the Térraba river, the multinational corporation Del Monte, through its subsidiary company Pindeco, maintains a large-scale pineapple monocrop. Pineapple plantations are widespread in the middle basin of the Térraba river (i.e. Volcán, Buenos Aires) and in the upper reaches of the Coto river (i.e. Potrero Grande) (Alfaro et al., 2022; León, 2016). The production system employed by Del Monte encompasses specific agricultural techniques, including cultivation along the slopes and the utilization of soil preparation methods that can contribute to soil degradation. These practices involve activities such as mechanical tillage and the prolonged exposure of soils without vegetation cover, leading to soil erosion and subsequent sedimentation of nearby surface water bodies (see Chapter 4)(Bonnatii et al., 2005). Moreover, the production system relies heavily on the use of pesticides, resulting in the contamination of the Térraba river through the runoff of these chemical substances (Echeverría-Sáenz et al., 2022; Picado Blanco, 2014) (see Appendix 1).

During the past decade, pesticide residues have been detected in Térraba-Sierpe wetland, as I will closely explain in Chapter 6 (included as Appendix 1). These new patterns of socio-environmental exposure to these substances add to a long-standing history from the 1930s, when the chemicalization of agriculture in the delta began (see Chapter 3).

1.4 Studying the making of the delta Térraba-Sierpe

We, say the fisherfolk of San Jorge, are people-turtles,

we suffer a lot but we also enjoy life, and when adding it all up,

despite our poverty, they say, joy prevails. Thus,

the amphibious culture is a summary of a way of living.

Orlando Fals-Borda

This research adopts a multidisciplinary approach that combines political ecology and environmental sciences, which is reflected in the methodology employed. In this subsection, I will explain some general aspects of how I engaged with the project of studying the delta, including a stylized description of the fieldwork and research methods. The specific materials and methods used in ecotoxicology are outlined in Chapter 6 included in Appendix 1.

This dissertation is primarily based on a critical ethnographic study that takes inspiration from Marx's method to start from the real concrete, "proceeding through processes of 'abstraction'… to construct concrete concepts that are the product of multiple relations and determinations" Hart (2016: 9). It is grounded in a relational understanding of space that focuses on how ecologies, subjectivities, and places are constituted in relation to one another through power relations established in everyday life. As Hart explains (2006:995), "places are always formed through relations with wider arenas and other places; boundaries are always socially constructed and contested; and the specificity of a place—however defined—arises from the particularity of interrelations with what lies beyond it, that come into conjuncture in specific ways." In a similar vein, I have been influenced by other critical development ethnographies and their interest in questioning the "why"of matters (Li, 2014; Watts, 2001). I have also drawn from the "follow the thing" approach, particularly in tracing the entire downstream chains of pesticides, from their registration and sale to their use and environmental fate (Cook, 2004).

Although participatory action research (PAR) was not initially central to my methodology, my previous work experience and training in Central American popular education and the nature of my research questions, led me to incorporate a number of PAR elements. Participatory techniques of popular education and various other tools and ways of engaging with the field from the perspective of PAR were significant in both my planning and conducting fieldwork activities (De Oliveira, 2015; Fals-Borda and Mohammad, 1991; Fals Borda, 1999; Vargas and Bustillos de Nuñez, 1987). The works of Paulo Freire and Orlando Fals-Borda have been influential for me, and in this particular project, I have been inspired by Borda's work in the Mojana region in Colombia (e.g. Borda, 2015; Freire, 2005). I discuss participatory activities more below.

Fieldwork description

I spent twenty months in Costa Rica between 2018 and 2022, dividing my fieldwork into five periods: Fieldwork I, one month in 2018; Fieldwork II, three months in 2019; Fieldwork III, nine months in 2019-2020; Fieldwork IV, five months in 2021; and Fieldwork V, two months between 2021-2022.

Before starting my PhD, I conducted one month of exploratory fieldwork in San José to establish connections with key stakeholders involved in the research topic. Given the environmental sciences aspect of my study, it was crucial to gain a comprehensive understanding of the fieldwork area, including identifying major crops and their proximity to water bodies. Through initial engagement with relevant actors, I had the opportunity to join a field trip organized by the Agronomy School at the University of Costa Rica, as part of the follow-up to a project they implemented between 2013 and 2017 on the Térraba Sierpe wetland. During this field trip, I contacted regional state representatives to introduce my research project. I accompanied two members of the project on a field tour to visit their sampling sites, where we discussed the rationale behind site selection and had insightful conversations about their findings, including retrospective reflections.

After preparing an advanced research proposal, I conducted preliminary fieldwork to review the research design with key interlocutors in my study area in 2019. I continued to actively participate in ongoing debates regarding pesticide regulation and agricultural issues. Furthermore, I initiated a collaborative partnership with artist Diana Barquero, merging arts and political ecology, resulting in the realization of two projects.[8)] As part of this collaboration, we conducted joint fieldwork primarily based in Ciudad Cortés, traversing the Térraba river basin, including the delta and mangrove areas. We organized and facilitated two participatory workshops focused on waterscape perception and life stories, held in Ajuntaderas and the Finca Chánguena packaging facility (see Fig. 3). This enduring collaboration has been a source of inspiration and intellectual exchange.

Towards the end of Fieldwork II, I conducted another preliminary water sampling campaign at three sites. It should be noted that I had an informal collaboration agreement with the Agronomy Faculty of the University of Costa Rica to utilize the baseline on the presence of pesticide residues in the wetland. Based on this pesticide exposure assessment, I could focus on evaluating the effects on the aquatic ecosystem. However, at the last minute, the Agronomy Faculty denied me permission to use the baseline data, which they

8) We presented the first project "Triggering the apparitions: Spectres of chemical seascapes" at the Royal Geographical Society Conference in London, UK, held in 2019. This conference paper was published in 2021 as a book chapter in the collection titled, Imagining Apocalyptic Politics in the Anthropocene (see Appendix 2). We presented the second project "Pesticide contaminated waterscapes: Entanglements that shape uneven chemical geographies" at EASST/4S Conference, 18-21 August 2020, in the "Making chemical kin" panel, convened by Angeliki Balayanis and Emma Garnett and discussed by Michelle Murphy.

have not published to this day. This hinders public and environmental health, as their study revealed the presence of residues of multiple pesticides, including the banned herbicide bromacil, used in the pineapple agroindustry (Picado Blanco, 2014).

In Fieldwork III, I conducted a research stay at the Centre for Research and Policy Studies of the University of Costa Rica (CIEP-UCR in Spanish), guided by Dr. Andrés León. During the early initial phase of my fieldwork, the COVID-19 pandemic began, leading to significant impacts on my planned activities. The implementation of lockdown measures in Costa Rica disrupted my scheduled activities and research planning. This included a workshop on pesticide regulations, a joint fieldwork itinerary with my supervisor Dr Werner, and an extensive sampling campaign of water, sediments and mollusks in the Térraba Sierpe wetland. Furthermore, I had made all the necessary arrangements, such as flights, membership, and registration, to participate in the American Association of Geographers Annual Conference in Denver and the "Global Glyphosate" workshop in the University at Buffalo, State University of New York. Unfortunately, all of these plans were cancelled as a result of the pandemic. The dry season sampling campaign was also unable to proceed due to government restrictions and the closure of facilities at the Regional Institute for the Study of Toxic Substances from the National University (IRET-UNA in Spanish). Consequently, I had to make rushed decisions without a solid foundation to assess the best or worst course of action.

Gradually, amidst the uncertainties, I resumed my fieldwork activities. This involved extensive logistical planning, unexpected engagement in unanticipated tasks, and the development of specific protocols for conducting interviews while adhering to precautionary measures to prevent the spread of the virus. Despite these challenges, I engaged in online and in-person interviews in San José, adhering to prevailing restrictions. I also participated in meetings, workshops, and other events related to pesticide regulation issues. In the southern region, although transportation and movement restrictions posed challenges, the lower population density and ample outdoor spaces provided certain advantages. Between fieldwork III and V, I occasionally rented a house in Sierpe, which I used as my main base and which constituted a key site due to its strategic position between Palmar Sur and the mangroves. To minimize the risk of virus transmission, I organized open-air activities such as bike rides or walks with former banana plantation workers and guided tours with local fisherfolk through the wetland. However, I was in the southern region during some of the most severe lockdown periods when rural extension services from public institutions, academia, and NGOs had been completely cut off. It was also a very challenging time for the local communities. For example, due to transportation disruptions, a significant portion of the plantain harvest in Palmar Sur was lost as it could not be sold. In response, I collaborated in organizing two fundraising campaigns to purchase food supplies, followed by their distribution to farms and mangrove areas where people had lost their main sources of livelihood. Throughout these journeys, I observed local dynamics and interactions that had previously gone unnoticed by me in preceding fieldwork. Although it was a difficult and demanding time, it also had warm and touching moments that will remain imprinted in my memory.

At the end of the extended nine-month stay, I organized an online workshop on pesticide use, regulation and registration in Costa Rica, attended by stakeholders from institutions, academia and civil society organisations. At this event, Dr Werner and I presented the preliminary results of our research on that matter. Furthermore, I finally managed to conduct the rainy season sampling campaign in August 2020. It is worth noting that the component of ecotoxicology involved an extensive literature review, obtaining permission and a collection license from the Ministry of Environment, establishing a cooperative agreement with IRET-UNA, and mobilizing resources for both field sampling and laboratory analyses, including the procurement of materials.

I had initially identified Punta Llorona, within the Corcovado National Park, as the designated control site. This selection was based on its conservation categorization and geographical distance from agricultural areas. However, due to the escalating presence of illicit drug trafficking activities and associated safety hazards in the area, the SINAC imposed restrictions on conducting scientific research in that particular sector. Consequently, I sought the expertise of local advisors to identify an alternative control site, which led to the identification of Boca Ganadito. Moreover, in general terms, the selection of sampling sites was informed by recommendations and guidance provided by local individuals during the initial two phases of fieldwork. The coordination and execution of these sampling campaigns would not have been possible without the collaboration of the *piangüeros/as*. The logistics involved in accessing the six sampling sites were highly complex, considering factors such as tides, distances, and the extraction of *piangua* (which can only be collected during low tide). Each sampling campaign entailed three full days of on-site work, visiting remote areas throughout the wetland by boat. Furthermore, it required securing a cargo vehicle, collecting equipment from the IRET-UNA laboratories, travelling to Sierpe to conduct the sampling, and subsequently transporting living organisms back to the IRET-UNA laboratories, to purify them under controlled conditions and start the laboratory work.

Fieldwork IV began in March 2021 with the objective to complete the pending sampling for the dry season and conduct interviews. The sampling was carried out in a participatory manner, involving *piangüeros/as*, selected individuals from Sierpe, Ajuntaderas, and the *parcelas*, with the supportive collaboration of a group of professionals in agronomic sciences. However, in April, a rapid surge in COVID-19 infections collapsed national hospitals, introducing a new set of complications and unforeseen circumstances. Within the framework of the collaboration with IRET-UNA, I successfully conducted laboratory analysis in ecotoxicology alongside Professor Freylan Mena, employing a battery of biomarkers on *piangua*. However, due to strict restrictions imposed at that time, the analysis of the results at the Pesticide Residue Analysis Laboratory (LAREP) could not proceed. During Fieldwork IV, I also returned to Indigenous Territories, and conducted a number of remaining institutional interviews, such as with the Costa Rican Institute of Fisheries and Aquaculture (Incopesca in Spanish) and Cooperative for the Commercialization of Oil Palm Producers in the Osa Peninsula (OSACOOP), and delved deeper into the agricultural aspects of the *parcelas* in the area of Palmar Sur. After each interview, I explored the plot with each *parcelero/a*, engaging in on-site observations of their agricultural practices, challenges faced, and pesticide applications. I also visited pesticide distribution warehouses and conducted interviews with sellers and resident agronomists, among others. In March, I organized and coordinated two community activities at Finca Chánguina, accompanied by two specialized agronomists from the Centre Specialized in Organic Agriculture at the National Learning Institute (CEAO-INA). One activity involved discussions with *parceleros/as* on the challenges of agroecological farming in their plots as a follow-up to the training they had received under the "*Mujeres Semilla*" program from CEAO-INA. Additionally, together with the CEAO agronomists and local leaders, we conducted an assembly with the participation of approximately 30-40 people, focusing on challenges and constraints regarding the use of pesticides on *parcelas*. This initiative resulted in a collective commitment to address the challenges faced in agriculture on the farms of Palmar Sur. And last but not least, during Fieldwork IV, I filed a *Recurso de Amparo* or Freedom of Information Request in the Costa Rican Constitutional Chamber against the director of the State Phytosanitary Service of the Ministry of Agriculture and Livestock to obtain information on the status of legacy registrations (see Chapter 2).

During Fieldwork V, I visited the *parcelas* again, accompanied by one of the agronomists from CEAO-INA to conduct a more specific diagnosis of the main challenges and obstacles. Subsequently, we organized a training course offered by CEAO-INA, which attracted a higher level of interest and participation than previously observed, likely due to the substantial increase in pesticide costs during that time. It is worth noting the heightened interest among *parceleros/as* in obtaining agricultural inputs at a lower cost.

Finally, I would like to share some reflections on the fieldwork. First and foremost, it would not have been possible without the invaluable support and collaboration of numerous people throughout the different phases of this project. Rather than acknowledging their contributions, I want to emphasize that it has been a collective effort, carried out in partnership with those who have believed in the project and generously dedicated their time and energy to contribute. Secondly, it is important to note that the process has been challenging and risky. The fieldwork periods I-IV were conducted without the availability of vaccination at that time. In addition to concerns about the potential transmission of COVID-19, which posed a higher risk for me as an asthmatic, there was a constant sense of concern and responsibility to prevent any transmission during the fieldwork activities. Moreover, the desolation caused by the pandemic exacerbated existing dynamics in the region, including the growing presence of drug trafficking. This is not a flashy context, as sometimes portrayed in the accounts of academics from the Global North who conduct fieldwork in the Global South and then return to their secure homes. The reality is much sadder and more challenging, involving navigation through highly turbulent waters, particularly for those who inhabit these places on a daily basis. I briefly mention these aspects as they prompt reflection on the risks encountered in research, the need to confront them, and to what extent they are worth it. I consider it important to highlight the aspects that did not go as planned, and the things that I wish I could have done differently. Presenting scientific contributions that only showcase achievements may create a misleading perception of the research process itself. This investigation is the result of facing dead ends, developing emergency plans, dealing with deep uncertainties, overcoming fears, and undoubtedly, learning valuable lessons along the way.

Methodological approach

In terms of research methods, I conducted semi-structured interviews, participant observation, workshops and archival research.I interviewed a total of 117 informants, some on several occasions depending on the need to go deeper into certain aspects. For instance, owing to the lack of available information in the archives about UFCo, I spent more time with former UFCo workers, which included field trips to observe their explanations on-site. During the two initial fieldwork phases, I identified the main sectors and institutions to interview, and in particular cases, also key stakeholders (e.g. state institutions representatives). Then, I used the snowball sampling technique, asking at the end of each interview for suggestions or recommendations (Gomez and Jones III, 2010). Throughout the fieldwork, I developed periodic working plans that included objectives, activities and a timetable. I continuously adapted this working plan based on the interviewees' recommendations in light of my own observations.

The interviews were conducted using a semi-structured approach, enabling me to ask pertinent questions while also giving space to discuss themes that I may not have initially considered. They took on average between one and a half to two hours. At the beginning of the research process, I developed semi-structured interview guides adapted to each sector of stakeholders, which I refined during Fieldwork II. Each guide was divided into different categories of analysis, such as life stories, agricultural practices and pesticide use, and risk perception, among others (see Supplementary Material for an example). In some cases, for instance, in the interviews that form part of Chapter 2, I adapted the guide before each interview, sharpening the specificities that each informant could provide on that specific topic. In the interviews more closely related to the Térraba-Sierpe wetland, I included a set of questions derived from the DPSIR framework, to use as an analytical window to address pesticide contamination of water ecosystems. Originally I thought the framework could serve as a bridge to relate informants' perspectives to specific conditions, which could later be triangulated with the ecotoxicology findings. In retrospect, it also served to flesh out some abstract issues.

The workshops held in *parcelas* and in the mangrove were designed and inspired by methods of critical geographies, such as counter cartographies, resulting from a process of joint creation and facilitation with the artist Diana Barquero (kollektiv orangotango+, 2018). We included activities to create linear and non-linear life stories, mapping of the waterscape and drawings about the relationship with the waterscape. The workshop conducted with stakeholders involved in pesticide regulation consisted of presentations and a collective debate. The other activities consisted of collective debates, facilitated through participatory techniques of popular education, to stimulate discussion (Vargas and Bustillos de Nuñez, 1987).

Regarding participant observation, throughout the fieldwork, I took notes during each interview and kept a fieldwork diary. Subsequently, I digitized the notes and systematized key information in an actor analysis table, incorporating elements from the diary. As I explained earlier, because of COVID-19 I sought to carry out open-air activities. These included cycling around the old banana plantation checking the remaining water infrastructure, learning to prepare *ceviche de piangua* from scratch, supporting meetings and tasks in the plots, learning to drive speedboats with *piangüeros/as*, going on boat trips through the mangrove swamp to talk about the reason behind some popular names of the estuaries, and so on. I provide these examples to illustrate the process of participant observation.

The interviews were transcribed both manually and using transcript software for the initial data systematization, and then I reviewed and edited them, focusing on those most relevant to the research. I used the MAXQDA software for two projects to code the information. In the first project, corresponding to the second chapter of this dissertation, I incorporated the complete notes and transcriptions of each interview, as well as systematic documentation of press notes on the topic. I organized the information according to pre-defined categories of analysis, and then conducted an inductive analysis that included various codes and new categories that emerged during the process. Finally, I conducted specific coding to identify mentions in the press based on regulatory instruments of analysis. In the second project, corresponding to the third and fourth chapters, I also included the notes and transcriptions of each interview. Due to the magnitude of the information and the complexity of each category, the coding system was more extensive. From both projects, I was able to identify key elements of analysis that I had not previously considered.

Regarding giving back the research findings, in October 2022, I organized an online seminar as part of the activities aimed at sharing and providing training based on the first publication. The seminar was titled "From the global pesticide complex to the pesticide use crisis in Costa Rica." We invited four speakers to discuss trade, regulation, hazards, and concerns related to pesticide use, placing Costa Rica within the global context. The seminar had around 100 participants principally from Costa Rica. In early 2024, I will travel to Costa Rica to share the findings from the remaining three chapters/articles. To accomplish this, I will organize activities in the study area that will include popular education tools. Additionally, I plan to hold meetings with relevant state institutions to inform them about the study results.

1.5 Positionality

My positionality is a two-fold story. On the one hand, I explain the background that led me here, which is a process that goes far beyond myself. On the other hand, I situate the research based on my personal experience.

Collective questions

In October 2007, I participated for the first time in a meeting of the Foro Emaús. This space, founded in 1992, brought together various social organizations concerned about the human and environmental health impacts of the banana agro-industry (Barraza et al., 2013). Within Foro Emaús, a working committee had been formed to address the issue of pineapple production in the North Caribbean region as pineapple cultivation expanded in the area. Amidst cups of coffee and the humour that characterized many of its members, I began to unravel a demanding and challenging work agenda that reflected several longstanding issues. On that day, community members from La Perla in Guácimo, Limón, who had organized themselves in response to the establishment of a pineapple plantation in the upland areas of their community, expressed concerns about the potential impacts pineapple cultivation might have on their water quality and supply. I also had the opportunity to meet Erlinda Quesada, Carlos Arguedas, and Mayra Eugenia Umaña, who have been staunchly fighting for dignified living conditions for neighbouring communities and workers in banana and pineapple plantations. The following year, on March 8, 2008, the La Perla community, supported by the Foro Emaús, convened a national gathering of communities affected by pineapple production in the Huétar Norte, North Caribbean, and South Pacific regions. It was on that day that the National Front of Sectors Affected by Pineapple Production (FRENASAPP in Spanish) was born, serving as an articulation space. As part of my work at an environmental NGO, I closely accompanied FRENASAPP's efforts and the struggles of the Milano, Cairo, Louisiana, and La Francia communities in Siquirres, Limón, as they confronted the issue of pesticide contamination in their drinking water caused by pineapple cultivation (Cuadrado-Quesada, 2020). We organised numerous activities to discuss the problem of water contamination and its implications for the affected communities. Furthermore, together with Xinia Briceño, and other people from the affected communities, we filed numerous legal and juridical actions, until we exhausted all existing channels at a national level, and requested a hearing at the Inter-American Commission on Human Rights in 2015 (Castro-Vargas et al., 2015).

In tandem with these activities, since 2004, I have been closely associated with environmental organizations in Costa Rica, particularly the *ecologista* movement. This movement has consistently addressed pesticide-related issues from various perspectives. It emerged in the late 1980s as a distinct branch of environmentalism, setting itself apart from other approaches through its strong critique of extractivist activities (Franceshi, 2002). Over the years, this movement has spearheaded social struggles to defend common goods and territories, encompassing a broad range of causes, from mobilizing against the 2009 Free Trade Agreement with Central America and the Dominican Republic (CAFTA-DR) to opposing genetically modified crop cultivation, and open-pit mining. Since 2011, the *ecologista* movement launched the campaign "Stop Fumigating" in response to mounting concerns about the intensive use of pesticides in domestic agriculture. This campaign, along with other ongoing struggles, has played a pivotal role in raising awareness about the impact of pesticide exposure on human and environmental health. Moreover, in 2016, the *ecologista* movement actively engaged in the debate surrounding pesticide regulations, drawing upon past experiences related to water contamination. Some of their actions have included advocacy strategies to ban pesticides such as paraquat, chlorothalonil or glyphosate, or dissemination actions about the hazards of pesticides used in the country.

I refer to these two trajectories because they constitute key background to my research, and my questions and the way I position myself and act in certain contexts stem from these processes. The involvement in these long-standing struggles and debates has also served as a foundation and driving force throughout the whole process. When one door closed, it allowed me to seek alternative paths, such as pursuing a court action to access unavailable information, requesting documents through multiple channels to each of the entities involved, and persistently searching for data, even if it didn't always yield results.

Untangling the personal as political

I did not write this thesis from a kind and quiet place, on the contrary, I did it between distress and tachycardia, but trying to advance at any cost because I could not allow myself to fall into complaints. Here, I will give a brief account of my experience during this process, because I think it is important to name the place where our reflections, our thoughts, are based. I bring this up because I have been, and I am still, profoundly angry, and this rage, I think, is valid and legitimate. Rage, as indicated by Bell Hooks (1995), can potentially be constructive and act as a catalyst that inspires us to take action. Specifically in academic production, rage can enhance mobilization and transformation (Delpino-Marimón et al., 2022). I expose my experience because I think it might be useful for someone who identifies or feels reflected in it.

I did my PhD with a scholarship from the Ministry of Science of Costa Rica. Being a Costa Rican scholarship holder, I did not have access to a research contract, in contrast to all my PhD colleagues and the large majority of ICTA-UAB researchers. However, as I did not have a contract, I could not obtain a residence permit, subjecting me to temporary student-stay permits. In the Spanish migratory context, this generated uncountable difficulties and injustices. The Costa Rican scholarship posed challenges from the beginning due to recurring delays in disbursements of my stipend. These delays escalated over time, stretching from three months to seven, nine, and ultimately reaching fourteen months in the final year. The situation worsened with the closure of the scholarship program, the dismissal of employees, and the dismantling of the National Council for Scientific and Technological Research (CONICIT), transformed into the Costa Rican Promoter of Innovation and Research, as part of neoliberal reforms in Costa Rica. Consequently, we, the self-proclaimed "scholarship holders without a scholarship," became around ten files lost in a system of unresolved cases.

When the pandemic started, I was doing fieldwork in Costa Rica when airports were shut down. As I explained in subsection 1.4, I had planned to travel to the US and then return to Costa Rica to continue fieldwork. Due to the airport shutdown, I could not travel until nine months later. Because of that, I was penalized by the MICITT, downgrading my scholarship to less than 500 euros during all months of fieldwork without previous notice (which was around one thousand euros, depending on the exchange rate). That is, the next year, they paid me less money retroactively. This situation has brought endless problems, as you can imagine, to sustaining life in this territory. Furthermore, it exacerbated the existing challenges related to migration. Due to the lack of payments for my stipend and university fees, coupled with the inability to demonstrate sufficient funds in the bank, obtaining the yearly study permit became even more complicated.

Over the past two years, these complications have taken a toll on my well-being, leading to the development of a retinal illness diagnosed as stemming from a state of general anxiety. Unfortunately, without a contract, I did not have the right to medical sick leave, leaving me no choice but to continue studying/working despite my health concerns. The lack of scholarship payment during the last fourteen months before handing in the thesis meant living out of loans from my PhD colleagues who kindly supported me. Moreover, at the beginning of 2023, my mother fell and broke her hip. However, due to my irregular migratory situation, I was unable to travel to assist her. Being an only child added to her delicate health condition, implies that her care is one of my priorities and responsibilities. Thus, this situation was very painful, and it highlights how my scholarship problems, the lack of a contract, the discriminatory migration policies from the EU, and the global North-global South relations interrelate creating an asphyxiating mesh.

Nowadays, it is fashionable to discuss decolonizing academia. However, I don't see this translating into efforts to address the racism and colonialism prevailing both inside and outside universities (e.g. political arena), nor into acknowledging the uneven geographies of knowledge. The fact that our countries are fostering this kind of neoliberal dismantlement of state scientific institutions and universities deepens these uneven circuits of knowledge. As evidenced by Borras (2023), the great majority of authors in the Journal of Peasant Studies, including corresponding authors and co-authors, are from the Global North, which is clearly not a coincidence.

I allow myself to end with some questions, which are questionings more than questions: Which lives have a place in neoliberal academia? Whose lives? Where do they think from? How? And, under what conditions?

1.6 Dissertation outline

In this dissertation, I aimed to answer my research questions through four analytical lenses, included in four empirical chapters.

Chapter 2 examines the gridlock of the pesticide registry, a regulatory process for approving pesticides assumed to be collapsed. Despite different regulatory reforms spanning nearly two decades, the registry is widely acknowledged as dysfunctional, with many pesticides in administrative limbo and few new compounds approved. Through interviews and policy analysis, I identified four reform phases and analyzed the process through a strategic-relational approach to the state. The chapter concludes that the registry's impasse reflects a form of governance called "regulation by impasse", perpetuated by conflicts among ministries, juridical bodies, and other regulating authorities in relation to the shifting strategies and contexts of political economic and wider social forces. Ultimately, the hegemony is tenuously maintained through the registry dispute itself, revealing the deeply frayed condition of the Costa Rican development model.

Chapter 3 investigates pesticide use in the southern Pacific region of Costa Rica over the long twentieth century, starting from *parceleros/as*' aspirations and obstacles to cultivate livelihoods and forge agrarian futures in plantation lands. This analysis calls for deeper attention to shifting institutional orders, socioecological legacies, and commercial dynamics that maintain pesticides over time at the center of our agro-food ecological regime. More than inputs, I show how pesticides serve as stabilizing agents for an ecological regime that depends upon the surpluses that they gather: as byproducts of extractive industries, as compounds that externalize harms, and as biocides that tap organisms' susceptibility. Here, I conclude that the susceptibility of monocrops to pathogens, and the erosion of these target organisms' susceptibility to pesticides, create a patchwork of biotechnical and chemical fixes. The reworking of this patchwork maintains accumulation via monocrop plantations, and also conditions proximate land-based rural livelihood strategies.

Chapter 4 builds on the notion of waterscapes as a conceptual tool to interrogate the scope of the plantation as an object of agrarian studies. Plantations are objects of renewed inquiry in agrarian studies, however, taking them as an object can risk universalizing understandings of agrarian transformations. Key elements in agricultural production, like water and agrichemicals, have not previously been considered in such studies, even though they play a determinant role in shaping agrarian landscapes. This chapter investigates the plantation through the lens of waterways and hydrological infrastructure in a historical and geographical context. I do this by 1) analysing how UFCo created a water system for drainage and irrigation that expanded the area of the plantation beyond its territorial limits and that persisted through time, conditioning the spatial dynamics through successive land uses and increasing the magnitude of floods due to climate events, 2) examining what occurs beyond the apparent limits of plantations by following effluent flows, sediments and pesticide residues along the delta, 3) exploring how plantation legacies are expressed not only in the pesticide stratification (e.g. copper residues in the soil), but also as a remainder in the population, reshaping territories and subjects. Finally, I argue that the delta materializes the ever-changing configurations of agrarian capital in and through plantations.

Chapter 5 provides an overview of the conclusions reached in each chapter and highlights the main methodological and theoretical-empirical contributions made in the dissertation. Finally, the chapter concludes by offering insights into future research directions.

Chapter 6, included as Appendix 1, takes an ecotoxicological approach, identifying and quantifying pesticide residues in water and sediment samples in the Wetland Térraba-Sierpe and its areas of influence, as well as testing a battery of biomarkers in the bivalve mollusk *Anadara tuberculosa*. Results showed pesticides in the Térraba river waters and the northern Térraba-influenced wetland area, with diuron, carbendazim, diazinon and ethoprophos being at the highest concentrations. The geographical distribution of these substances and their utilization in pineapple cultivation suggest an association between this agricultural activity and the observed impacts on the wetland. Moreover, *A. tuberculosa* proved to be a suitable organism for biomarker assessment of pesticide contamination in the area, although further studies will be required to calibrate these biomarker responses under different salinity conditions and reproductive stages.

Lens I: Power geometries and regulations

LOS TOMATES

Le doy vueltas al tomate
bajo el agua fría
siento su turgencia
mientras una punzada
se me mete en el estómago.
Los tomates
que se los llevaron un día en barco
al otro lado del charco
los tomates
que bañan pizzas
y tradiciones gastronómicas
los tomates
tan típicos de tantas partes
los tomates
por los que me gusta discutir
en conversaciones absurdas
los tomates
cargados de plaguicidas
para los mercados populares
Corto el tomate
y le digo a mi abuela
"tita, ¿usted sabe que debería comprar tomates ecológicos,
porque estos tienen muchos agroquímicos...?"
no he terminado la frase
y ya me siento absurda
mi abuela
que con costo y tiene tomates
se me queda mirando
pienso en mi infancia
la familia, el barrio, la feria
los tomates de fondo
como tantas frutas y verduras
envenenados.
Me quedo en silencio
me siento en la mesa
y agradezco la comida de mi abuela

Soledad Castro Vargas

TOMATOES

I spin the tomato
under cold water
I feel its turgidity
while a pang
gets in my stomach.
Tomatoes
who were taken away
on a ship one day
across the ocean
the tomatoes
that bathe pizzas
and gastronomic traditions
tomatoes
typical
of so many places
tomatoes
for which I like to argue
in foolish conversations
tomatoes
loaded with pesticides
for the popular markets
I cut the tomato
I say to my grandmother
"Auntie, do you know that you should buy organic tomatoes?
because these have a lot of agrochemicals...?"
I haven't finished the sentence
and I already feel stupid
my grandmother
who barely has tomatoes
stares at me
I think of my childhood
the family, the neighborhood, the street market
the tomatoes in the background
like so many fruits and vegetables
contaminated.
I remain silent
I sit at the table
and I thank my grandmother's food.

Soledad Castro Vargas


SOLO PERSONAL AUTORIZADO
PELIGRO
"GREEN GO"
PARAQUAT 20 SL
RADAMENTE PELIGR
RADEX 20 SL
MODERADAMENTE PELIGROSO
SERACSA
SERAXONE 20 SL
RADAMENTE PELIGR
LAVAX 20 SL
MODERADAMENTE PELIGROSO
Rafaga 20 SL
MODERADAMENTE PELIGROSO
GRAMOXONE SUPER 20 SL
MODERADAMENTE PELIGROSO

Regulation by impasse:

Pesticide registration, capital and the state in Costa Rica

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Highlights

• Prodigious pesticide use is pivotal to Costa Rica's plantations and smallholder production in tension with its image as a 'green republic'.

• We examine a two-decade effort to modernize the country's pesticide registry.

• The result of reforms is continued gridlock that de facto extends legacy pesticides with no risk data and hampers new registrations.

• A strategic-relational approach to the state is used to understand the multi-scalar and institutional dynamics that shape the registry dispute.

• The concept of 'regulation by impasse' is developed to understand this outcome in the context of the country's frayed green development model.

Abstract

Costa Rica's prodigious use of pesticides, as well as the burgeoning plantation sector that these agrochemicals support, exacerbates the tensions between extraction and preservation at the heart of the country's development model. We explore these tensions through a study of the country's pesticide registry, the regulatory process to approve active ingredients and formulations for use. After nearly two decades of reform efforts, the registry is widely recognized to be non-functioning: most of the country's pesticides exist in administrative limbo and relatively few new compounds have been approved. Based on extensive interviews and in-depth policy analysis, we construct four phases of reform and use a strategic-relational approach to the state to analyze this process. We conceptualize the registry's gridlock as a form of governance that we term regulation by impasse, an arrangement reproduced through disputes within and between the cognizant ministries, juridical bodies and other regulating authorities, in relation to the shifting strategies and contexts of political economic and wider social forces. We argue that hegemony is tenuously maintained through the registry dispute itself, while revealing the deeply frayed condition of the Costa Rican development model.

Keywords Political economy, environmental governance, critical state theory, environmental movements, chemical geographies

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2.1 Introduction

In June, 2020, the Director of the State Phytosanitary Service (SFE in Spanish), the agency responsible for the country's pesticide registry, convened a meeting of stakeholders from Costa Rica's ecologista movement.[1)] The Director sought to explain reforms that his office was making to the registry, i.e. the regulatory process to approve active ingredients, formulations and other chemical ingredients in pesticides for use. He repeated a narrative that reverberated in the press, sector reports, and in interviews conducted by Castro-Vargas with representatives of the agrochemical sector (e.g. Sáenz Segura and Chaves Moreira, 2013; Vargas, 2017). The pesticide registry 'was collapsed', he explained. New registrations suffered innumerable delays and efforts to regularize old registrations led to mountains of files that could not be efficiently evaluated. An office chair with a stack of papers about one meter high was presented to the attendees as evidence of the kind of bureaucratic obstacles faced by his office. He explained the reasons for Costa Rica's defunct pesticide registry in the following terms:

> Part of the peculiarity that characterizes Costa Rica as different in the region is our legislation -- environmental, health, labor and the rest -- which is also different. We could not be different if we simply did everything the same as the other [Central American] countries. This historical dispute [over the registry] has been many years in the making, and has generated much jurisprudence, rulings, criteria and other situations that have in some cases diverted us from what we should be doing, which is to work scientifically and technically, and in proper order, to attend to each case.

The Director's explanation reflected both popular and academic narratives of Costa Rica as an exceptional country in the region given its relatively peaceful and democratic political history (Acuña, 2002; Jiménez, 2005), and, more recently, its record of environmental governance.[2)] Not lost on the Director was the significance of his audience: several of those present had led struggles to restrict pesticide use and had filed demands for stricter registration protocols. The Director outlined a detailed plan to revamp the process for registering pesticides and promised to convene the group again for consultation. A representative from the Export Promotion office continued. She warned

[1)]This term is used by a broad range of organizations and actors in Costa Rica to designate a focus on social and ecological transformation, and to distinguish their politics from green or conservationist movements that marginalize broader social, systemic demands (Fallas, 1992). The movement was born during the late 1980s, articulated in various social organizations. These groups have successfully mobilized a broad public around socio-environmental struggles (Montero, 2013; Álvarez and Casa, 2020).

[2)]The invention of Costa Rican difference emerged after independence (1821–1870), based on the idea of constituting a people who were democratic, peaceful, homogeneous, and constructed as "white" and of European origin. The elimination of the army following a brief civil war (1948) and subsequent promotion of the country as civilized and educated extended the idea into the late twentieth century (see Acuña, 2002; Jiménez, 2005).

that the registry's collapse was forcing Costa Rican farmers to rely on older generation pesticides that could lead to loss of export markets in North America and Europe due to restrictions on these compounds, a claim frequently repeated by industry representatives (Croplife, March 2020, interview).

As various scholars have noted, the Costa Rican state has constructed its hegemony across the conflicting priorities of conservation and natural resource exploitation (Fletcher et al., 2020; León Araya, 2021; Obando Campos, 2020; Ramírez Cover, 2020). Following three rounds of structural adjustment, the country's democratic legacy and technical capacity were mobilized to support a green development model based upon an extensive system of protected areas and ecotourism. Yet Costa Rica's reputation as the 'Green Republic' (Evans, 1999) rested upon a paradox: it was both a global leader in conservation policy and simultaneously a center of practices, innovations and technologies for monoculture agro-exports (Ramírez Cover, 2020). Spurred by foreign investment, state promotion policies and domestic innovations in agronomic sciences, plantation agriculture has expanded in the past decade, deepening these tensions in the country's development model (Galt, 2020; León Araya, 2021). Central both to the plantation sector and smallholder agriculture is the prodigious use of pesticides (Galt, 2014). A highly contentious calculation, even among different state institutions, the Agriculture Ministry estimates use intensity at 11.50 kg a.i./ha, while the Environment and Energy Ministry (henceforth Environment Ministry) and the UNDP recently published significantly higher estimates, 32.56 and 34.45 kg a.i./ha, respectively (SFE, 2020b; Vargas, 2019; 2022). A comparative study found Costa Rica to have the highest use intensity among middle-income countries (24.3 kg a.i./ha), and the third highest among all 119 study countries (Schreinemachers and Tipraqsa, 2012).

Mired in regulatory gridlock, the bulk of the country's pesticides exists in an administrative limbo, while approvals of new pesticide registrations for domestic use have been reduced to a mere trickle. A series of reforms enacted over nearly two decades – negotiated and stalled at the crux of tensions among sectors of pesticide capital, the skilled activism of ecologistas, and disputes within and between the cognizant ministries and other regulating bodies – has not yielded an administrative resolution. We take this long-standing regulatory dilemma as a window through which to examine struggles over the terrain of the state itself and how these ultimately shape environmental governance. We argue that the 'collapse' of the country's registry is neither simply a product of serial failed reforms, nor a deliberate strategy by a subset of actors. Rather, we conceptualize this non-functioning of the registry – evident in four phases of reform that we construct below – as a form of governance that we term regulation by impasse. Regulation by impasse is an arrangement arrived at and reproduced through the contested efforts of the state to suture hegemony across class and intra-class conflicts stemming from the inherent tensions within the country's development model. Particularly crucial to our analysis is the institutional terrain of the state: far from homogeneous, regulation by impasse is reproduced in part through disputes within and between the cognizant ministries, juridical bodies and other regulating authorities. As we show, the boundaries of the state are porous and contested, not only in the most common sense of ‘revolving doors’ between government and industry, but also in terms of perceptions and actions of ecologistas and technical staff in the ministries. We conclude that as a form of environmental governance, regulation by impasse manifests the deeply frayed condition of the Costa Rican development model.

The paper is based on eighteen months of fieldwork conducted between 2018 and 2021 by Castro-Vargas as part of a larger study. We undertook an initial analysis of relevant policy documents, press articles and legal filings to identify key actors. A total of seventeen key-informant interviews were conducted with representatives of the generic and research and development (R&D) agrochemical sectors, domestic pesticide company executives, industry agronomists, technical staff at the SFE and the Environment Ministry’s Quality Management office (DIGECA in Spanish), a former Minister of Agriculture, and leaders of the ecologista movement. Repeat interviews were conducted with several key informants for further clarification. In addition, CastroVargas attended a dialogue session convened by SFE with key stakeholders. Interview materials and observations were triangulated with three other principal sources of information. First, Castro-Vargas conducted an extensive review of policies, decrees, laws and petitions to the Constitutional Chamber; petitions were sorted and analyzed by key actor and thematically coded. Second, we analyzed all publicly available pesticide registrations by policy instrument. Third, Castro-Vargas successfully obtained data on the status of backlogged registrations hitherto not disclosed publicly by filing a freedom of information request with the Constitutional Chamber. Finally, both authors held a workshop with relevant stakeholders to share preliminary results.

In what follows, we develop our argument in four sections. First, we introduce Costa

Table 1. Key terms for pesticide registration.

Term	Description
Risk data	Data on chemical identity, efficacy, toxicological and ecotoxicological studies, etc.
Complete data package	Risk data required to file for registration; standards of what is considered to be a complete package vary by country and supra-national institution (e.g. OECD).
Reference profile	A complete data package of an active ingredient registered by R&D companies, evaluated and approved during the registry process.
Registration by equivalence	Principal mode to register generic pesticides. Generic firms seeking registration need only to show that the pesticide is chemically equivalent (e.g. measure of impurity, etc.) to a pesticide with an approved reference profile.
Referenced information	Publicly available scientific studies or an approved database to allow for registration by equivalence, without a reference profile; a novel concept introduced in Costa Rica.
Registration by incorporation	Registration of an active ingredient through recognition of either studies or a registration in an approved reference country.

Source: the authors.

Rica's regulatory dispute and the strategic-relational approach to the state that we use to understand it. This approach interrogates the state as a set of contested social relations and highlights the conjunctural nature of environmental governance within structural constraints. We proceed to construct four phases of pesticide registry reform in the following section 'Reproducing regulatory gridlock'. We demonstrate how regulatory gridlock is reproduced through disputes within and between different organs of the state, fractions of pesticide capital and the ecologista movement. In 'Regulation by impasse: Struggles over the terrain of the state', we analyze the reform process through a multi-scalar, strategic-relational lens. We focus on the shifting dynamics of agrochemical capital domestically and internationally, in relation to social contests over the boundary and role of the state. Through this analysis, we develop our argument that the pesticide registry dispute is a form of regulation by impasse, wherein hegemony is tenuously maintained through the dispute itself. We conclude with reflections on the implications of our study for our understanding of the Costa Rican development model and environmental governance more broadly.

2.2 Environmental governance through institutional struggles within and beyond the state

Our study builds on Jansen (2017b), who focused on the global contest between the two sectors of pesticide capital as it played out in an earlier effort to reform Costa Rica's pesticide registry (i.e. Phase 1, below). Jansen analyzed the business conflict between R&D agri-business multinationals (ABMs) and the generic sector. At the time, the latter was comprised principally of domestic firms, with arms-length links to generic ABMs. In the late 1990s, R&D ABMs moved to extend intellectual property rights to the *risk data* required to register patented pesticides and to expand the data requirements to register generic pesticides (see Table 1 for all definitions of italicized terms). These efforts were enshrined in UN Food and Agriculture Organization (FAO) guidelines issued in 1999 and Regional Trade Agreements, including the Dominican Republic, Central America Free Trade Agreement (CAFTA-DR). These changes made generic pesticide registrations more difficult because they increased the requirements to establish equivalence between an already registered compound and a generic product. *Registration by equivalence* is the principal mechanism for generic product registration since generic firms do not have the resources to prepare and submit a *complete data package*. These actions by the R&D ABMs hampered access to the *reference profiles* that generic firms needed to establish equivalence, making registration more difficult and delaying it further due to extended data protection timelines. R&D ABMs succeeded in instituting ten-year exclusivity on risk data via CAFTA-DR, thereby inhibiting generic registrations. The contentious struggle over adhesion to CAFTA-DR in Costa Rica thus saw the generic pesticide sector align with small and medium farmers in opposition to the agreement. This coalition mobilized an antiimperialist framing that positioned generic agrochemical firms as champions of domestic agriculture. In this narrative, generic firms secured lower prices for Costa Rican farmers, whose markets were already threatened by the impending trade liberalization. In the wake of a national referendum that was narrowly lost by opponents of the trade agreement, the state sought to mediate between the R&D and generic sectors in order to find a consensus that would satisfy both parties (Ibid.).

There are two reasons for reexamining the Costa Rican pesticide registry in light of this earlier work. First, the structure of the global agrochemical industry has changed radically over the course of the last decade, with important implications for the generic sector in Costa Rica. Industry restructuring driven in part by Chinese industrial policy, coupled with a dearth of new, patented chemistries, has led to a shift in the market share of generic products and the power of generic agrochemical firms globally (Oliveira et al., 2020; Shattuck, 2021). From 2011 to 2019, generic firms' market share grew from 30 to 40 percent, while the share of generic products increased from 50 to 75 percent (PMD, 2021). Generic ABMs, in turn, have grown considerably over the decade and expanded their territorial reach through exports, licensing, mergers and acquisitions. Moreover, the boundary between R&D and generic companies has blurred. R&D companies increasingly sell off-patent chemicals and employ value chain strategies to sustain their industry dominance (Werner et al., 2022). These institutional changes in the agrochemical sector beg the question of their effects on national pesticide regulations. As we discuss below, Costa Rica offers a key site to address this question because of the growth in its generic formulation sector and increased participation of generic ABMs in the country.

If competition between generic and R&D pesticide firms is attenuated by these changing commercial dynamics that blur their boundaries, the proposed solution for registration through a modality called incorporation should have yielded a stable detente. Registration by incorporation allows for pesticide registration based either on studies or a registration in a reference country or region, often the US or the EU. This modality, proposed as part of a series of decrees aimed at breaking the regulatory gridlock, would avoid the need for R&D ABMs to release proprietary data to Costa Rican authorities, while easing the burden of registration for generic firms by allowing them to register products without a reference profile in the country. The failure of this proposal, we argue, cannot be fully explained by the business conflict.

The second reason to revisit this case, then, is to better understand the dynamics of additional key players whose actions offer unique insights into environmental governance, the state and regulatory forms. Although *ecologista* groups were not initially involved in the pesticide registry debate, long-standing struggles over pesticide contamination and campaigns to ban particular substances (e.g. paraquat, glyphosate) led to their involvement in pesticide registry reform. The on-going debate and long series of decrees, injunctions and legislative proposals have brought tensions between and within government ministries into sharp relief, uncovering the role played by midlevel technical staff. As we expand upon below, the roles played by civil society actors and technical staff raise important

Table 2. The four phases of registry reform.

	Principal instruments	Main provisions	Outcomes
Phase 1: 2004-2009	DE-33495; Law 8702	Three registry modalities established: registration by full data package, registration by equivalence, registration of formulations; sets 10-year terms on registrations; all previous registrations must be 'revalidated'	400 old registrations revalidated; 16 registrations issued over next decade
Phase 2: 2016-2019	DE-40059; DE-39995; DE-41481	Introduction of registration by incorporation using sworn statement, loosened registration by equivalence using 'referenced information' rather than standard reference profile; use of 'referenced information' to update old registrations; dispense with revalidation process for old registrations	149 registrations processed but not granted; all three decrees suspended by Constitutional Chamber
Phase 3: 2020-2021	DE-42769; DE-42262; DE-43469	Registration by incorporation using OECD process and OECD countries as reference; introduction of registration by incorporation in the main regulatory instrument	1513 registrations plus 371 registrations temporarily revalidated in Phase 1 exist in administrative limbo.
Phase 4: 2021-?	Bill #22437; DE-43563	Sworn declaration sufficient for all registrations currently active or in process of renewal; simultaneous recognition of studies from several OECD countries in a single registry	Yet unknown

Source: the authors.

analytical questions regarding the boundaries of the state itself. Just as many *ecologistas* perceive the state as a mediator for, or an agent of, agribusiness capital, the pesticide industry views part of the state bureaucracy as a redoubt for radical environmental interests.

To account for the variety of actors and their relationships to the state, this paper adopts a strategic-relational approach (Jessop, 2008). Building on the work of state theorists Antonio Gramsci and Nikos Poulantzas, the strategic-relational approach offers systematic insights into state power as a social relation that mediates between class and political forces, themselves not taken as coherent but rather conjuncturally determined. '[T]he state is neither a unified subject nor a neutral instrument', Jessop explains, 'but rather an *asymmetrical institutional terrain* on which various political forces (including state managers) contest control over the state apparatusand its capacities' (2008: 31, emphasis added). State power is not presumed to be wielded by authorities representing particular class interests; instead, state power is a problematic that is investigated to understand the changing balance of forces that shape its exercise. From this perspective, environmental governance cannot be presumed to represent the interests of capital since, in the first instance, the interests of capital are fractured by competing firm-level, sector (i.e. chambers of commerce) and broader political (i.e. party) objectives (Burawoy, 2003; Gramsci, 1971). The strategies mobilized by different political economic forces to shape state action are developed in relation to state structures and the strategies of other social forces, or what Jessop called ‘strategic selectivity’ (1990). Moreover, the coherence of state structures, as an ‘operational unity’, is not a given butrather an outcome achieved (or not) though the tactics and strategies of state officials (Ibid.).

A significant strength of this approach for our analysis is its explicit treatment of spatio-temporal dimensions. Analyses of neoliberalism that mobilize strategic-relational or analogous critical realist framings of the state demonstrate how past strategies and settlements shape current struggles and regulatory forms (Brenner et al., 2010). The forms that environmental regulations take reflect not only the constrained actions of political forces both within and outside of state institutions, but also how these forces are shaped and conditioned by the political economic settlements of previous rounds of accumulation. Changes in political economic, environmental and social relations at multiple scales combine with these past trajectories of political settlements to create novel regulatory arrangement. In particular, as geographers have long noted, political scales can constrain or enable opportunities for political strategies (see Marston, 2000). In the case of pesticide registration, as we noted, global norms and regional trade agreements were mobilized in the early reform period to enshrine the particular interests of R&D capital. More recent efforts to harmonize registry procedures draw upon norms established by the Organization for Economic Development and Cooperation (OECD) as part of Costa Rica’s accession to that organization. As others have shown, and as we demonstrate below, these global norms do not simply drop onto the desks of government ministers for implementation (Peck and Theodore, 2015); rather, extra-national norms and regulations are mediated and shaped by domestic contests over the role of the state in environmental governance. Our analysis thus deepens understanding of the Costa Rican state, while signaling actually existing mechanisms that shape pesticide flows and thus environmental outcomes in the country.

2.3 Reproducing regulatory gridlock

We reconstruct the registry’s regulatory gridlock in four phases (see Table 2). Phase 1 corresponds to the precedent-setting intervention by the Auditor General of the Republic (henceforth Auditor General) in 2004. The Auditor General argued that the country lacked a clear national policy on pesticides and demanded reforms that would both reduce the country’s reliance on them and address their socio-environmental consequences (CGR, 2004). The Auditor General also contended that the SFE, under the authority of the Agriculture Ministry, dispensed with scientific evaluations consistent with international standards and instead prioritized commercial concerns through ‘the facilitation of pesticide registration’ (Ibid: 12). Based on these findings, the Auditor General mandated that pesticide registration become the joint mandate of the Agriculture, Environment and Health Ministries as the competent authorities for granting pesticide registrations. Finally, all existing registrations were suspended until new regulations could be approved.

Following the Auditor General's intervention, the first national regulation on pesticides to require a complete data package for risk analysis was issued in 2006 (DE-No 33495-MAG-S-MINAE-MEIC,2007; Jansen, 2017a; see Table 1). Previously, registrations were not term-limited and formulations were approved without prior approval of their active ingredients. The new decree authorized registrations for ten-year terms that would now be issued under three different registration modalities: registration of technical grade active ingredient (henceforth active ingredient) with a complete data package (i.e. for patented compounds), active ingredient registration by equivalence (i.e. for generic compounds) and registration of formulated synthetic pesticides and co-adjuvants (i.e. for patented and generic substances).[3)] Crucially, the regulation established the mandatory updating or revalidation of all existing registrations in the national registry under the new regulatory requirements, allowing three or four years for revalidation depending on whether the registration in question was dated before or after 1995. Law 8702 (2009) was passed as a three-year stopgap measure to facilitate the revalidation process by extending the deadline and easing some requirements (Jansen, 2017b). Although some 400 registrations were successfully revalidated under the law, the temporary pause on new registrations between the Auditor General's intervention and the issuance of DE-33495, combined with the lack of supporting information necessary for the revalidation of old registrations, created a backlog of unresolved registry files.

The second phase of the registry reform process began in 2016, ten years after the initial reform was passed and which, by all accounts, had failed. Only sixteen registrations had been issued over the decade and well over a thousand registrations had never been brought into compliance.[4)] A series of four executive decrees were issued as part of a coordinated effort to fully transform the registry and resolve the gridlock (Defensoría de Habitantes, 2018). The Minister of Agriculture, Felipe Arauz, led the reform effort promising to break this deadlock with direct support from the Costa Rican President's office. For negotiations, he relied heavily on the then-President of the National Chamber of Agriculture and Agribusiness (CNAA), Juan Rafael Lizano, who was a former Minister of Agriculture and highly respected within the business community. Lizano mediated between the R&D ABMs, organized into the Chamber of Agriculture and Livestock Inputs (CIA in Spanish), and the National Chamber of Generic Producers (CANAPROGE). Lizano was initially successful in getting both groups to agree not to take any legal actions against the new decrees (Arauz, March 2020, interview). Presiding over the public release of these decrees, the President of the College of Agronomists heralded them as bringing an end to 'a very dark stain on our agricultural history' (Chacón, 2017).

[3)]A fourth modality, registration for co-formulants, is both a minor category and marginal to the registry dispute. We exclude it from our analysis.

[4)]For comparison, 3958 registrations were on the books from 1969 to 2007 (Seminario Universidad, 6 July, 2020).

The principal decree (DE-40059), signed by all three ministries (Agriculture, Health and Environment), sought to replace the failed 2006 reform as the main legal instrument for pesticide registration. Two main stipulations stand out. First, the decree expanded the modalities for registration by introducing the figure of registration by incorporation (see Table 1). This modality verified compliance in the reference country of registration instead of requiring an evaluation of chemical, toxicological and ecotoxicological studies by the competent national authority. In the Costa Rican case, registrants would submit a statement attesting to the existence of these assessments in the reference country. Second, the decree significantly loosened requirements for registration by equivalence for generic active ingredients without a reference profile. To comply with the stricter CAFTA-DR data protections, the new regulation permitted registrants to submit referenced information, or publicly available studies, to allow for registration by equivalence without a reference profile. The decree favored generics even further by replacing the FAO-standard of equivalence testing for a sworn statement attesting to the chemical's purity (DE-40059-MAG-MINAE-S, 2016; Defensoría de Habitantes, 2018; Dirección de Gestión de Calidad Ambiental, 2018).

The decree was the subject of a series of inter-institutional discussions that took place over aperiod of nearly two years. The mid-level technical staff at the three Ministries strongly opposed the decree, but their opposition was not heeded by the ministerial authorities (e.g. Constitutional Court File DE-39995, 2019; Constitutional Court File DE-40059, 2018). The confrontation between these two levels of government (i.e. technical staff and political directorate) led to the intervention of the government Ombudsperson's Office, which initiated a mediation process with representatives from both levels of the three ministries. The main points of disagreement were the centralization of the registry in the Agriculture Ministry and the lack of legal precedent, basis in international instruments and scientific rigor of the apparently novel concept of referenced information. The failure to achieve a compromise between the technical and executive levels of the threeministries led the Ombudsperson's Office to file an action of unconstitutionality against DE-40059 in the Constitutional Chamber (Defensoría de Habitantes, 2018), leading to its suspension. Although the Ombudsperson's actions stemmed from tensions within the cognizant Ministries, the results reverberated through civil society, reflected in a series of press releases and articles from the business sector, which had largely united in support of the decree (Lanzas, 2019; Molina, 2018), and the *ecologista* movement, which had opposed it (e.g. Chacón, 2018; FECON, 2017). The SFE continued to process applications for registrations but was unable to grant them until the challenge was resolved, thereby increasing the administrative backlog. These included 11 active ingredients in process with a complete datapackage, 84 active ingredients in the process of registration by equivalence and 54 formulated products in the process of registration (SFE, 2021a). No registrations by incorporation were on the books under this decree.

Around the same time, the Agriculture Ministry issued two additional decrees on its own.

These two decrees (DE-39995-MAG, 2017; DE-41481-MAG, 2018) sought to resolve the accumulated backlog of registration files prior to 2004. The Agriculture Ministry substituted the process of revalidation specified in the first reform phase with an 'updating' process (i.e. 'actualización') (seeDE-41481, Art. 10; SFE, 2021c). This change was not merely semantic; rather, it sought to eliminate the administrative process of evaluating the well-over eighteen hundred substances in the registry mandated to be brought into compliance by the Auditor General during the first reform phase. Consistent with the (now suspended) primary decree (i.e. DE-40059), these two decrees also included the novel notion of referenced information as a way to loosen registration by equivalence for generics in the absence of a reference profile. They also extended the use of referenced information to the 'updating process' for old registrations: because no technical information was required for the registration of active ingredients and formulated products prior to the mid-2000 reform, these registrations lacked risk data. These decrees would allow for referenced information to substitute for standard risk assessments, opening the possibility that submitted information would not come from reliable sources based on international protocols for the protection of human and environmental health. This is particularly relevant since the majority of these 1884 registrations without risk assessments are considered highly hazardous pesticides banned in many countries (e.g. the EU) (Vargas, 2022). Blind to its critics, the Agriculture Ministry pledged to 'simplify procedures'[5)] by way of these decrees, including a mandate of five working days for the SFE to review the information and respond to the registrant. Furthermore, no agricultural effectiveness tests would be required and toxicological and ecotoxicological studies would only be mandated for substances found by the SFE to have impurities. The latter transferred the responsibility for demonstrating chemical purity from the registrant to the state (DIGECA, February 2020, interview). Importantly, the decrees granted the registrations' validity until the updating process was resolved, once again opening the possibility for indefinite terms (SFE, 2021b, 2021c).

The *ecologista* movement opposed these two decrees. In 2018, the Costa Rican Federation for Environmental Conservation (henceforth the Environmental Federation) filed an Action of Unconstitutionality requesting the annulment of DE-39995 on behalf of the *ecologista* movement. The Environmental Federation argued that the requirements to update registrations were insufficient and overly flexible (FECON, 2018; FECON, July 2020, interview). The Environment Ministry's technical staff also opposed the decree, but it was not until a new Minister was appointed following the 2018 national elections that the Ministry officially registered its opposition. In February, 2019, the Environment Ministry formally requested that the Constitutional Chamber suspend DE-39995, stating that 'the Ministry shares in all measure the allegations made by Environmental Federation, since the decree lacks a technical basis and promotes the commercialization of agrochemicals over the protection of public health and the environment' (MINAE, 2019).

[5)] A broader strategy from the Costa Rican government which aimed to streamline administrative procedures.

The *ecologista* movement, represented by the Organic Agriculture Movement (MAOCO), filed an Action of Unconstitutionality against DE-41481 two months later. Thus, by the end of 2019, nearly all efforts to break the regulatory gridlock were held up in the Constitutional Chamber, the result of an unlikely correlation of forces from within and outside the formal state apparatus.

In the face of this stiff opposition and the suspension of the Phase 2 decrees, the SFE took a different tack the following year, inaugurating what we identify as the third phase of registry reform. Rather than the Minister taking the lead and sidelining what he perceived to be slow and uncooperative technocrats (Arauz, March 2020, interview), the SFE Director became the public face of the process. A technical bureaucrat, the Director sought to build relationships with critics while promising to resolve the registry debacle for the agricultural sector through a different strategy since 'history has shown that all such decrees have been appealed' (SFE, 2020c). The office had the good fortune of a new regulatory horizon towards which it could orient these efforts.[6)] In 2015, Costa Rica applied for entry in the OECD and was invited to joinin 2020, the first country in Central America, and only the fourth in Latin America, to become a member. The OECD has a long history of implementing harmonization initiatives for pesticide registration and has recently done so successfully in Colombia (Valbuena et al.,2021). The next round of decrees saw far more cooperation amongst the Ministries, including their technical staff, citing the OECD framework and initially supported by both the generic and the R&D business sectors.

Shortly after, the three Ministries developed a series of three joint consensual regulations that laid down the conditions for the registration of active ingredients with a complete data package that had been approved in another OECD country (Poder Ejecutivo, 2020b; DIGECA, February2020, interview; CANAPROGE, July 2020, interview; CIA, July 2020, interview). Although the new consensus also included registration by incorporation, unlike the Phase 2 decree (i.e. DE-40059), it included a series of requirements that enabled technical staff to evaluate studies. These evaluations were less involved than the process specified in Phase 1, but went well beyond the sworn declaration proposed in Phase 2. Despite the legalization of registration by incorporation, only three registrations were approved under this modality more than two years following its approval (SFE, 2022). Although finally achieving this long-held registration modality (i.e. registration by incorporation) that satisfied the interests of both business sectors, the ministerial consensus lost support from both the generic and R&D sectors, who expressed their opposition during the public consultation process (CANAPROGE, 2020b; CIA, 2020; CNAA, 2020). According to the then CNAA president, Francisco Muñoz, this OECD-linked solution

[6)]The 2016 decree that introduced the figure of registration by incorporation (40059) did reference OECD countries as reference countries, but as the membership process advanced, the OECD harmonization standards figured more prominently in both the discourse surrounding the 2020 regulations and in the decrees themselves.

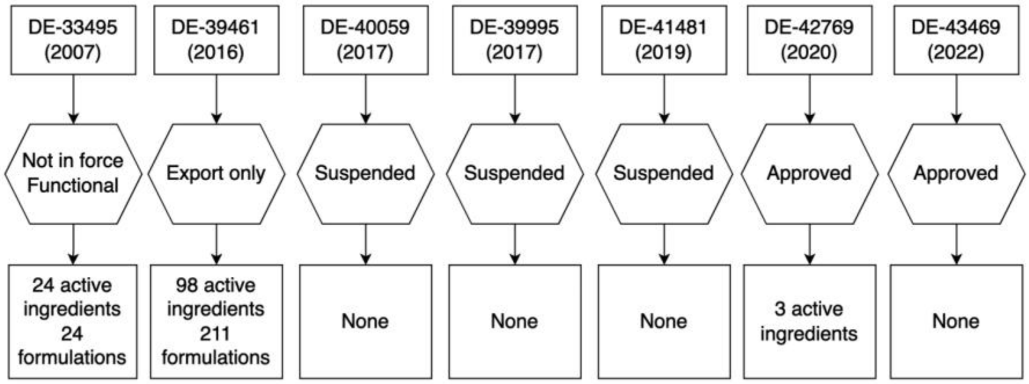

Figure 1. Legal status of main regulatory instruments, number of registrations approved. Source: adapted by the authors from updated data provided by SFE (2022).

resolved just 5% of the registry debacle since it did not address the 13 years of backlog of registrations that existed in administrative limbo (Lanzas, 2021).

Opposition to the ministerial consensus from both the R&D and generics sectors demonstrated that renewal of old registrations remains the principal sticking point for industry (Defensoría de Habitantes, August 2021, interview; RCB, August 2021, interview). These revalidations are divided into two groups. The first group contains around 1513 legacy registrations granted before Phase 1 reforms began, when registrations were not term limited (SFE, 2021c). A major goal of the initial reform spurred by the Auditor General, however, was precisely to reevaluate these registrations based on modern criteria and grant maximum 10-year periods of validity. The second group consists of the 371 registrations approved under temporary Law 8702 (during Phase 1), which expired between 2019 and 2020 (Ibid.). These two groups include 257 active ingredients. Despite the expiration of these registrations, they are shrouded in administrative uncertainty, which has not been resolved through legal channels (see Figure 1 for a summary). In a bid to satisfy the business sector's concerns, the last decree of the ministerial consensus (DE-43469-MAG-MINAE-S, 2022), approved in April 2022 at the end of the government's term, granted additional five-year extensions to legacy registrations. In short, despite having forged an inter- and intra-ministerial consensus over the course of phase 3, which approved registration by incorporation and offered this extension, the ministerial consensus faced strong headwinds from the business sector. The much sought compromise was already being undermined by political economic forces that would soon consolidate political power.

We identify a fourth phase of reform that begins before the end of the third, with the withdrawal of support from the business chambers and the turn to a legislative strategy. In early 2021, Laura Bonilla, then President of the Costa Rican Chamber of Exporters, introduced Bill # 22437 'Law for the Registration of Agrochemicals' in the parliament. The proposed law would allow sworn declarations for registration of both active ingredients and formulations and grant a ten-year validity to all registrations currently active and in the process of renewal. The effort was clearly aligned with the interests of the business sector to secure legacy registrations without updated risk data, but incontrast to the previous two phases, it sought to bypass the Ministerial process by appealing to the legislature. In May 2022, a candidate from a newly formed right-wing party, Rodrigo Chaves, assumed the presidency of the country. During his electoral campaign, Chaves declared that one of his five priority executive actions would be pesticide registry reform to allow 'registration by homologation', understood as an even more permissive version of the already approved registration by incorporation, since registrants would not be required to provide any risk data. The newly elected Chaves installed Laura Bonilla as the country's new Minister of Agriculture. On the twentieth day of Chaves' government, the ministries of Agriculture, Environment and Health signed a decree to modify DE-42769 (i.e. OECD driven reform of Phase 3), to allow registration of any single active ingredient by assembling studies from one or more OECD countries (DE-43563-MAG-S-MINAE, 2022). All indications are that in this fourth phase, the ministerial consensus achieved in Phase 3 will be undermined through executive power consolidated in the President's office and the political appointees to head the ministries. We analyze the dynamics within the state apparatus and between the state and various civil society actors that have propelled these reform phases while reproducing the registry gridlock below.

2.4 Regulation by impasse: Struggles over the terrain of the state

Explaining the long-standing registry reform process requires a deeper understanding of the struggles over the terrain of the state 'as the site, the generator, and the product of strategies' (Jessop, 2008: 35) of political economic and broader social forces. In what follows we divide our discussion into two parts. First, taking a multi-scalar perspective, we consider how macro-level changes in the agrochemical industry shaped the current regulatory gridlock through shifting dynamics of competition and cooperation. Second, we situate these dynamics in the on-going societal tensions over the boundary and role of the state. In both parts of our discussion, we consider strategies in their material and ideational sense (Sum and Jessop, 2013), including discourses of competitiveness and the subjects of state regulation. Although the registry dispute appears as a series of failed reforms, our analysis concludes otherwise. Taken together, the relational strategies developed by distinct social groups, including state managers, and the function of state institutions disputed in and through these strategies are best understood as a form of regulation by impasse. Hegemony is not achieved through a stabilized regulatory arrangement – in this case, a pesticide registry that functions to arbitrate the legal approval of pesticides in the country – but instead is tenuously obtained by the continuation of the registry dispute.

Business conflicts revisited

As noted earlier, the global pesticide industry has witnessed significant changes over the last decade, from mergers among the largest firms (Bayer-Monsanto, Syngenta-ChemChina) to value chain strategies that have opened up market entry and expansion possibilities for second- and third tier generic firms from the global South. In Costa Rica, while tensions over issues of data protection and registration by equivalence so prevalent during the first reform phase have not abated entirely, the dynamics of competition and cooperation among the two business sectors have changed. The business sectors increasingly share the same strategy for registry reform and cooperate to advocatefor this shared agenda. This change, we argue, is due primarily to two related factors: first, the transnationalization of the Costa Rican generics sector; and second, increasing commercial and strategic links between the two sectors as each repositions in relation to the other, in turn shaping their strategies to shape state regulation.

The business conflict over data protection continued during the recent reform efforts. Representatives of the generics sector continued to lament the practices of the R&D sector. In particular, once a molecule is off-patent, a reference profile should be created allowing for the registration by equivalence of generic active ingredients. R&D firms were said to hamper this process by failing to provide the reference profiles against which equivalence could be measured. Additionally, generic firm representatives argued that R&D firms insisted upon impurity standards beyond FAO guidelines. As the CANAPROGE President explained, '[t]he principle of this is whether or not the concentration and levels of impurity are acceptable so that something can be chemically equal. Not to accept [some level of impurity] is commercial war, not a technical dispute' (CANAPROGE, July2020, interview). In contrast, the CIA, representing R&D interests, downplayed the business sector tensions. To emphasize the point, the group's Executive Director noted that the CIA included generic formulator firms, and that data protection standards followed widely accepted international norms and were thus not subject to domestic business disputes (CIA, July 2020, interview). Despite these claims, the R&D sector spoke against the OECD-linked ministerial consensus in Phase 3 because of its stipulation that information presented from OECD countries for registration by incorporation be converted into a reference profile once data protection limits expired, opening up further registrations by equivalence (CIA, 2020).

Despite these on-going disputes, the underlying power imbalances between these two sectors have shifted significantly over the past decade. The generics sector has expanded and transnationalized with substantial foreign direct investment and growing regional exports. Official data reports a three-fold increase in the number of formulator firms from 15 in 2011 to 48 in 2017 (Alpízar, 2017; Dirección de Estudios Económicos, 2011). Of the three principal generic formulation and distribution firms, one, Bioquim, was purchased in 2019 by India-based United Phosphorous Limited (UPL), its first Central American acquisition. The company cited Bioquim's large number of pesticide registrations as the principal motivation for the purchase (Empresas & Management, 2021; Gutiérrez, 2019). Given the registry impasse, acquisition of Bioquim allowed UPL to quadruple its active ingredient registrations and nearly double its formulation registrations, giving it control over one-third of all active ingredient generic company registrations and half of all formulations (CANAPROGE, 2020a). Another element of the sector's transnationalization is its increasing participation in pesticide exports. Since 2000, imports of formulated pesticides have increased by 44 percent, while exports have grown nearly five-fold (476%) (COMTRADE, 2021, authors' calculations). Indeed, in 2008, Costa Rica became a net exporter of formulated pesticides for the first time, and the gap between exports and imports continues to grow (Ibid.).

Costa Rica's new position as a regional pesticide exporter was bolstered during the second phase of registry reform. In 2016, as part of the packet of decrees discussed above, the Agriculture Ministry created an Export Processing regime that extended tax and tariff exemptions to generic manufacturers for the transformation of imported active ingredients into formulated pesticides for export (DE-39461-MAG, 2016). This decree was the only one not to be suspended and remains the only significant mechanism for approved registrations, all for export. By 2020, 164 formulations and 84 active ingredients were registered, all by just three companies, at least one with close personal ties to the government's executive branch.[7)] Here, again, the participation of foreign capital is notable: Bioquim (now UPL) and ChemChina-owned Adama have 72 (51 formulations and 21 active ingredients) and 48 (24 formulations and 24 active ingredients) registrations, respectively (SFE, 2020a).

These sectoral changes shaped the registry dispute in the changing coalition of interests around registry reform. The first reform phase, in the throes of the country's CAFTA-DR debate, pitched R&D ABMs as representatives of foreign capital's monopolistic interests against domestic generic firms and farmers pushing for accessible, low-cost inputs (Jansen, 2017b). During the subsequent phases of registry reform under study here, a more unified business sector emerged, sharing representation and strategy, while the R&D sector also distanced itself publicly from the registry dispute. The negotiations that led to Phase 2 took place under the auspices of the CNAA, the joint business chamber representing both R&D and generics. This effort yielded a package of reforms that finally established registration by incorporation, the modality that, in principle, satisfies both sectors by allowing for registrations while protecting R&D data. During this period, boutique, highly-specialized law firms that previously only supported R&D policy activities began to work with generic firms too. The increased coordination on legal strategy is evident in the decision by a number of R&D firms to withdraw administrative charges against SFE for the granting of registrations, which were seen to favor the generics sector, in order to avoid creating jurisprudence (to contextualize, see Tribunal Contencioso Administrativo, 2014, 2016) that could have negatively affected the commercial interests of both sectors in the future (CANAPROGE, July 2020, interview; MINAE, February 2020, interview). The

[7)]The General Manager of one of these firms is the brother f then President of Costa Rica Luis Guillermo Solís.

CNAA continued to coordinate the business sectors in negotiations with the state during subsequent phases of reform.

As this coalition slowly consolidated, generic firm representatives became its public face, while the debate polarized, construing *ecologista*s as obstructive elements within and outsidethe state. In the press and interviews, the agrochemical sector repeatedly alleged that pesticide approvals were subject to 'regulation by ideology', an allegation that the state failed to fulfill its formal role as a technical, objective evaluator of registrations. As a generics sector representative explained, '[there] is a lot of subjectivity among the authorities. Among some state and civilsociety sectors, the only good agrochemical is one that is not approved. You have a problem. And this is the prevalent logic' (CANAPROGE, July 2020, interview). The boundaries of the state were central to this discourse: anti-pesticide forces were said to be within the state bureaucracy and using its regulatory function to hamper, if not destroy, the sector. This added to a more general sentiment of the problems with state bureaucracy, or the 'mid-level staff effect', a longstanding target of complaint by agribusiness generally against a state perceived to be unresponsive to its needs (e.g. Chaves Solera, 2018). While the R&D sector representatives remained highly critical of the failed registry reforms, they also distanced themselves from this conflict. Representatives were at pains to present their businesses as integrated services companies with pesticides decreasing in significance. Concrete evidence of this change in Costa Rica, and the wider region, is suggested by recent restructuring. Over the last five years, Corteva and Bayer, two of the top four R&D firms globally, have significantly cut agricultural field sales staff in the region, depending instead exclusively on licensed distributors (Croplife, March 2020, interview; CIA, July 2020, interview). In short, due to shifting transnational and domestic dynamics between the two sectors, the terms of the business conflict changed in the decade following the first reform. A more coordinated strategy emerged to break the regulatory gridlock and to produce new registration norms that would satisfy the commercial needs of both fractions of agrochemical capital.

Tensions within and through the state

Despite increased coordination among agrochemical interests, these efforts had failed due to stiff opposition not only from the *ecologista* movement, but also from officials in state agencies. It is precisely this kind of outcome that Jessop's strategic-relational approach helps to explain: the ability of particular class forces to pursue their interests 'is not inscribed in the state system as such but in relation between state structures and the strategies different forces adopt towards it' (2008: 36). Here, we explain the failure of the Phase 2 reforms and the emergence of a delicate consensus between the technical and political levels of the state and between the state and *ecologista* actors in Phase 3 as the result of two strategic-relational factors: first, disputes between and within the responsible ministries, and second, tensions over the boundary of the state itself.

The institutional debate surrounding the Phase 2 executive decrees displayed conflicting positions among and between the different state institutions. Initial splits pitted the mid-level technical staff against their cognizant political directors. Similar to Jansen's findings in Honduras, technical staff valued their professionalism and independence from political influence (2008). Distinct, however, was the role played by this group due to extensive training not only in agronomy but also eco-toxicology and public health, as well as career service in government, rather than cycling frequently between state and industry jobs (as is common elsewhere in the region). Costa Rica has long served as a regional hub for the production of scientific expertise and technical knowledge in tropical agriculture, facilitated through its various education and research centers (Picado Umaña, 2012). Coming from this position, career technical staff objected to the Phase 2 reforms on two grounds. First, the agency staff insisted that they knew the appropriate criteria for the conduct of risk assessments. The proposal to implement registration by incorporation with only minimal submitted requirements would transform these skilled staff into 'mere verifiers of a list of requirements', whose participation would be circumscribed to 'the simple completion of a checklist' (Defensoría de Habitantes, 2018: 22, 23). The move towards registration by incorporation with minimal verification (i.e. using a sworn statement), the minimum requirement recommended for countries without capacity to exercise regulatory control as per the FAO standard (Cabrera, 2019), would effectively delegate technical assessments to other states and sideline the role of this highly trained group. The second, and related objection, was the rigor of the requirements: the staff argued that the proposed norms were grossly insufficient to evaluate the health, safety and effectiveness of the pesticides under consideration. The technical departments of each ministry issued reports that expressed their opposition to DE-40059 and filed these in the Constitutional Chamber. It is widely believed that the subsequent transfer of the head of the Agrochemical Registration Unit to a different department in the Agriculture Ministry was a reprisal for his role in preparing and filing one of these reports. The Agriculture Ministry also failed to respond to the positions presented in the Environment Ministry's technical report, and the report itself disappeared from the public consultation file (DIGECA, 2018).

Debate over the Phase 2 reforms also manifested in inter-ministerial tensions that reached a surprisingly fractious pitch. Recall that the Agriculture Ministry issued two key decrees aimed at regularizing (i.e. 'updating') old registrations to break the deadlock without either the Health or the Environment Ministry, despite the mandate for co-regulation of pesticide registration. The Agriculture Ministry replicated the arguments of the generics sector, discussed above, in its defense of these decrees. For example, in its petition to the Constitutional Chamber, the Agriculture Ministry accused the Environment Ministry of having a 'dogmatic ideological bias that leads them to oppose the registration and use of pesticides in agriculture, since it is no secret, as we have already said, that for RADICAL ENVIRONMENTAL ACTIVISTS THE ONLY GOOD AGRICULTURAL PESTICIDE IS

THE ONE THAT IS BANNED' (MAG,2019: 8, emphasis in original). Indeed, here we see that Agriculture Ministry officials conflated the Environment Ministry with 'radical activists' and accused the body of 'regulating by ideology' instead of using scientific criteria. The confrontation between the Environment Ministry and Agriculture Ministry exploded publicly once the former filed its petition against the Agriculture Ministry in the Constitutional Chamber. The Minister of Agriculture declared the Minister of Environment to be 'the worst enemy of agriculture' in the national press (Naranjo, 2020).

The transposition of this polarizing discourse from civil society to the state offers one window into the contested boundaries of the state itself. Another perspective is offered by examining the circulation of key actors between civil society groups and official state positions. For example, two former directors of CANAPROGE, Román Macaya and Sigurd Vargas, subsequently occupied important positions within the Public Health System and the Agriculture Ministry, respectively. The latter offers a paradigmatic case for pesticide regulation. In 2019, the government designated Vargas to serve as the country's representative at the ninth meeting of the Conference of the Parties to the Rotterdam Convention (COP-9), which governs trade in highly hazardous pesticides. His nomination was fiercely questioned by sixteen environmental organizations, who saw it as a demonstration that 'the revolving doors in MAG made it possible for representatives of the agrochemical industry to draft regulations and provisions directly related to their economic interests at the expense of people's health' (FECON, 2019). Vargas' nomination was subsequently rescinded.

The terrain of the state – and whose interests are entrenched there – is central to our consideration of the pivotal role played by the *ecologista* movement throughout this dispute. The intervention of environmental organizations in the process was decisive in successfully blocking the second-phase regulatory reform through a combination of legal, technical and political strategies. While a detailed history of the country's remarkable *ecologista* movement is beyond the scope of this paper, we note that prior campaigns waged to restrict or ban pesticides in the 2000s led togreater attention on the part of movement leaders to the registry debate (Bloque Verde, March2021, interview; RCB, March 2020, interview; FECON, July 2020, interview). The movement actors who successfully filed petitions in the Constitutional Chamber on behalf of the movementwere highly skilled: all were agronomists and most trained themselves in the legal skills required to undertake such actions. The movement's success in shaping state regulations has granted its representatives 'an uncomfortable seat' at the table in state-sponsored fora of citizen participation. As one representative explained, 'there is a very big contradiction that we in the movement have not yet fully understood, which is the possibility of defending these spaces for participation and understanding their limitations' (FECON, July 2020, interview). The most poignant example of these tensions is the effort by Costa

Rica's governing party (until 2022), the PAC, to incorporate social movement political leaders into the apparatus of the state itself.[8] Although not directly a member or movement leader, Felipe Arauz, the Minister of Agriculture in the first PAC administration who spearheaded Phase 2 of registry reform, had a history of active campaigning against GMOs associated with the movement as dean of the Faculty of Agronomy at the University of Costa Rica, before going into the administration. The role he played as a committed scientist critical of industrial agriculture (e.g. Arauz, 2012) lent him political credibility consistent with the PAC's progressive project. This background would become a source of considerable tension with the *ecologista* movement when, in his leadership of the second phase of reform, Arauz took a decidedly pro-business sector position and frequently appeared surrounded by its representatives in public events.

In the third phase, the three cognizant ministries managed to reach a consensus to move the reform process forward. From a strategic-relational perspective, the *ecologista* forces represented in these agencies reached a tacit truce with their political counterparts. But the business chambers' opposition stirred up the waters again (FECON, July 2020, interview; Casa Presidencial, 2021; Ávila, 2021) and they found a sympathetic hearing in the parliament, with the proposition of a new law (Pomareda, 2021). The business chambers sought a resolution by by-passing the ministerial consensus so carefully crafted during the third phase of reform, marking a fourth phase. The 2022 elections offered a potent opportunity to codify a reform consistent with the business chambers' aligned, but diverse interests. But as our analysis has shown, state managers and *ecologistas* would surely remain potent forces shaping these on-going reform efforts.

2.5 Conclusion

A cursory assessment of the pesticide registry reform process in Costa Rica would highlight its failure to provide an adequate remedy for the various interests involved. Our analysis, however, suggests an alternative reading: in identifying the actors and dynamics that drove each reform phase and its outcome, we see neither a failure to regulate, nor an absence of regulation, but rather the precarious maintenance of hegemony via regulation by impasse. Regulation by impasse takes its form through the continued reworking of selective strategies – by political economic and other social forces, along with state managers – in relation to one another. The contest to shape the state's asymmetrical institutional terrain manifests as highly technical and bureaucratically byzantine. The strategies mobilized by the business sectors and *ecologistas* to shape state actions are developed in relation to state structures, themselves not fixed but conjuncturally achieved. We also emphasize the significance of extra-national norms and interests, attending to their transformation when combined with past trajectories of political settlements to create

[8] The integration of social movement leaders into the state was especially prominent during the first PAC administration (2014–2018). Moves like these triggered an internal rupture within the *ecologista* movement. Activists saw these appointments as a strategy to weaken or even silence its critics. This tendency has been dubbed as a form of 'neoliberal progressivism' among Costa Rican political scientists (see Molina Jiménez and Días Arias, 2021).

novel regulatory arrangement. Global norms like those of the OECD are mediated through domestic political contests over the legitimate actions and form of the state. In the shifting composition of transnational capital, we identify how the resulting change in dynamics of competition and cooperation reverberate through the regulatory dispute. Finally, the state's (in)operability rests in large part with state managers whose abilities to shape environmental governance are determined by the outcome of linked intra-institutional struggles and extra-stateforces. The boundary of the state is thus continually negotiated, traversed, blurred and re-established.

From an environmental perspective, the results of regulation by impasse are not only institutionally sobering, but also ecologically and socially detrimental. The bulk of registrations in Costa Rica today – those on the books prior to the first reform phase, and those provisionally renewed during that period – exist in a state of administrative ambiguity that remains unclear even for those responsible for managing the process. Although the ministerial consensus reached in Phase 3 offered a clear path forward, in failing to codify the administrative status quo for these 1800+ registrations that have never been brought into compliance with modern standards, the business sector opposed this solution. As a result, these legacy registrations remain officially categorized as 'irresolutely valid' despite the mandate issued by the Auditor General nearly twenty years ago. Thus, widely used substances, decades old, approved with no risk evaluations and restricted or banned in other countries, are legally sanctioned to circulate in and through the waters, soils, non-human organisms, and bodies of farmers, farmworkers and communities throughout the country.

Scholars have long indicated the exceptional character of Costa Rican neoliberal development, which has seen, on the one hand, the adoption of market-led regulation, while, on the other, relative preservation of social democratic norms and environmental protections (Fletcher et al., 2020;Ramírez Cover, 2020; Sandbrook et al., 2006). As Fletcher et al. note, however, 'roll-out' forms of neoliberal regulation following structural adjustment integrated conservation and development more deeply, and thereby 'intensified the long-standing strain between extraction and preservation' (2020: 15). Registration by impasse, we have argued, is a manifestation of this tension in the context of the country's strained green development model. As Jiménez (2005) and León Araya (2021) have argued, Costa Rica is in a transition period characterized by the loss of state authority and the ideological erosion of its exceptionalism. The country continues to position itself as a global leader in environmental regulations while facing deepening contradictions between environmental protection and capital accumulation. Far from an ideal outcome, regulation by impasse reflects the increasingly frayed hegemony that sustains Costa Rica's green development model, wherein environmental governance is tenuously achieved through a protracted regulatory dispute. Any future change in the regulatory modality of the registry away from the impasse cannot be foretold. The election of the country's first right-wing populist President, however, suggests the tenuousness of this arrangement and manifests the wider tensions within the country's development model.

Lens II: Human/nature relationships

LOS MAYORES

a Enrique Rivera (1945-2022)

Van muriendo los mayores
aquellos de convicciones firmes
como el silencio de la tierra
aquellos que caminaron días enteros
cada semana
para llevar ideas de liberación y esperanza
a pueblos distantes
los mayores que sabían navegar el Río Térraba
Dí ques de las aguas grandes
embarcaciones árbol en un cauce llano y furioso
aquellos que vieron pasar décadas de luchas
huelgas bananeras, insurrecciones, encarcelamientos
hasta las nubes negras que acompañaron el milenio
megaproyectos sombra en los territorios
planos para dibujar el despojo
la inundación como pesadilla sudorosa
clavada en la angustia del suelo descubierto
van muriendo los mayores
se cierran los ojos
que vieron enfermar al río y su gente
los mayores
siempre puntuales en las reuniones
aquellos de la palabra justa
la acción clara
la sabiduría enraizada
van muriendo los mayores
los salones comunitarios están vacíos
las redes sociales colapsan de historias de un día
pájaros virtuales aletean sus alas
se posan en el vacío del pecho
somos la condena del yo
la pérdida del nosotros
ni las ojeras del miedo acortan la distancia
relámpagos azules anuncian catástrofes
estamos en la intemperie

Soldedad Castro Vargas

THE ELDERS

to Enrique Rivera (1945-2022)

The elders are passing away
those with firm convictions
like the silence of the earth.
Those who walked entire days
every week
to carry ideas of liberation and hope
to distant towns.
The elders who knew how to navigate the Térraba River,
Dí Crí^ of the abundant waters
tree vessels in a plain and rough river flow
Those who witnessed decades of struggles, banana strikes,
insurrections, imprisonments,
up to the black clouds that accompanied the millennium,
shadow megaprojects over the territories,
blueprints to draw dispossession,
the flooding as a sweaty nightmare,
pierced into the anguish of bare soil.
The elders are passing away,
the eyes that saw the river and its people fall ill
are closing.
The elders,
the ones always punctual in meetings,
those with the right words
clear actions
a deeply rooted wisdom
The elders are passing away,
community halls are empty,
social media is overwhelmed with fleeting stories,
virtual birds flap their wings,
perching on the emptiness of the chest.
We are the condemnation of the self,
the loss of an "us,"
not even the baggy eyes of fear shorten the distances,
blue lightning announces catastrophes,
we are in the open fields.

Soldedad Castro Vargas

Pesticides and the Agro-food Ecological Regime:

A view from Costa Rica over the long twentieth century

Maria Soledad Castro-Vargas

Marion Werner

Under revision in Antipode: A Radical Journal of Geography

Abstract

More than inputs, pesticides serve as stabilizing agents for an ecological regime that depends upon the surpluses that they marshal: as byproducts of extractive industries, as compounds that externalize harms, and as biocides that tap organisms' susceptibility. Susceptibility of monocrops to pathogens, and the erosion of these target organisms' susceptibility to pesticides, creates a patchwork of biotechnical and chemical fixes. We develop a framework for understanding the relationship of pesticides to this patchwork of fixes that their use triggers. Our understanding draws from parceleros/as' aspirations and obstacles to cultivate livelihoods and forge agrarian futures in plantation lands in the southern Pacific region of Costa Rica, a region made and remade through monocrop plantation agriculture. Our analysis calls for deeper attention to shifting institutional orders, socioecological legacies, and commercial dynamics that have sustained pesticides at the center of our agro-food ecological regime over the long twentieth century.

Keywords: Monocrops, political ecology, plantations, capitalist agriculture, pesticide treadmill, Costa Rica

3.1 Introduction

In Palmar Sur, on the lower stretch of the Térraba river in Costa Rica's southern Pacific region, *parceleros/as*[1] farm on former banana plantation lands, such as 'finca Chánguena' and 'finca Térraba'. Oil palms surround their plots and their waterways carry residues from Del Monte's pineapple plantation located upstream. On an average plot size of three hectares, *parceleros/as* cultivate plantain for sale combined with staple crops for household consumption. Despite great expectations for this agrarian movement to reclaim plantations for smallholders, tensions among *parceleros/as* persist. Land use decisions and agricultural practices must navigate the plantation's legacies. The soils are inhabited by old and renewed pests and pathogens. Rice and corn cultivation is hampered by copper residues from pesticides applied more than 60 years ago; a thick layer of buried mecate (synthetic twine) chokes cassava and other tuber crops; nematodes and *Mycosphaerella fijiensis*, long-time foes of banana monocrops, threaten smallholders' modest plantain harvest. Parceleros/as face these vertiginous challenges with a weak set of technical solutions. Pesticides are prohibitively expensive but farming without them, in these degraded, sterile, and toxic soils, seems impossible to many. Deemed unprofitable by commercial distributors, they must travel long distances and constantly change compounds and brands to acquire the cheapest possible inputs. While some *parceleros/as* aspire to produce without pesticides, the horizon of organic production recedes behind the chemical, biological and social inheritances of eighty years of monocrop cultivation.

This paper takes Costa Rica's south Pacific region, the challenges posed by pesticide legacies and the present dilemmas that surround their use in reclaimed plantation lands as its departure point. Pesticide is the general term for chemical biocides, including insecticides, fungicides, and herbicides, that kill pathogens, pests or weeds. Dominant thinking in the political economy of pesticides centers their role in the intensification of capitalist agriculture. The turn towards synthetic fertilizers, mechanization and monocropping created innumerable outbreaks for which pesticides became a principal remedy (Goodman et al. 1987; Van Den Bosch 1989). As key tools of capitalist agriculture, pesticides facilitated profits for agro-food corporations and food surpluses through increased yields, shortened cropping cycles, and reduced labor demand. But this understanding of pesticides as key inputs in capitalist agriculture is insufficient to comprehend their role over successive periods of investment, socioecological crises, rural mobilizations, consumption pattern changes and related agricultural restructuring over time. In this paper, we unpack pesticides-as-inputs and, through an historically grounded analysis of pesticide use in Costa Rica, we address two questions: first, what work do pesticides do for capital accumulation, and thus, the reproduction of capitalism; and second, how does this role change over time?

[1] Parceleros/as are former agricultural workers and peasants who migrated from other regions of the country to work in UFCo's banana plantation in the Southern Pacific region. After several processes of proletarianization and peasantization, the people who inhabit the plots, embody both

To answer these questions, we draw on and develop the concept of the ecological regime. In political economy, “regimes” (e.g., food, labor, or growth regimes) are analytical constructs that examine social, and increasingly, ecological, relations that temporarily stabilize arrangements of capital accumulation, while identifying emergent tensions or contradictions that eventually lead to revolutionary transformations. We draw on Jason Moore’s notion of the ecological regime to consider pesticides as key stabilizing elements of capitalist agriculture, and as conditional and fraught means to expropriate ecological surplus, i.e., returns from the unpaid work/energy of nature. Pesticides enroll three types of ecological surplus into the accumulation process: as biocides, they harness organisms’ susceptibility; as commodities, they valorize waste streams of industrial processing; and as externalized pollutants, they distribute violence unevenly among those who work with them and in the environment. We focus in particular on the interactions between the chemicalization of agriculture and susceptibility. Susceptibility in our framework is Janus-faced. On the one hand, the introduction of commercial cultivars, and their associated agronomic systems (e.g., monocropping), produces vulnerability to pathogens, pests and weeds through ecological disruptions caused by these homogenizing innovations. On the other hand, pesticides expropriate the susceptibility of the pathogens, weeds, and pests that emerge from these ecological disruptions, which erodes over time through resistance, or creates conditions for secondary outbreaks and disruptions. These susceptibility interactions lead agro-industrial capital to adopt interrelated, non-linear chemical and biotechnical fixes to maintain the ecological regime of chemicalized agriculture. Popularly discussed as the technological or pesticide treadmill, we marshal these processes to offer a theoretically informed, historically situated analysis of their operation through the lens of Costa Rica’s southern Pacific region.

In the following section, we argue that pesticides maintain the ecological regime of capitalist agriculture through a patchwork of interventions assembled and reassembled to expropriate and capitalize ecological surplus. We then proceed to consider the interactions between susceptibility, biotech/chemical fixes, and spatial-temporal strategies in three different periods in Costa Rica over the “long twentieth century” of US hegemony (Arrighi 1994): frontier expansion of tropical monocrops through infrastructure development that facilitated the mass application of inorganic pesticides in the early 20th century (Section 3); the consolidation of national agriculture and export monocrops through petrochemical derivative pesticides in the post-WWII period (Section 4); and finally, pesticide and biotech interactions in export diversification strategies to service the country’s debt in the wake of the oil crisis and subsequent debt regime in Latin America (Section 5). In Section 6, we return to Palmar Sur, to consider how these successive periods are reflected in the present dilemmas facing *parceleros/as*, where low-cost, generic pesticides circulate through a hyper-commercialized logic in landscapes that bear the material residues of pesticides’ long twentieth century. We conclude by calling for attention to pesticides’ changing role in the agro-food ecological regime and its implications for agrarian futures.

This paper is based on [primary author's] long-standing engagement with the problematic of pesticides in Costa Rican agriculture over fifteen years, including 18 months of fieldwork from 2018 to 2021. Semi-structured interviews were held with over one hundred informants from different sectors including state institutions, academia, NGOs, pesticide vendors, agricultural extension agents, and inhabitants from communities located along the Térraba River watershed, as part of a wider research project. In this article we focus principally on the research conducted in Palmar Sur, which included visits to *parcela*s with farmers to discuss their crops and challenges, semi-structured interviews focused on life histories and agricultural aspects of production in the plots, two workshops, two participatory pesticide water and mollusk sampling visits, and collaboration in an agroecology training. Drawing methodological inspiration from Gill Hart (2018) and Doreen Massey (1995), we attend to the layered, racialized histories of accumulation and expropriation, and their spatial and temporal effects on subsequent arrangements in and through the southern Pacific region. We argue that maintaining the ecological regime of chemicalized agriculture can only be achieved through the contingent reworking of the spatiotemporal arrangements of biotechnical and chemical fixes. In what follows, we offer a relational analysis of the ecological regime sustained by pesticides through an examination of the socio-ecological arrangements of agricultural capital accumulation in Costa Rica's Pacific region. By relational analysis, here, we are quite specific: we want to illustrate particular moments when socio-ecological and market crises at other scales and in other places reproduced the region as an apt place to (re)initiate or intensify monocrop plantations and the agrochemicals that made this possible (Hart 2018). We posit this view from Costa Rica, as neither case study nor idiographic description, but rather as a window into understanding what work pesticides do for capital, the shifting institutional orders that shape their use, the epistemologies that normalize their harms, and their socioecological traces that condition the agrarian present and future.

3.2 Susceptibility circuits and patchwork fixes to maintain ecological regimes

Monocrops constitute deeply fragile agro-ecosystems that are vulnerable to disease, pests and climatic events due to their logics of simplification and homogenization (i.e. single genotypes), and the relocation of plants or germplasm to different habitats (Kloppenburg 2005; Leon 2020; Zhu et al. 2000; Wan et al. 2022). The geographic and climatic characteristics typical of tropical ecosystems – elevated humidity and rainfall, and high biodiversity, among others – exacerbate these dynamics. Monocrops, in plantation and other tenure forms, are in permanent social and ecological disequilibrium, which requires continuous economic, political, geographic, chemical and biological maintenance work to ensure they function as capital to produce surplus (e.g. Soluri 2021; Li and Semedi 2021). In her research on the strawberry socio-technical assemblage in California, Guthman theorizes long-standing efforts to maintain profitable strawberry monocropping in the face of these destabilizing forces. Chemical stopgaps or fixes bring about "an entire suite of practices… to 'revolutionize the industry' – as well as embed its infrastructures" (43-44). Each biotechnical or chemical fix, or what Guthman calls repair[2)], exacerbates known pathogens, pests and weeds or induces new ones (e.g., secondary pests). These negative feedback loops are driven by iatrogenic harms, that is, the chemical interventions meant to solve (i.e., kill) the causes of agro-ecosystem disruption incubate new ones.

As chemical fixes, pesticides can be conceptualized as conditional and fraught means to expropriate ecological surplus in order to stabilize the ecological regime of chemicalized agriculture. Ecological surplus describes the relationship between capitalization and expropriation, that is, between capitalist value and the value relations in and through nature and life upon which capitalist value depends (Moore 2015; Mies 1986).[3)] To defer crisis in time and space, capital constantly seeks to expropriate the unpaid work/energy of nature/life and in doing so, erodes the latter as more and more of this unpaid work/energy becomes capitalized (O'Connor 1998). Ecological surplus – i.e., this relationship between capitalization and expropriation – is spatial and temporal, "a relational movement between capital and labor, between town and country, [and] between metropole and frontier…" (Moore 2015: 154). The primary means for capitalist agriculture to expropriate unpaid work/energy is through the racialized process of making and seizing upon frontiers: colonial monocrops and mines where capital need not pay the cost of labor's social reproduction – through racialized hyper-exploitation and/or enrollment of semi-proletarianized peasants only "formally subsumed" to capital – nor the soil's fertility (which it "discovers"). The doctrine of manifest destiny and eventual consolidation of US hegemony in the West and in Latin America depended upon rail and steamship revolutions of the late 19th and early 20th centuries that "set free" vast amounts of cheap (i.e., expropriated) labor and nature. But as accumulation proceeds, the progressive enrollment of expropriated value into circuits of profit-making "undermines the systemic conditions of accumulation"(Ibid: 157). As Moore writes, "the specific strategies that create the Four Cheaps [i.e., expropriated labor, food, energy and other resources] in any given era are one-off affairs. You cannot discover something twice"(153).

[2)] Repair references the temporary nature of these measures, their inherent instability that sooner or later requires new measures. Key to Guthman's argument is that R&D is focused narrowly on how to control a given pathogen that is incubated through the ecological disruptions of monocultures. We adopt the term "fix" instead because repair also speaks to redress for past harms, as in reparations, and its limits (e.g., Lewis 2020). Our use of fix is the same as Guthman's repair, and, importantly, distinct from the sense offered by David Harvey, i.e., as a spatial or temporal solution for overaccumulated capital (Harvey 1985; Ekers and Prudham 2017).

[3)] We use the term expropriation, following Fraser (Fraser 2016), where Moore uses appropriation. Both terms emphasize the regular process of accumulating surplus based upon the ability of capital to capture the unpaid labor of humans and nature. Whereas appropriation in Marx emphasizes how this happens within the wage relation itself (Marx B 1976: 729-730), expropriation emphasizes accumulation from labor and nature "subject to domination unmediated by a wage contract" (Fraser 2016: 165). Both processes are important and related. They rely upon racial hierarchies of domination that rationalize "confiscating capacities and resources and conscripting them into capital's circuits of self-expansion" (Ibid: 166).

How we understand the "free gifts" that pesticides expropriate from nature and labor matters for our understanding of the socioecological relations that they induce and the durability of the ecological regime that they maintain. In the first instance, the most direct "free gift" of nature that pesticides expropriate is the susceptibility of living organisms to harm or to their death by chemical biocides. Given the evolutionary potential of organisms to develop resistance to biocides, susceptibility is a temporary condition and not a static property. Thrupp described susceptibility as a kind of "'biological capital'... a resource stock subject to depletion in a manner similar to resource stocks in extractive industries" (1990:174). Depletion of this resource is advanced through plants, fungi, bacteria and insects' evolutionary responses to selection. Declining discovery represents a fundamental condition of pesticides as chemical fixes over the long twentieth century. Writing in 1981, a crop protection (sic) analyst from a major chemical company, I.C.I., noted the steady descent in new discoveries as a major challenge to the industry's future (Braunholtz 1981); nearly three decades later, the herbicide glyphosate would be both hailed and lamented as a "once-in-a-century herbicide" (Duke and Powles 2008). In the past twenty years, social scientists and historians have noted the turn to biotech innovations through genetic engineering as, in part, driven by drops in discovery in addition to high costs to pass regulatory hurdles in the EU for commercial development (Shattuck 2021; Clapp 2021). These dynamics drive massive growth in the generic pesticide sector, to which we return in our final section. For now, we note that the patchwork of fixes that maintain the agro-food ecological regime emerges from this basic dilemma of monocrop-induced susceptibility and selection-induced resistance. Rather than interpreting this susceptibility circuit and eroding pesticide effectiveness as a signal crisis of the ecological regime, however, we instead consider these biotech/chemical fixes, and their combinations over time as the *sine qua non* of the regime's durability over the long twentieth century.

The introduction and development of pesticides from the late 19th century onward relies upon an adjacent source of ecological surplus: the valorization of waste streams from mineral and oil extraction (Romero 2022). As "economic poisons" fashioned into by-products from the industrial waste of extractive industries, pesticides became a significant source of capitalist value (Ibid.). US agro-industrial capital, for example, converted arsenic waste produced in mass quantities as a by-product of copper smelting into widely used heavy metal (also called inorganic) pesticides (Ibid; Bertomeu-Sánchez 2019; Özkara, Akyil, and Konuk 2016). Use of arsenical insecticides spread widely due to their stability in the environment compared to botanical alternatives (Davis 2017). Inorganic, mineral or metal-based compounds would proliferate until regulatory restrictions finally curbed their use in the US in the early 20th century, but they would continue to be deployed in tropical monocrops for decades to follow. Petroleum-based organochlorine and organophosphate pesticides would largely replace these compounds by the mid-20th century, as a rash of discoveries transformed chemicalized agriculture. Historian Bart Elmore characterizes the capital that formed through the discovery and commercialization of petroleum-based chemical products as "scavenger capitalism" (2018). In the heady days of the US oil boom, the Oil Majors disposed of refinery waste to third parties at low cost. These firms, in turn, used the material as feedstock for plastics, PCBs, fertilizers, and of course, pesticides (see also Hanieh 2021). Agrichemical giant Monsanto procured petroleum derivatives from oil companies in the US and abroad to make its fortune from the 1930s until the 1970s, when the oil crisis prompted the Majors to accelerate their forward integration into petrochemicals. Monsanto executives would remake the company through biotechnology, eventually leading to the introduction of "Roundup-Ready" (glyphosate-tolerant) soybeans and Bt-cotton in the 1990s, recombining biotechnical and chemical fixes in profoundly novel ways with far-reaching effects (Elmore 2018).

The final source of ecological surplus that pesticides rely upon is the expropriation of human and nonhuman organisms and the environment as sinks for contamination. The fate of the agrochemicals that stabilize particular expropriation-capitalization arrangements manifest in spatial relations, institutional orders, epistemologies, and biopolitical effects that are posited as external to the relations of production and consumption that are seen to drive their use (Murphy 2008). Pesticides depend upon colonial epistemologies that normalize "zones of dispossession… in which life is rendered not just precarious to chemicals but also disenfranchised and devalued in the larger political economy" (Ibid:697; see also Liboiron 2021). Pesticides move in and accumulate through bodies and landscapes (Agard-Jones 2013), within and well beyond the particular sites where they are produced and applied. Chemical fixes create material layers that shape and condition subsequent arrangements of accumulation, reproduction, life-chances, and associated subjectivities of farmers, farmworkers, agronomists, and others. As Harriet Friedmann wrote in her assessment of an allied concept, the food regime, "cumulative histories shape cycles via the sediments left by past cycles in each place" (Friedmann 2016, p. 682). Over the long twentieth century, capital has recombined its sources of ecological surplus and devalued labor to maintain the ecological regime of capitalist agriculture. The patchwork of biotech and chemical fixes that developed as a result determines not only pesticide use in capital-intensive monocrops, but also land-based rural livelihood strategies that develop in relationship to them. We proceed to explain how these shifting strategies of expropriation and exploitation work from the perspective of Costa Rica's Pacific region in three main periods, before returning to the present dilemma facing *parceleros/as*.

3.3 Plantations and infrastructures towards chemicalization (1898-1940s)

The development of transportation infrastructure, including ports, roads, and trains, that allowed the circulation of commodities, especially bananas and their inputs, laid a foundation for the chemicalization of agriculture in Costa Rica. The construction of the

Panama Canal from 1904 to 1915 marked a watershed moment in this process (Putnam 2006). The geostrategic position that Central America occupied as a bridge between North and South America, and as an isthmus between the Atlantic Ocean and the Pacific Ocean (Granados 1986), curiously defined the role that Costa Rica would hold as an experimental site of chemical control in agriculture. Infrastructure development was inseparable from expansion of the agricultural frontier and both relied upon a social cum racial division of labor that was also intimately related. Banana production in Central America drove a long cycle of land grabbing, following a previous cycle related to coffee production financed mainly by British capital (Edelman and León 2013). By the early 20th century, a handful of mostly US multinationals consolidated ownership and control of the sector, particularly the United Fruit Company (UFCo), which came to manage all the stages of production and distribution, from growing to packing to shipping (Moberg and Strifler 2003). UFCo expanded through different countries in Central America and South America, but had major presence in Colombia, Panama, Costa Rica, Honduras, and Guatemala (Ibid).

UFCo was founded in the Caribbean region of Costa Rica in 1899 by the merger of Boston Fruit Co. and a small company owned by a US entrepreneur named Minor Keith. Keith had obtained the concession to build the railroad in Costa Rica, which quickly became the chief rail freight conduit for banana exports (Ellis 1983).[4)] Black workers from the insular Caribbean were recruited to Costa Rica to build the railroad and canal, and then to work on the nascent banana plantations. Some scholars estimate that as many as 4,000 workers died in the construction of the train (Stewart 1964; Sánchez-Lowell 2020). The US government and UFCo recruited West Indian workers from the same labor pool, and labor relations in both banana enclaves and the Canal Zone reinforced a racialized division of labor (Bourgois 1994; Colby 2011). Many West Indian workers came with experience in banana cultivation (Marquardt 2001a), and moved between the Canal zone and banana enclaves in an effort to marshal some autonomy (Colby 2011). UFCo initially incorporated these workers' agronomic practices, before moving to input-intensive methods to reach scale (Marquardt 2001a; Soluri 2021).

Intensive banana monocropping incubated new diseases that would threaten its viability. *Fusarium oxysporum f. sp. cubense*, a tropical soil-borne fungus, caused one of the most destructive diseases in bananas, Fusarium wilt, also known as Panama disease (Ploetz and Evans 2015). In its plant-pathogenic form in bananas, *Fusarium oxysporum* was first recorded in Costa Rica and Panama in 1890, and by the early 1900s, it had spread widely (Ploetz 2015). The principal cultivar used by UFCo and other large banana corporations, Gros Michel, was especially susceptible to *Fusarium oxysporum* and no chemical biocide seemed to control it. As a result, *Fusarium oxysporum* would inaugurate a long and complex history marked by land acquisition and abandonment, capital restructuring, changing racialized labor dynamics, and the development of new cultivars (Marquardt

[4)]The concession provided to Minor Keith access to large tracts of land, a fundamental component for the development of the banana agroindustry (León et al. 2014).

2001b; Jansen 2006).

Costa Rica offers a key site from which to observe these dynamics spurred by *Fusarium oxysporum*. With no chemical solution, or fix, available, UFCo shifted production from the Caribbean to the Pacific region of Costa Rica in 1935, where soils were not yet affected (Cerdas Albertazzi 1993). This movement was made in the midst of a period of social upheaval, following the Great Banana Strike of 1934 (Acuña 1984). Three succeeding contracts were signed between UFCo and the Costa Rican government (1930, 1934, 1938), in which the state granted the company tax reductions and land access in the southern Pacific and the Caribbean, and the company committed to sustaining active banana production in both regions (see Royo 2004). The regional shift went hand in hand with remaking the racialized division of labor that existed in the Caribbean plantations (see Bourgois 1994). In 1934, the Costa Rican state enacted Law No. 31, which explicitly prohibited hiring *gente de color* (literally, people of color, an emerging, contested category) in the Pacific banana plantations (Cerdas Albertazzi 1993). This category referenced West Indian migrants and their descendants. A racist spatial division of labor ensued in Pacific banana enclaves, where residence was organized in a "white zone" (high-ranking US or European managers), a "yellow zone" (middle-ranking administrative staff, mestizo/a workers), and a "gray zone" (migrants from Costa Rica's central valley, the northern Pacific, Panamá and Afro-descent workers) (Colby 2011; Cano Sanchiz 2017; Conejo Barboza 2018). Debate continued over the position of Afro-descent Costa Ricans from the Pacific region, who had migrated earlier from Nicaragua, and where these workers "fit" in the hierarchy as the impetus for the Law was to "nationalize" the workforce.[5)] In its new terrain of operations, UFCo (through its subsidiary Compañía Bananera Nacional) absorbed existing banana producers and by 1940, banana production in Costa Rica's Pacific exceeded that of the Caribbean region (Royo 2004). Despite its pledge to continue production in the Caribbean, UFCo largely abandoned the region, leaving exhausted and fungus riddled soils, triggering a long economic downturn in the area (Viales Hurtado 1998; Montero and Viales 2013). Both UFCo and Standard Fruit (later Dole) deployed this kind of "shifting plantation agriculture" in other Central American countries (Soluri 2021) and in Colombia, as *Fusarium oxysporum* drove frontier expansion to seek soils free from the pathogen (Marquardt 2001b; Cordoba and Jansen 2014).

In contrast to *Fusarium oxysporum*, a second fungal plant pathogen incubated through banana monocropping, *Mycosphaerella musicola*, would lead to massive pesticide applications and inaugurate Costa Rica and the wider region's chemical intensification of agriculture (Marquardt 2001b). *Mycosphaerella musicola*, which causes yellow Sigatoka

[5)]UFCo complained that exclusion of West Indians under this arrangement made them less competitive as independent producers continued to employ these more experienced workers (Cerdas Albertazzi 1993).

disease, long existed in the South Pacific, and was first detected in the Western hemisphere in Trinidad in 1934 (Marquardt 2001a; Ploetz and Evans 2015).[6] By 1939, UFCo made its first large-scale application of copper sulfate dissolved in lime (calcium hydroxide), known as Bordeaux mixture, to control it (Cordero and Ramírez 1978; García 2003). Bordeaux mixture mediated the relationship between fungi and plants (Soluri 2021) and expropriated the "free gift" of *Mycosphaerella*'s susceptibility, while extracting surplus from workers who faced toxic exposures with lasting consequences. From 1939 to 1962, in Central America, 10,000-15,000 workers annually applied Bordeaux mixture on banana plantations, 20-30 times per year (Ellis 1983; Marquardt 2001b). Massive chemical applications required significant infrastructure and equipment imported from the US and Germany, including pipes, high-pressure pumps, storage tanks, and chemicals (Marquardt 2001b; Soluri 2021). Workers were called parakeets, or '*pericos*' in Spanish, because their skin took on a blue tone as a result of applying the blue-green chemical. Exposure to Bordeaux caused tuberculosis-like symptoms, yet health problems were neither addressed by UFCo nor rallied around by workers' unions (Ibid). Although inorganic pesticides like Bordeaux mixture and London Purple (an arsenical insecticide) were largely banned or obsolete by the early 20th century for use in the global North (Davis 2014), their use continued in tropical regions with burgeoning plantation economies like Costa Rica well

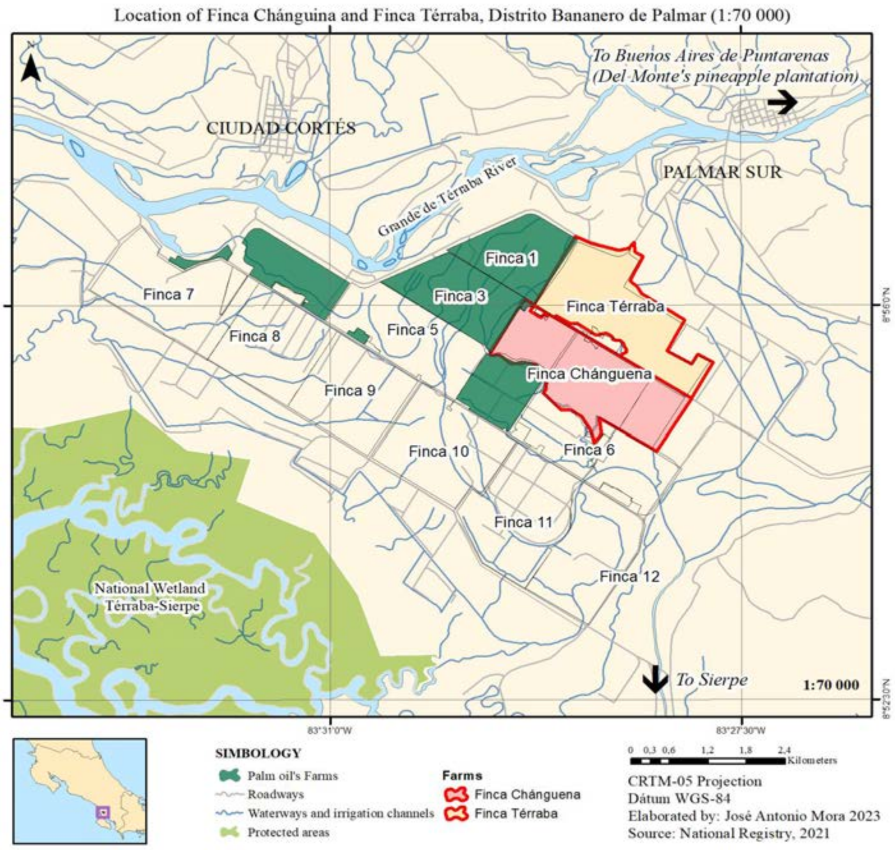

Figure 1 Location of Finca Chánguena and Finca Térraba, Palmar banana district, Costa Rica.

[6]Mycosphaerella musicola was first recorded in Java in 1904 (Ploetz and Evans 2015).

into the twentieth century.[7] UFCo's massive applications of Bordeaux mixture in Costa Rica's Pacific region left its mark: a layer of copper sulfate remains visible in the soil sediment of former UFCo plantation lands from the intensive use of this inorganic pesticide, a stratified imprint of this chemical legacy (Cordero & Ramírez 1978). Copper reacted with the area's alluvial soils, which have a high content of organic material, causing high soil acidity (Thrupp 1991a).

3.4 Extending monocrops through pesticide intensification (1940s-1970s)

The introduction and rapid expansion of petroleum-derived organochlorines and organophosphate pesticides coincided with the period of consolidation of US hegemony in global capitalism. The development of the organochlorine insecticide dichloro-diphenyl-trichloroethane (DDT) during World War II, which became available for agricultural purposes in 1945 (Davis 2014), spurred the creation of a large variety of new molecules. Different groups of insecticides, herbicides and fungicides were released from the science/war technology complex for civilian purposes from vector control (for insecticides) to agricultural uses (see Russell 2001).

The Green Revolution played a fundamental role in this process. Through this large-scale US public and philanthropic intervention, breeding techniques and corresponding demand for inputs – fertilizer and pesticides – were transferred from temperate to tropical zones (Goodman, Sorj, and Wilkinson 1987). The beginnings of the institutional architecture for the Green Revolution would be built in Costa Rica during WWII, with implications far beyond the country's borders. US officials viewed Costa Rica as possessing the optimum conditions – climatic and political – to test pest management strategies (Picado Umaña 2012b, 2012a). In 1942, the US and Costa Rican governments jointly founded the Inter-American Institute of Agricultural Sciences (IICA in Spanish) for this purpose.[8] Henry Wallace, the US Vice President and Green Revolution proponent, participated in the inauguration of this specialized agency, which was linked to the U.S. State Department (Ibid). An agricultural cooperation agreement was signed at the Panama Canal to guarantee food provisions for US troops stationed there. In return for ensuring this food supply, the Costa Rican government received seeds, fertilizers, pesticides, funding and know-how for agricultural infrastructure from the U.S (León 2012).

Following WWII, these institutions and resources were repurposed to fund the Inter-American Technical Service for Agricultural Sciences (STICA in Spanish). STICA, like IICA before it, continued to promote and distribute low-cost pesticides and spraying

[7] London Purple was one of the principal pesticides imported, together with DDT, by the first half of the twentieth century (García 2003).

[8] The institute was renamed and it is currently called the Inter-American Institute for Cooperation in Agriculture.

equipment through a network of rural agencies that functioned as agricultural centers (Jiménez Acuña 1997; León 2012). A series of agricultural extension and technical assistance programs and the introduction of fertilizers and pesticides (e.g. arsenic and copper sulfate) were rolled out, expanding their use beyond banana plantations to other crops including vegetables (García 2003). In only seven years of existence (1948-1955), STICA spurred the institutionalization of pesticides in Costa Rican agriculture in three ways: consolidation of an Agricultural Extension Service, expansion of the national agrochemical market, and development of a chemical control strategy for agricultural problems (Ibid). Agricultural sciences magazines like the Bulletin of Development, Costa Rican Soil and the Journal of the Costa Rican Coffee Defense Institute, played a key role, recommending recipes and modes of application to farmers and extension agents across the country (Ibid). The chemicalization promoted by STICA served as a bridge between UFCo's large-scale export agriculture and domestic production by small and medium-sized farmers. It consolidated the architecture of the Green Revolution through a set of institutions that generated scientific knowledge and transmitted it through different initiatives and programs (circulars, extension services, and training centers) (Picado Umaña 2012b, 2012a; León 2012).

Between the 1950s and the late 1970s, the Costa Rican state created additional institutions, again primarily dedicated to the promotion of capital-intensive agriculture (Jiménez 1997). Farmers could obtain not only cheap fertilizers and pesticides from the national fertilizer company, but also state-supported technical assistance and plenty of extension services (Edelman 2019; León 2012). The agriculture sector also diversified with state support. The first major agrochemical companies in Costa Rica appeared in the 1960s, as part of the import-substitution industrialization policies adopted by the Central American Common Market (Murray 1994). Pesticide use would become a condition to access agricultural credit: farmers would be required to comply with specific pesticide use guidelines in order to qualify for public loans (Thrupp 1990b). Although pesticide use increased 1200% during these decades, their use remained largely concentrated in export crops like bananas, although adoption in domestic production of potatoes, rice and tobacco was underway (León, Aguilar, and Barboza 1982; Galt 2014).

The process of creating a national capitalist agriculture remained deeply imbricated with banana production throughout this period. In 1956, the Costa Rican government signed an agreement with Standard Fruit (Dole), to restart banana production in the Caribbean region, which had lapsed since UFCo abandoned the area due to *Fusarium* (Viales 1998, Montero & Viales 2013). Since the 1940s, Standard Fruit had been testing a new banana variety, Cavendish, which was more tolerant to the pathogen. Cavendish was finally made suitable for export through the development of a new packing system that would protect the fruit from bruising because it was more fragile and easily damaged in transit (Cano Sanchiz 2017). In 1962, UFCo followed suit and replaced Gros Michel with Cavendish, although the company had already lost considerable market share from the competition

(Marquardt 2001a). The resuscitation of banana monocropping played an outsized role in pesticide consumption. By 1963, bananas accounted for 65% of total pesticide use (García 2003).

The new biotech fix for banana monocrops introduced novel dimensions of susceptibility that in turn would threaten capital accumulation. Cavendish cultivars were more susceptible to plant-pathogenic nematodes, specifically *Radopholus similis*, which attacked their root system and caused blackhead toppling disease (Ploetz and Evans 2015). The nematicides that would become central to mid-century Cavendish production were first developed by the University of Hawaii's Pineapple Research Institute (PRI) (Romero 2022). Organic (e.g., guano) and later inorganic fertilizers (via the Haber-Bosch process) eliminated the need to rotate crops, but lack of crop rotation exacerbated the problem of pest control. Plant-pathogenic nematodes, in particular, threatened the viability of capitalist pineapple production. After experimenting with a number of pre-war toxicants, including chloropicrin (used in chemical warfare but not made cheap enough in the political economy of post-WWII to qualify as an economic poison), lead PRI researcher, Walter Carter, wrote to numerous petroleum companies to ask for waste from petroleum refining to test on Hawaiian pineapple farms. He found success in the contents of steel drums shipped by Shell Oil and eventually developed the soil fumigant 1,3-dichloropropene-1,2-dichloropropane (DD), which would not only defer the collapse of Hawaiian pineapple, but also revolutionize chemical agriculture more widely by enabling intensive, non-rotating, short-cycle cultivation (Ibid; see also Guthman 2019). After this initial success, PRI researchers would go on to develop a second-generation nematicide in the early 1950s, 1,2-dibromo-3-chloropropane (DBCP), commercialized by Dow and Shell as Fumazone and Nemagon respectively. DBCP, also a soil fumigant, could be applied post-planting (unlike DD), vastly increasing its appeal and commercial success (Bohme 2014, 34-35; Bertomeu-Sánchez 2019). DBCP was broadly applied in banana plantations during the 1960s and 1970s due to the damage caused by nematode infestations, which compensated for the high cost of using this treatment (Soluri 2021). Despite its risks to human health, DBCP was used indiscriminately, leading to severe health consequences to at least 30,000 workers in Costa Rica (Thrupp 1991b; Mora Solano 2014).

While fumigation proceeded underground, insect infestations devastated banana plants and threatened production above. The same delivery infrastructure used to apply copper sulfate was redeployed for organochlorines and organophosphate insecticides, including dieldrin, DDT, malathion, and other mixtures from 1954 to 1958. But aerial spraying using aircraft, first introduced in the Mississippi and Louisiana Delta in the 1920s owing to its vast lowlands (Williams and Porter 2022), quickly became the principal method for application. In 1954, 12,000 ha of UFCo plantations in the Pacific region were sprayed aerially with the organochlorine dieldrin, which killed off natural predators and spurred outbreaks of secondary pests (Nicholls and Altieri 1997). Just five years later, by 1959, target insects already showed resistance to dieldrin, and the company replaced the compound with a carbamate insecticide (Thrupp 1990a, 1988). From 1954 to 1973, insecticides continued to be heavily applied on a calendar basis, triggering a classic pesticide treadmill with resistance developing among target insects, and the provocation of secondary and tertiary outbreaks as natural predators were eliminated. While scholarly accounts attribute the sudden cessation of aerial applications to a decision by company entomologists in 1973 (Ibid.), the decision may not solely have been a reaction to intractable pests, secondary outbreaks, and the mass ecological disruptions that aerial spraying had provoked. The oil crisis would rapidly change the economic calculus of such intensive treatments, as prices for fuel, pesticides and fertilizers soared (Goodman, Sorj, and Wilkinson 1987).

3.5 Debt crisis, new monocrops and extending pesticide life cycles (1980s-present)

With the debt regime of the 1980s in Latin America and beyond, IMF structural adjustment policies prioritized so-called non-traditional exports and defunded and dismantled much of the Green Revolution architecture for national production (McAfee 1991; Murray 1994; L. P. Vargas 2015). In Costa Rica, oil palm and pineapple became "export superstars": over the course of the next four decades, production of the two crops would expand from 14,000 to over 110,000 hectares, extending across the south Pacific Region, with an estimated area of 50,000 ha of oil palm and 7,800 ha of pineapple in the region (Galt 2020; Arguedas-González, Vargas Bolaños, and Miller Granados 2021; Y. Vargas, Vargas, and Miller 2021).

The institutional retreat from national agriculture, including subsidy and credit cuts and the downsizing of extension services, was accompanied by the growing commercialization of pesticides that led to an increase in use among small and medium farmers (see Galt 2014). By 1992, 209 active ingredients were registered and marketed under the name of 794 commercial brands by 450 agricultural distributors. Of these active ingredients, 2,4-D, mancozeb, and propanil were sold under the largest number of brand names (Garcia 1993), a practice that continued under structural adjustment even as the availability of public agricultural credit and subsidies for pesticides declined (except for the export superstars, see below).

The promotion of large-scale pineapple agriculture became one mechanism to boost export earnings and thus service the country's debt commitments. Once again, Hawaiian-based agro-industrial innovation was key, this time for a biotech fix with important implications for pesticide use. The Pineapple Research Institute developed a new pineapple hybrid, called MD2, in the early 1970s. Del Monte, a key stakeholder in the Institute, would move quickly to field test and commercialize the new varietal through its new Costa Rican subsidiary, the Pineapple Development Company (PINDECO) in 1978 (Vagneron, Faure, and Loeillet 2009). A vast infrastructure was developed, including mechanized harvesting and advanced technologies in packing, to support large-scale production. The success of the varietal was due to its sweetness and yellow color, its quick rate of vegetative reproduction, and, significantly, its longer shelf life. Durability allowed for long-distance shipping, opening the possibility for Costa Rica to export pineapple to Europe. This combination of traits and aggressive marketing "[redrew] the geography of the global pineapple market" (Ouma 2015: 179). West African producers, growing the more perishable, less sweet, and greener Sweet Cayenne variety, lost their share of the European market while demand for the new variety soared (Ibid.). Costa Rican exporters jumped into the breach. PINDECO gained a dominant foothold with a generous export subsidy called a Tax Credit Certificate (CAT in Spanish) (Edelman 2019). Despite its debt burden, the state spent 8% of its national budget in 1990 on these credits for non-traditional exporters (Vagneron, Faure, and Loeillet 2009), with PINDECO receiving 10% of the total (Leon 2020). PINDECO rolled out large-scale production in 1996 through a vast infrastructure to support mechanized harvesting, advanced technologies in packing and a production system highly dependent on pesticide use.[9)] Plantations were located in the upstream watershed that flows into the Térraba-Sierpe delta of the Pacific region. Between 2000 and 2005, exports to the US and the EU grew at an average rate of 11% and 26% annually (Vagneron et al. 2009).

Oil palm cultivation was conceived in the heart of the banana plantation. Beginning in the 1930s, UFCo started collecting in its botanical gardens in Lencetilla Honduras, different plant varieties from experimental stations and botanical gardens in Sierra Leona, Congo, Malaysia and Indonesia (Clare Rhoades 2011). In 1943, it launched its first experimental sites in Alejo, Honduras and Quepos, Costa Rica (Richardson 1995). The company founded a research program called Agricultural Services Development or ASD, a branch specialized in genetic material development and research, along with a department specialized in production, which later became Palma Tica (Clare Rhoades 2011). Since the 1970s, the company gradually migrated production towards oil palm through the company Palma Tica, which it spun off but maintained shares (Clare Rhoades 2011; Abarca 2016). The variety developed by UFCo in its Pacific plantations, called original compact palm or OCP, was a major innovation in the sector due to the benefits of its smaller size and tolerance to Lethal Bud Rot disease (Ibid.).

These new export crops, field tested and acclimatized in the Pacific region, offered biotech fixes to the persistent dilemmas facing banana monocropping through crop diversification and hybrid resistance or tolerance traits. As production of these monocrops grew exponentially, banana production flagged, burdened by declining profits and agricultural challenges, including the appearance of the ascomycete fungus *Mycosphaerella fijiensis*

[9)]Due to the agronomic specifications of the crop (e.g. year-round production, plant characteristics, soil techniques), pineapple cultivation is highly dependent on chemical inputs. The technological package includes herbicides, fungicides, nematicides, and insecticides (Acosta 2008; Castro-Vargas, Picado, and Vega 2015).

diformis which causes black Sigatoka disease. By the early 1980s, this pathogen prevailed in the areas previously affected with *Mycosphaerella musicola* (Ploetz and Evans 2015)[10). To combat *Mycosphaerella fijiensis*, the banana agroindustry introduced an aerially applied treatment, triggering another pesticide treadmill. The system consisted of rotating cocktails of multiple-action fungicides combined with oils on a calendar basis, which started with 35 cycles per year and in one decade increased to 45-50 cycles (Thrupp 1988).This resulted in a four-fold increase in the cost per hectare (Ibid).

In 1984, UFCo closed its banana plantation in the Southern Pacific as a strategy to diversify its operations towards oil palm production, while concentrating on the marketing stage of the global banana supply chain (Clare Rhoades 2011; Abarca 2016). Although UFCo's banana production was already facing a series of challenges including soil depletion, low productivity, high cost of chemical inputs, and market difficulties, the company took advantage of a three-month workers' strike that year to terminate its contract with the government unilaterally (Royo 2004; Cano Sanchiz 2017). The state responded to UFCo's retreat by promoting agricultural cooperatives[11)] integrated by former banana workers, peasants, and people from other rural areas of the country (Arias Mora 2007; Guillén Araya 2020). One of these cooperatives was COOPALCA DEL SUR, created in 1986, to which UFCo directly transferred 900 ha. of land, namely, Finca 2, Finca 4, and Finca 6 (Mora Calderón 2022). Five years later, after a failed cocoa production project on these farms, COOPALCA attempted to reactivate banana production. Without access to sufficient credit, the coop entered into a contract farming scheme, called a banana consortium, with a Costa Rican entrepreneur backed by CORBANA, a national joint venture company (Ibid).[12)] From 1991 to 2001, Bananera Térraba in Finca 2 (277 ha) and Bananera Chánguena in Finca 4 (300 hectares) grew bananas for export to the US, through this arrangement (CGR 2003) (see Figure 1). As one former worker explained, the banana consortium maintained the same technological package to treat black Sigatoka as UFCo, aerially spraying the same brand-name fungicides, mancozeb (Dithane), propiconazole (Tilt), and tridemorph (Calixin), although the work was now outsourced to a local company that sold services to different plantations in Palmar Sur. Low banana prices and non-payment by the exporter led the business to fail (Contraloría General de la República 2003). After staying in the fields with their salaries unpaid, cooperative members and workers went on an unfruitful strike that ended up in the land occupation of Finca Térraba (Hernández González 2018). That same year, in 1991, they founded a new cooperative, COOTRAOSA, which pooled small-scale productive

[10)]Similar to Mycosphaerella musicola but more pernicious, Mycosphaerella fijiensis first appeared in Honduras in 1972 and spread to Costa Rica in 1978-1979, representing the most expensive and resistant of all pests/diseases affecting bananas in the country (Thrupp 1988).

[11)]To reactivate agricultural production, four cooperatives emerged during the first wave of cooperativism: COOPALSUR, COOPROPALCA, COOPALCA DEL SUR and COOPEADELANTE (Mora Calderón 2022).

[12)]CORBANA was a mixed capital company with the participation of the state, the national banking system, and independent banana producers (CGR 2003).

projects and peasants farming. When the lease of Finca Chánguena expired in May 2014, an agrarian movement named Chánguena Por Siempre[13)] took over the farm. On these lands, divided into *parcela*s, agriculture has been a great challenge, despite sustained efforts to recover the soil, the agroecological aspirations of many members in the movement, and the support received from national organizations, institutions, and universities. We now return to our departure point and the present dilemmas in these *parcela*s, which we discuss in the final section.

3.6 Making agrarian futures from the patchwork of "fixes" in Palmar Sur

The patchwork of biotechnical-chemical fixes that sustains the ecological regime across the 'long twentieth century' extends materially and symbolically in *parcela*s, as human-ecological relationships that inhere in soils, waterways and life histories.This iterative susceptibility-resistance spiral fosters a generalized dependency on a shifting set of legacy pesticides in the context of the *parceleros/as*' ever-changing relationship with pests, pathogens, and weeds. The constraints on the plantation land recuperation process are formidable, as José Julián, a worker in the nearby oil palm plantation Palma Tica, and a parcelero who serves as coordinator of Chánguina Por Siempre, expressed: "it is quite difficult, given the pests, the contamination in the soil, well, also there is a lot of mecate, there are parts where it is quite difficult to make a hole, so it has not been as easy as that, but well, we have looked for methods to do it and here we are, right?" To stay in the land has meant seeking mechanisms and strategies that depend upon pesticides in the face of nematode-infested soils and aggressive *Mycosphaerella fijensis*.

Parceleros/as cobbled together chemical fixes made feasible by a growing "low-cost" generic pesticide industry. By the early 2000s, the ecological surpluses afforded by "eureka-type" discoveries and protected by patents, like DDT and later glyphosate, had waned (Shattuck 2021; Werner, Berndt, and Mansfield 2021). R&D firms were restructuring to find new sources of monopoly profits (principally through biotech seeds, and more recently, "platform" data services) and outsource production (Ibid.). By 2018, the market share by sales of proprietary pesticides reached its lowest level ever, just 15% of sales compared to 30% in 2000 (IHS Markit 2020). Bolstered by manufacture of generics, China had become the world's principal exporter of pesticides (33% by volume), followed by India (9%) (Stobbart and Rana 2022). Globally, imports of formulated pesticides nearly doubled from 2.5 million metric tons (MT) in 2005 to 4.8 million MT in 2019 (Shattuck et al. 2023). In Costa Rica, domestic formulating firms were linking up to these global supply chains, and by 2009, the country became a net exporter of pesticides for the first time in its history, a trend that continued to increase (Castro-Vargas and Werner 2022). For small farmers and *parceleros/as*, like those in Palmar Sur, generic

[13)]A group of approximately 80 families including former banana workers, oil palm workers, and peasants.

formulations promised access to pesticides that were hitherto out of reach although products were certainly not low-cost in a relative sense.[14]

In 2019, after much internal debate, Chánguena Por Siempre members appealed to the Agricultural Development Institute (INDER in Spanish) for pesticide inputs. INDER acceded and delivered a bundle of sacks to each *parcela* and departed, offering no instructions or follow-up. Each *parcela* received the highly toxic organophosphate nematicide-insecticide terbufos and several herbicides – paraquat, 2,4-D, glyphosate and metsulfuron-methyl. The delivery of publicly supplied pesticides was not the norm. In general, *parceleros/as* visited different small agricultural centers in the southern Pacific, searching for pesticides, which they recommended to each other based on common experiences. As Sebastián, a leader of Chánguena Por Siempre, explained “the agronomist here is the neighbor, each of us here is the agronomist.” The only requirement to access scheduled substances, restricted by the government due to high toxicity, was a prescription from a state-licensed agronomist. Retailers easily circumvented regulatory controls on the sale of restricted pesticides, such as paraquat. While some stores had more strict controls maintained by supervision of a permanent state-licensed agronomist, in others, a designated agronomist visited once a week and signed all the prescriptions without talking to farmers or visiting their fields. In both cases, the prescription had limitations for adequate control: “The prescriptions do not change anything,” explained Alicia, a pesticide vendor at the Sugar Cane business association’s supply store in the region, “imagine that I make more than three hundred prescriptions a day.” The prescription also functioned as a mechanism to “cure oneself in health” (*curarse en salud*) in case of poisoning: when a farmer or worker suffered an acute intoxication, the agronomist possessed the documentation to prove that the appropriate doses and protective forms of use had been duly prescribed. The farmer, then, was responsible for “misuse” of the product, she continued. A wide range of commercial brands, under different names and formulations, were available in the warehouse crammed with products and popular among farmers for its low prices. Small producers and peasants were constantly testing different combinations of generics. From Alicia’s perspective, generic companies used colored packaging as a marketing strategy: “2-4D is yellow, paraquat is orange, glyphosate is light blue, so they are very bright colors, and the farmer then buys by color, not by name.” Paraquat, derived partly from coal tar and first launched in 1962, remained one of the most widely used herbicides in the southern Pacific, sold under a range of generic brands such as Blast (Ráfaga in Spanish), GreenGo, Radex, and Seraxone. Although Paraquat is considered a highly hazardous pesticide and has been banned in 67 countries for its health risks, including EU, UK, Switzerland and China (Stuart et al. 2023), in Costa Rica the

14) Supply chain disruptions, together with regulatory changes in China, had driven up costs of pesticides and fertilizers in 2020-2021, during the time of fieldwork. But overall, generics offered the possibility of using pesticides that could not have been accessed otherwise

prescription system assured its continued circulation. This herbicide, just like other agrichemicals, were sold in a market dominated by old molecules.[15)]

Mixtures were a constant topic among *parceleros/as* as they sought bespoke solutions to the loss of pesticide effectiveness and lack of technical advice. The most common mixture was glyphosate with Arranque (means 'starter' in Spanish), the generic brand name for the selective herbicide metsulfuron-methyl. Venancio, a more experienced parcelero who cultivated plantain and had worked for UFCo in the early 1980s, explained that the mixture helped farmers face the low prices of plantain in local markets ($0.15/kg), since manual weed management would increase production prices. "Arranque is an herbicide, it kills the broadleaf, let's say, *bejuco* and *hojilla*, and glyphosate is systemic, it penetrates more into the soil and only kills grass, but when mixed it works well, some plantain producers here have been using this for 14 years." Other mixtures were used, like paraquat with glyphosate, even though a contact herbicide like paraquat reduces the efficacy of a systemic one like glyphosate. Multiple generic brand names for the same active ingredient, or similar brand names for different active ingredients, generated confusion, e.g. Arranque (metsulfuron-methyl) or Arrasador (glyphosate). As Alicia explained: "I have seen people who burned their crop because they took Trigger instead of Tiger, and applied that, and one is an insecticide and the other is an herbicide."

The frequency of applications of pesticides in Palmar Sur has also increased over time, to counteract the persistence of pests and pathogens. In the face of the nematode infestations that UFCo left behind, granules of terbufos were widely applied on *parcela*s. Alonso, a young *parcelero* who cultivated squash for the domestic market, explained how he used terbufos granules provided by INDER to combat nematodes: "a friend told me to change to a different insecticide every 4 days, 5 days, every week, but the only thing that worked was terbufos. I even tried to apply it with the hand pump, by dissolving it in water, until one day I almost ended up in the hospital, and then I finally decided not to plant any more squash." Venancio, said, "I don't use it because I saw workers [in UFCo] intoxicated with that Counter [terbufos] and I became 'allergic' to it [averse to its use]." The toxicity of the nematicide was troubling. As Sebastián explained: "when you poured that, even if it was just a little bit, but every critter that gets close to it dies there, a shrike, a snake, a lizard, everything, a hen came and ate one of those granules and died there, hens die, it is very toxic." Plantain, the most viable domestic market crop, remained a vexing problem for *parceleros/as*, as they had "more losses than gains." Parceleros/as would switch to other, less marketable crops, forgoing possibilities to sell their produce, or be constantly exposed

15)In 2022, the 21 most commonly used pesticides were, in order of quantity, mancozeb, glyphosate, paraquat, chlorothalonil, ethoprophos, diazinon, 2,4-D, chlorpyrifos, terbufos, diuron, metam sodium, oxamyl, ametryn, fosetyl-Al, fenamiphos, propineb, fenpropimorph, cadusafos, imidacloprid, carbendazim, terbutryn (E. Vargas 2022). Of these substances, nineteen were introduced or commercialized between 1945 and 1977, and only ferpropimorph (1983) and imidacloprid (1991) were developed after the 1980s.

to highly toxic and hazardous substances.[16] The pesticide treadmill triggered to control *Mycosphaerella fijensis* in the 1980s had never ceased and *parceleros/as* struggles were the latest chapter. The fungi remained active and efforts to eliminate it had led to copious amounts of mancozeb applications, launched in 1943 and the main agrochemical used nationally. Fungicide application for bananas reached 52 rounds per year, nearing a weekly basis (Brühl et al. 2023). Indeed, the industry was struggling to maintain the free gift of *Mycosphaerella fijensis*' susceptibility, internationally classified as being at high risk to develop resistance (FRAC 2019). *Parceleros/as* worked to produce a viable plantain crop for domestic markets without technical support, either public or private to achieve the required quality standards. Herbicides and terbufos remained central and necessary if they were to produce plantain for sale. Eliseo, a former worker at the banana consortium and a leader of COOTRAOSA, who cultivated a 5 ha. *parcela* with plantain mixed with subsistence crops, explained, "if I want to reach a market [domestic], I have to apply fertilizer every month, I have to keep the plantation clean, I have to make sure that the plants are green, so I have to apply fertilizer every month, I have to irrigate two times a month [against] Sigatoka, I have to combat the weeds every time the weeds grow."

Institutionally, the legacies of exposure in the area were made illegible through various state maneuvers of bureaucratic neglect, expropriating the ecological surplus of contaminated landscapes and bodies. Since UFCo ceased banana cultivation in 1984, no state agency had conducted adequate studies to analyze pesticide residues in the soil, surface waters, or groundwater. Residents accessed water by digging artesian wells on each *parcela*, combined with a water tank installed since 2017 by the Water Institute (AyA in Spanish), the result of a community struggle led by *parceleros/as*. Public institutions responded to [First Author's] inquiries into health effects due to pesticide exposure through tactics of deferral. For instance, the regional officer from the Ministry of Health regretted that no epidemiological studies had been ever conducted to understand possible health consequences for workers and inhabitants of the former banana districts and that historical health data was located in the central office archives (i.e., specific information like acute intoxication reports). Officials in the central office explained that historical health data before the 2000s (i.e. physical files) had been not conserved. Regrettably, more attention had been paid to the impact of pesticides on the surrounding wetlands, an internationally declared Ramsar site since 1996, which had long concentrated wealthy international climate change funds destined for conservation and restoration of the mangrove (SINAC-PNUD-GEF 2018). In interviews, NGO representatives and officers from the Ministry of Environment showed their concern about the wetland's contamination both with legacy and currently applied pesticides from nearby plantations. Although pesticides were identified as a principal threat to the wetland, studies generally

[16] A recent study from UNDP (2022) revealed the absence of information on the health consequences associated with the high use of pesticides in the country. Despite the existing poor documentation of acute poisonings in the country, 1700 hospitalizations, 271 poisonings and 800 sick leaves were registered between 2012-2020 (Alvarado et al. 2022).

ignored their effects on human and non-human organisms, and concentrated instead on strictly environmental concerns such as geomorphological changes in the delta or sedimentation patterns in the mangrove (Acuña-Piedra and Quesada-Román 2021; Silva Benavides et al. 2015). In the midst of myriad conservation initiatives, the health of local communities has been so far ignored, despite chronic exposure to pesticides through legacy contamination, aerial spray drift, plantation runoff, and leaching.

The layers of pesticide legacies not only remained in soil and waterways, but also permeated people's life histories. Teresa, born in 1949, was one of the founders of COOTRAOSA. She grew up in UFCo's plantation, where her mother worked in the soup kitchen, or fonda, while her stepfather applied Bordeaux mixture. Teresa recalled him and his co-workers dyed green: "everything, everything, from the clothes to the hoses, was green." In 1969, she started working in the banana packing plant, where she washed workers' pesticide equipment without personal protection for herself. By the 2001, she and her partner, Manuel, had joined hundreds of people affected by DBCP to demand indemnification by the Costa Rican State (Bill Nº 8130).[17] Manuel explained, "[when we applied it] we did not know anything about it, they knew it was toxic and nobody used protection or anything, today we are both in that fight." While Manuel and Teresa still hold out for economic compensation for their exposure, many co-claimants have already passed away. "I have lost a vast number of colleagues," Teresa remarked. Unfortunately, these stories are quite common among *parceleros/as*, where the burden of chronic exposure and harm has accumulated across generations.

Agricultural practice was a source of constant debate among *parceleros/as*, polarized between those inclined to subsistence farming and those who tried to produce for local markets. The former tried to reduce pesticide use through organic farming strategies but largely could only produce for their households, and the latter kept using pesticides as much as possible, despite their elevated cost, to sell domestically. For José Julián, the tensions over practices were related to previously established relationships with the land. "[It] has not been easy," he explained, "because throughout history, well, our ancestors, mainly here on the farm, a lot of agrochemicals were used, like nemagon [DBCP], which was so harmful, among others. And that culture has remained here." Eliseo had decided to cultivate a second *parcela*, also of 5 hectares, with oil palm. He was struggling with the high costs of agrochemical inputs, including fertilizers, plus the insect *picudo* (*Rhynchophorus palmarum*) in oil palm, and the "eternal headache" *Mycosphaerella fijensis* in plantain. Nearby, Palma Tica benefited from a technological package designed

[17] In 2001, the Costa Rican government approved Bill Nº 8130, assuming responsibility for the damage caused by DBCP, which led the Costa Rican National Health Service (CCSS in Spanish) and the National Insurance Institute (INS in Spanish) to undertake the process of financial compensation for the population affected by the nematicide (Mora Solano 2014). By 2022, not all affected former workers have been indemnized, thus the deputies were discussing modifications to the law to improve its effectiveness and scope, e.g. an increase in the total amount of indemnization or inclusion of family members (CCSS 2022).

by specialists that combined pesticides (principally herbicides) and biological control, alternating glyphosate use with vegetation coverage methods, owing to its possible phytotoxicity to the crop (Ramirez 2011; Stuart et al 2022). Rafael Solano, an agronomist who advised an oil palm farmer cooperative in the southern Pacific, explained that the cooperatives copied some methods from Palma Tica, like a pheromone-based weevil trapping system to combat *picudo* and its hexagonal planting pattern. But unlike Palma Tica, which used glyphosate or glufosinate ammonium to clear around its palms in order to qualify for international certification, cooperatives relied more heavily on paraquat. Eliseo preferred glyphosate and the insecticide diazinon to combat *picudo*, but was running out of options to pay for the pesticides to keep his oil palm *parcela* "running." Some coop members openly criticized Eliseo for betting on oil palm and plantain over diversified production. He ignored such critiques and tried to "stay afloat" by also working on a nearby banana plantation to earn money to produce cash crops on his *parcela*s, despite the low productivity. Whatever the formula *parceleros/as* had chosen – mixing crops, pesticides, wage work and own-production – they faced formidable constraints on reproducing life and livelihoods on plots that had accumulated symbolic and material layers over the long twentieth century.

3.7 Conclusion: Agrarian futures and the ecological regime

We have argued that pesticides are not simply inputs in crop production; they are stabilizing elements in the ecological regime that is capitalist agriculture. The distinction matters for conceptualizing how that regime is maintained over time, the role that pesticides play in regime stabilization, and the emergent tensions and contradictions that may provoke transformations. Our account centers on a dual dynamic of pesticides in relation to capital accumulation. On the one hand, pesticides augment or increase the ecological surpluses that capital depends upon for its realization. As commercialized byproducts of extractive industries, as compounds that externalize harms to racialized workers and peripheralized environments, and as biocides that tap organisms' susceptibility (their "killability"), pesticides marshal ecological surplus (i.e., these free gifts) towards the process of accumulation. But as chemical fixes, pesticides are deeply imbricated with the biotechnical strategies developed by capitalist agriculture (specifically firms and the public-private initiatives that they sponsor or appropriate) to overcome the socio-ecological limits germane to agriculture. These biotech fixes – new cultivars, hybrid or, increasingly genetically-modified – and their industrial massification in monocrops disrupt ecological relations. Monocrops function as live experimentation sites, articulating techno-scientific knowledge, applying trial and error strategies and initiating novel relationships between pathogens, pests, plants and humans. Stability of these precarious, dynamic arrangements is maintained through the "patchwork" of chemical and biotech fixes. Over the long twentieth century, material layers, accumulated in soils, organisms, and life histories, condition subsequent strategies of capitalist agriculture, and the possibilities to carve out alternative paths within these inherited chemicalized landscapes.

The mix of monocrop-plot production in Costa Rica's southern Pacific region, the flows of chemicals, knowledge of pesticide use, and exposures, are difficult to disentangle. With the globalization of the agrochemical industry and the rise of generics, pesticides are more accessible than ever, as small farmers "innovate" with mixes and combinations of compounds, work on their plots and on plantations, and share strategies between the two. The plots themselves are archives, patchy and blotted with toxic and synthetic legacies – from inorganic copper to synthetic twine – which condition the livelihood possibilities tied to these reclaimed plantation lands. Smallholder agriculture in these *parcela*s relies upon bespoke pesticide practices using legacy compounds introduced during the synthetics boom of the post-WWII period under current conditions of frayed public support and chemical- and pathogen-riddled soils.

If the future of capitalist agriculture is being advanced as one of "precision agriculture," "biological control," and "climate-smart" approaches that promise to draw down the chemical treadmill, the view from the southern Pacific region of Costa Rica suggests otherwise. This perspective calls for critical social science to take the long view of pesticides, the ecological surpluses they marshal in different ways over time, and together with biotech interventions, the ecological regime that they maintain. Such work requires practical, engaged, and sensitive solutions that recognize how deeply pesticides have been woven into monocropped landscapes and their implications over time and space, including environmental and health impacts, as well as entrenched practices of agricultural management that condition what and how to produce for markets, from which farmers draw minimal benefit. Our point is neither to double down on narratives of capitalist ruin, nor to imply that the frayed biotech-chemical fixes we identify spell the imminent demise of the ecological regime that they play such a central role in reproducing. Instead, our paper grounds the present dilemma of pesticide use in the aspirations and obstacles faced by subjects committed to cultivating livelihoods and forging agrarian futures in regions made and remade to stabilize capitalist agriculture. From this perspective, renewed attention to the pesticide patchwork including on-farm legacies and off-farm political economy is clearly needed. Our point is not to discourage the search for alternatives but rather to face the challenges involved with a deeper understanding of their severity and the concomitant urgency for novel strategies for change.

Lens III: The production of space

Las raíces del manglar se aferran al suelo. El agua va y viene. Las mareas lentamente llenan y vacían los esteros. El agua cubre las raíces, las raíces tímidamente se asoman. Mientras baja la marea, los moluscos aprovechan para hundirse en el barro. Suaves pasos recorren el manglar, buscándolos. La luna sigilosa cambia el movimiento del agua. Una mañana no es igual a otra. Tampoco la noche. Los caminos del agua no siempre están abiertos. El manglar respira. El mar quiere entrar, rompe en la costa. Pero la intemperie no es intemperie, adentro hay calma. En esta tierra, aprendimos a convivir con la sal.

Soledad Castro Vargas

Mangrove roots cling to the soil. Water comes and goes. The tides slowly fill and empty the estuaries. The water covers the roots. The roots timidly peek out. As the tide goes down, the mollusks sink into the mud. Soft footsteps run through the mangrove, searching for them. The steady moon changes the movement of the water. One morning is not the same as another. Neither is the night. The water's paths are not always open. The mangrove breathes. The sea wants to enter. It breaks on the coast. But the inclemency is not inclemency. There is calm inside. In this land, we learned to coexist with salt.

Soledad Castro Vargas

The making of the Térraba-Sierpe Delta waterscape in Costa Rica:

Thinking within and beyond the plantation

Maria Soledad Castro-Vargas

Abstract

Where does a plantation begin and where does it end? Plantations are objects of renewed inquiry in agrarian studies, in dialogue with critical perspectives on the Anthropocene such as the Plantationocene. Taking the plantation as an object, however, can risk universalizing understandings of agrarian transformations. Key elements in agricultural production, like water and agrichemicals, have not been considered in these debates, even though they play a determinant role in shaping agrarian landscapes. This article unpacks the plantation through the lens of waterways and hydrological infrastructure in historical and geographical context. Specifically, it analyzes the production of a pesticide-contaminated waterscape in the Térraba-Sierpe delta, Costa Rica, as a means to interrogate temporal and spatial relationships in and through plantations. In 1935, the United Fruit Company (UFCo) moved its banana plantations from the Caribbean to the country's South Pacific region -where the delta is located-, drastically transforming its tropical landscape and socio-ecological relations. In 1984, the UFCo stopped banana cultivation while partly transitioning remaining farms to oil palm production. Four decades on, the Térraba-Sierpe Delta is characterized by fragmented and shifting land use dynamics, where different monocrops coexist with conservation areas, small-holder land occupations and fisherfolk villages. Based on 18 months of fieldwork between 2018 and 2021, which combined environmental science (i.e. ecotoxicology), ethnography and archival research, I build on the notion of waterscapes as a conceptual tool to interrogate the limits and scope of the plantation.

The notion of waterscapes examines how water and society are deeply intertwined and co-produced symbolically, materially, discursively and politically. Firstly, I analyse how UFCo created a water system for drainage and irrigation that expanded the area of the plantation beyond its territorial limits and that has persisted through time. This water infrastructure conditioned the spatial dynamics through successive land uses, in oil palm plantations and land occupations by smallholders, and increased the magnitude of floods due to climate events. Secondly, I examine what occurs beyond the apparent limits of plantations by following effluent flows, the movement of sediments and pesticide residues from contemporary plantations located upstream to the downstream delta. Thirdly, I explore how plantation legacies are expressed not only in the pesticide stratification (e.g. copper residues in the soil), but also as a remainder in the population, which reshapes territories and subjects. Ultimately, I argue that the delta materializes the ever-changing configurations of agrarian capital in and through plantations.

Keywords

Monocrops, floods, political ecology, pesticides, Central America.

4.1 Introduction

"The pineapple company wanted to come and set up here in Palmar and through our struggle and resistance, we managed to stop them from coming,"explains Julián, a worker in the nearby oil palm plantation and leader of Chánguena por Siempre, a local agrarian movement. In December 2019, the Ministry of Environment cancelled a planned 600-ha pineapple plantation in Palmar Sur by the multinational company Del Monte, which would have used forty-one different agrochemicals.[1)] In the deltaic floodplain where Julián lives, from 1934 to 1984, the United Fruit Company (UFCo) established a banana enclave that stretched across the Southern Pacific region of Costa Rica. Following the cessation of banana production, the region entered into a severe economic depression. A longing for the enclave is common, as Don Beto, a former UFCo worker told me: "people thought that she [the company] would come back, but she never did." Despite the nostalgia for corporate occupation (Li and Semedi 2021), the proposed pineapple plantation raised a great deal of opposition both locally and nationally. It opened a lively debate about the possible implications in an area shaped by legacies of the banana enclave. As Julián tells me,"[i]t has been like a collision between peoples. Some think that when a company like this comes, what it brings is only benefits, and it is not like that. It may bring employment, but we say, at what price are we going to get that employment, destroying what we already have or what we have been taking of care of day by day?" Concerns about pineapple production, inaugurated by the establishment of Del Monte in the middle region of the river basin in the 1980s, are pervasive all along the water course of the Térraba river and down to its delta. "The commercial sector in Palmar wanted or intended that the pineapple company would come for commercial reasons, but most of the smallholders here in the area were opposed to this because we know what a negative impact it would have on us," Julián continues. In a region deeply entangled with the plantation, and largely identified with it, what explains the opposition to the pineapple plantation? Why did the proposed pineapple project galvanize opposition in an area so profoundly shaped by the legacies of the 20th century banana enclave?

[1)]The Ministry of Environment revoked the environmental viability in the face of exacerbated social pressure, arguing in its resolution that it constituted a megaproject that had obtained a permit without an environmental impact study, amplified by its high potential to contaminate the neighbouring RAMSAR protected area Wetland Térraba-Sierpe or damaging the archaeological heritage site declared by UNESCO (MINAE 2019).

This article analyses the production of the pesticide-contaminated waterscape in the Térraba-Sierpe delta, located in the South Pacific region of Costa Rica to interrogate temporal and spatial human-environment relationships between in and through plantations. As the opening vignette suggests, plantations articulate particular moments and socioecological relations, and their boundaries cannot be regarded as predetermined. For this reason, I offer a relational analysis derived from the interconnectedness of the river basin to explore the imprint of plantations on the delta. I conducted fieldwork between 2018 and 2021, which combined environmental science (i.e. ecotoxicology), ethnography and archival research. I conducted semi-structured interviews with one hundred informants, some of them over several occasions, through the middle and lower basin of the Térraba river, which included communities in neighbouring plantations, Indigenous territories, smallholder or *parcelas* areas, and mangroves. Other interviews were held in San José, Costa Rica's capital, with representatives of state institutions (e.g. Ministry of Environment) and non-governmental organizations (NGOs), along with academics and activists.

In San José, I participated in national debates on pesticide regulation and the consequences of intensive pesticide use in Costa Rica, while also conducting laboratory work in ecotoxicology at IRET-Universidad Nacional, and a research stay on political ecology at CIEP-University of Costa Rica. In the southern Pacific region, my primary base was in the

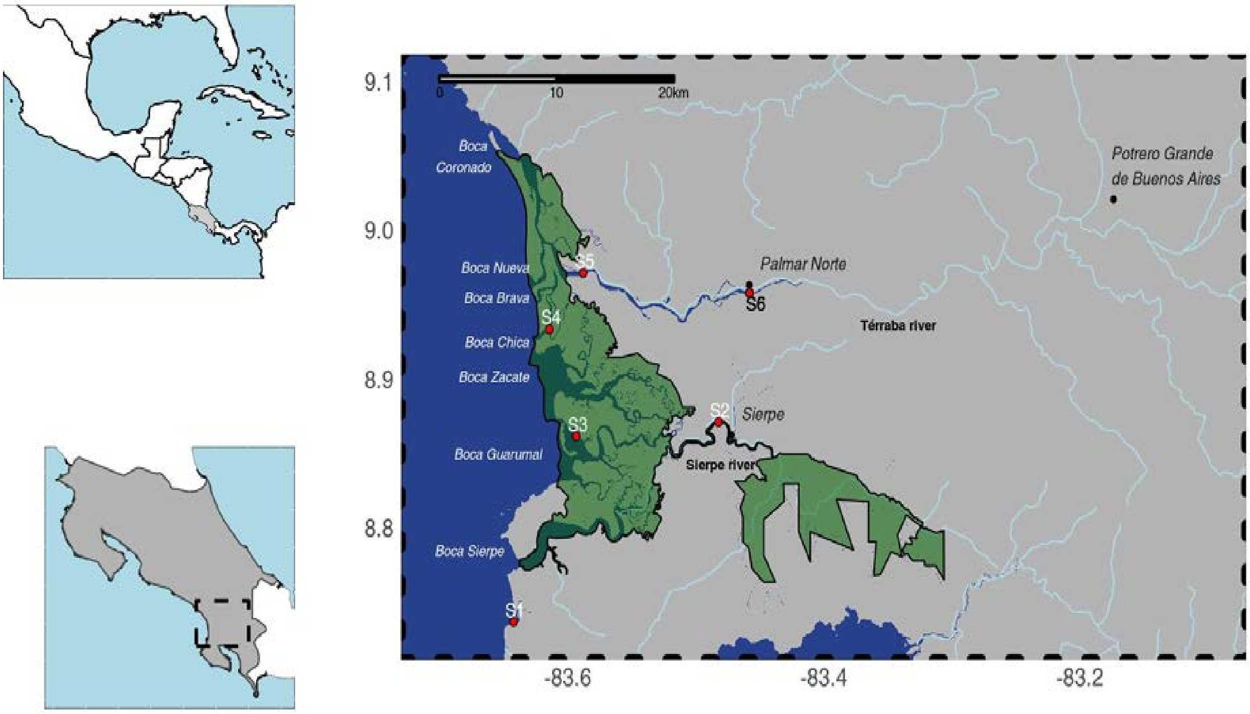

Figure 1. Main interview locations, namely: 1) Longo Mai, 2) Volcán, 3) Buenos Aires, 4) Térraba, 5) Rey Curré, 6) Boruca, 7) Ciudad Cortés, 8) Palmar Sur, 9) Finca 2-4, 10) Sierpe, 11) Ajuntaderas, 12) Isla Zacate, 13) Boca Guarumal.

town of Sierpe, an intermediate point between the terrestrial delta and the mangrove, from where many of my observations and analyses were derived. I complemented this with stays in other towns along the Térraba River and to a lesser extent the area of Golfo Dulce, to gain varied perspectives on the production of the waterscape (see Fig. 1).

This article is therefore an outcome of a broader study, in which I sought to draw from and speak across the environmental and social sciences. This opened different paths to excavate the delta-plantation relationship, such as sampling campaigns of water, sediment and the tropical mollusc *Anadara tuberculosa* or *piangua* in Spanish,[2] oral histories, journeys with former plantation workers, three workshops (one in the mangrove in 2019 and two in *parcelas* in 2019 and 2021), focus groups, and the coordination of a three-week training in agroecology in a *parcelas* region. Spending the day in the mangrove shifting through the mud to dig up molluscs, for example, not only served to explore the plantation-mangrove dynamics, but also generated engaging discussions with informants who gather *pianguas* for sustenance and/or income about the causes and effects of contamination. Lost archives, the lack of access to pesticide residue analysis, secrecy and fear, pervaded my research on monocrops in Costa Rica. Yet, the flexible combination of disciplines, and my personal engagement with agrarian issues, allowed me to use different strategies to deal with these and other challenges, including the Covid-19 pandemic (see Introduction).

In what follows, I build on the notion of waterscapes as a conceptual tool to interrogate the spatio-temporal form of the plantation. First, I introduce the theoretical framework of waterscapes and plantations studies. Second, I analyse the United Fruit Company's (UFCo) drainage and irrigation system and its persistence through time and space in the delta, expanding plantation areas beyond their formal territorial remit. I show how this water infrastructure conditioned successive land uses in oil palm plantations and peasant land occupations, and increased the magnitude of floods following climatic events. Third, I examine what occurs beyond the apparent limits of plantations by following effluent flows, and the movement of sediments and pesticide residues from different existing plantations located upstream to the downstream delta. Last, I explore how plantation legacies are entangled in soils, stratified with copper residues and *mecate* (or synthetic twine) layers, and constitute socio-material remainders in the local population. Far from latent compounds, these legacies and remainders are active constituting agents; they (re)make subjects and territories of the plantation's waterscapes far from its formal boundaries.

2) The extraction of this mollusc is the main source of livelihood for the people living in the mangroves (Bogantes 2017). According to Ifigenia Quintanilla, who conducted taxonomic identification research in archaeology on the diet of pre-Columbian peoples in the delta, the consumption of piangua can be traced back to pre-Columbian times (Ifigenia Quintanilla, interview, Abril 2019).

4.2 Plantations Revisited: Seeing through the waterscape

The study of plantations has a long-standing tradition in agrarian studies, and classic authors have grappled with identifying common characteristics to serve as a theoretical basis for comparative social science. To that end, Thompson (1930:3) defined a plantation as an institution of settlement, “a large landed estate, located in an area of open resources, in which social relations between diverse racial or cultural groups are based upon authority, involving the subordination of resident labourers to a planter for the purpose of producing an agricultural staple which is sold in a world market.” Wolf and Mintz (1957) built on Thompson’s work and differentiated *haciendas* (or large estates) from plantations. Plantations in particular were “operated by dominant owners (usually organized into a corporation) and a dependent labour force, organized to supply a large-scale market by means of abundant capital accumulation without reference to the status need of the owners” (1957:381).While the engagement to develop definitions and typologies represented a useful analytical step, it indirectly contributed to the downplaying of plantation-making processes in subsequent studies (Tomich 2011). In this regard, as argued by Edelman, the lack of historical contextualization and processual perspective resulted in an overly structural understanding of plantations. In addition, as Mintz would later point out, earlier research overlooked ecological aspects, such as the fragile elements of plantation production given the perishability of the product (Mintz 1985 cited in Edelman 2018).

In Central America, the banana enclave has occupied a central place in plantation studies. The term 'banana enclave' originally referred to the corporate control that banana companies exerted over states, territories, and societies, leading to a reliance on international markets and the loss of sovereignty (Torres Rivas 1969). Over time, scholars have sought to address the enclave’s complexity and multidimensionality, by exploring how class, race, and gender shaped these projects. The banana enclave was not a one-sided, straightforward imposition, and banana multinationals, despite their significant power, faced political challenges in every country where they operated (Striffler 2001). The study of the banana enclave remains salient today, but the restructuring of agrarian capital demands inquiries into its transformation. For example, one could ask: What are the legacies of the enclave? What characterizes emerging plantations in areas that have been unevenly incorporated into plantations over decades? In what ways have socio-natural relationships of contemporary plantations been reworked? It becomes paramount to rethink the plantation from an empirical and situated perspective, acknowledging its dynamism and variegation.

In this regard, Li & Semedi explore how oil palm plantations generate life under corporate occupation in Indonesia, tracing the imperial debris that remains from colonial rule.[3)] Based on ethnographic work, they define the plantation as "a machine for assembling land, labour and capital under centralized management for the purpose of making a profit; it is also a political technology that orders territories and populations, produces new subjects and makes new worlds" (2021:1). From a Central American critical agrarian studies perspective, León-Araya (2020) has posited that the spatial logic of the plantation is expressed through five main characteristics: simplification, homogenisation, disciplining (human and non-human), relocation and profit. Drawing on Mintz (1985), he argues that the socio-spatial dynamics of the plantation expand beyond the plantation, since profit, for instance, depends on the commodities for export reaching the global market. Incorporating a water gaze into the study of plantations further contributes to analysing the spatial dynamics and material flows that are articulated through plantations and extend well beyond their physical location.

Political ecologies of water analyze spatial dimensions through two main concepts: hydrosocial territories and waterscapes. Scholars investigating hydrosocial territories have predominantly directed their attention towards issues of environmental justice and actors' relationships in water conflicts. In contrast, waterscape scholars have examined the long-term production of space and how unevenness is being shaped, particularly focusing on water's materiality (Flaminio, Rouillé-Kielo, and Le Visage 2022). The "waterscape" perspective addresses central concerns in political ecology such as power, control, and agency, by examining how water and society are deeply intertwined (Swyngedouw 1999; Karpouzoglou and Vij 2017). Swyngedouw's (1999:449) pioneering research argued that "the flow of water, in its material, symbolic, political, and discursive constructions, embodies and expresses exactly how the 'production of nature' is both arena for and outcome of the tumultuous reordering of socionature in ever-changing and intricate manners."

The theoretical framework proposed by Swyngedouw (1999) is built on geographical theories on the production of space (Lefebvre 1991), the production of nature (Smith 2008), as well as socio-natural hybridity in science studies (Haraway 1991; Latour 1993). According to Lefebvre, an object can exist in three simultaneous but distinct registers, relating material (1), representational (2), and symbolic practices (3), each one with its own specific characteristics. The lived sphere (1) refers to the physical and pre-rational experience, the conceived sphere (2) to the understanding of space through knowledge and ideology and the perceived sphere (3) to the sensorial experience. As a result, the

[3)] Post-colonial scholars have embraced the concepts of ruins and ruination to elucidate the enduring presence of imperial formations over time and their reappropriation or neglect (Stoler 2013). While acknowledging these discussions, I adopt the concept of legacies to trace the remnants of the plantation, reserving the notions of ruins and ruination specifically for the analysis production of space is the unity of this triad of registers that describes a phenomenon created by different moments and modes (Lefebvre 1991; Pierce and Martin 2015). Neil Smith (2008) elaborates on Lefebvre's production of space, addressing the capital-nature relationship to show how nature is also an ideological concept. He understands the production of nature as the historical and geographical practices that people mobilize to create their environments, a metabolic process through which society and nature co-evolve simultaneously (Loftus 2017). From this vantage point, exploring a waterscape is a continuous approximation to the multiplicity of stories in the production of socio-natural networks (Swyngedouw 1999). Waterscapes trace the dialectical relationship between capital accumulation and the uneven production of socio-natures (Karpouzoglou and Vij 2017), including material, representational and symbolic dimensions (Lefebvre 1991).

Although Swyngedouw incorporated into his framework notions of multiplicity and hybridity to counter the rigidity of Lefebvre's concept of the production of space, it still tends to freeze space in certain ways. In that sense, Doreen Massey's ideas about space, place and relationality contribute to stirring the waters. Massey argues that space is a product of interrelations, a sphere of the multiple in constant construction. The main thrust of her intervention is to shift the concept of "space" from a neutral, static backdrop for the distribution of economic activity to a dynamic set of relations that actively (re)make economic organization and broader social relations. As she argues: "The simultaneity of space is not a surface, a continuous material landscape, but a momentary coexistence of trajectories, a configuration of a multiplicity of histories all in the process of being made" (Massey 2000). Waterscapes, in this vein, articulate dynamic socionatural trajectories, of capital (e.g., through water infrastructure and its disinvestment), contamination (e.g., agrichemical legacies and ongoing effluent flows), and agrarian livelihoods (e.g., in diverse relations to and in turn shaping the waterscape).

Inspired by the above, and taking the invitation of geographer Alejandro Camargo, based on his extensive work in La Mojana delta in Colombia, to see through biophysical phenomena in deltas (Camargo 2021, 2022), I follow three processes: accumulation, waterflows, and socio-ecological interactions and disruptions. In other words: What socioecological and material relations have accumulated through time in the Térrab-Sierpe delta and Palmar Sur? What flows and overflows through the delta? How do these (over)flows continue to shape socio-ecological relationships of fisherfolk and smallholders? In addressing these questions, I put plantation and waterscape studies into dialogue, while incorporating notions of relationality, to re-conceptualize the space/time boundaries of plantations and related processes of subject-formation.

4.3 The Térraba-Sierpe delta: 3.000 years of human occupation

The Térraba river is the backbone of the largest watershed in Costa Rica, with a 160-km course that flows into the Pacific Ocean; it is navigable 22 km upstream from its estuary (Rojas 2011; Montoya et al. 2012). It constitutes the main river of the hydrological system, originating in the middle watershed of the General River and Coto Brus River and covering an area of 5079 km^2. The lower part of the basin merges with the Sierpe River and other sub-watersheds to form the Térraba-Sierpe delta (Acuña-Piedra and Quesada-Román 2017). The deltaic system is characterized by meandering channels and islets defined by mangrove vegetation, created by the sediments of Térraba River and Sierpe River (Acuña and Quesada 2008). The Térraba-Sierpe National Wetland, a protected area managed by the System of Conservation Areas (SINAC) from the Ministry of Environment in Costa Rica, is the largest wetland in the country, with an area of approximately 33,031 hectares. It was listed as a Wetland of International Importance under the Ramsar Convention in 1995 (Picado 2015). From an ecosystem perspective, the Térraba-Sierpe Wetland has two different water systems. One is influenced by the Térraba river watershed towards the north, established as an inter-tidal estuarine wetland with a landscape categorised as a forest flooded by tidal influence. The other is related to the Sierpe river watershed, which constitutes a permanent and extended marsh area (Mora 2013). Both rivers outflow into the ocean through seven estuaries or 'river mouths' (see Fig. 1).

Human occupation of the Térraba-Sierpe delta has a rich history that spans more than three millennia (Quintanilla 2007; Corrales and Badilla 2012). The pre-Columbian period, lasting from 1500 BC to 1550 AD, saw the establishment of Indigenous populations who engaged in small-scale agriculture in dispersed villages. Over time, the number, size, and complexity of these settlements grew significantly, particularly during the period from 800 AD to 1500 AD. These communities, known as 'chiefdom societies' in the Costa Rican anthropological literature due to their hierarchical organization, had sophisticated knowledge in diverse fields, such as cartography, navigation, agriculture, metallurgy, and sculpture (Quintanilla 2007; Corrales 2018). The construction of over three hundred stone spheres are particularly notable, one hundred of which have been identified in the delta. The creation of these spheres was a highly specialized and labour-intensive process, requiring specific expertise in stone fracture patterns, grinding, and polishing. The presence of these stone spheres bears witness to the high degree of complexity and technological knowledge of these chiefdom societies. In recognition of the cultural and historical significance of both, UNESCO declared the area a World Heritage Site in 2014 (Corrales and Badilla 2012).

In the colonial period, the Spanish tried to rule Indigenous people and establish settlements in the delta. The first expeditions arrived from Panama in 1519 and 1522. Although Indigenous populations resisted the creation of settlements, they were dominated, reduced and displaced to the upstream villages of Boruca and Térraba (Albertazzi 1993). Over the course of the next four centuries, the region was largely depopulated, with some waves of migration from Panama, which led to the Costa Rican government's promotion of national migration as a counterbalance to immigration by the end of the 19th century.

At the turn of the 20th century, significant changes would transform the southern Pacific region. In 1914, the Costa Rican government founded the canton of Osa, an administrative division that marked the onset of the state’s presence in the area. This period, referred to as the formative years of the region by Arias (2007), saw the migration of two main population groups to the area: Costa Ricans from the Central Valley and Ngäbe Indigenous People from Panama, who were displaced by the construction of the Panama Canal. These populations engaged in small-scale agricultural activities such as rice, banana, and basic grain cultivation (Royo 2004). Meanwhile, a process of land grabbing began to be orchestrated by UFCo, which progressively started acquiring land in the South Pacific through third-party entities, such as the Golfo Dulce Land Company (Royo 2004).

UFCo had been founded in Costa Rica's Caribbean basin in 1899 by the U.S. entrepreneur Minor Keith, and developed an extensive and intensive system of banana production there. However, this system was based on a single cultivar, Gros Michel, that,combined with vegetative reproduction, resulted in high genetic uniformity and in turn a high susceptibility to diseases. Beginning in the early 1900s, *Fusarium oxysporum* f. sp. *cubense*, a tropical soil-borne fungus which causes Fusarium wilt disease, also known as Panama disease, proliferated in UFCo’s plantations in the Caribbean basin (Ploetz and Evans 2015; Marquardt 2001a). Owing to its destructive capacity and the lack of mechanisms to address it, the soil pathogen accelerated UFCo's practice of acquiring large tracts of land but selectively cultivating just a part of them, in order to constantly open up farming areas without debilitating levels of the soil-borne fungus (Soluri 2021).

To escape fungus-riddled soils, UFCo eventually made a strategic shift in its production from the Caribbean to the Pacific basin, through its domestic subsidiary Compañía Bananera Nacional. Once settled, it inaugurated the Golfito division, divided into districts-farms and plots, where it continuously exchanged operating farms throughout the region.[4] The Palmar District, located in the Térraba-Sierpe delta, consisted of 18 numbered farms ranging between 333-500 hectares each, while UFCo also maintained contracts with independent farmers in Sierpe (Royo 2004). The Palmar District remained a centre of banana production from 1938 to 1985, with a brief interruption between 1955 and 1960 due to a major flood event that will be discussed further below (Royo 2004; Villalobos 2006; Cano Sanchiz 2017).

[4] UFCo directly or through its affiliates signed numerous contracts with the Costa Rican state, committing in 1934 to cultivate 3,000 ha of banana plantations in the Caribbean region and 7,000 ha in the Pacific, adding in 1938 4,000 ha in the Pacific, and in 1939 a minimum additional extension of 2,500 ha in any region, in exchange of a series of benefits such as land access and tax exception or reduction (Procuraduría General de la República 1987).

Figure 2 The removal of the stone spheres from their original site made by UFCo. The picture was included in the first scientific article about the stone spheres published by Doris Stone, an archaeologist who directed the National Museum of Costa Rica and whose father, Samuel Zemurray, was the president of UFCo. Source: Stone 1943.

Throughout this period, UFCo progressively increased the use of pesticides. Initially, copper sulphate was applied over two decades to counteract the development of Yellow Sigatoka disease, caused by the fungal pathogen *Mycosphaerella musicola* (Marquardt 2001b). These applications were later replaced with other fungicides sprayed aerially (Thrupp 1988). The company also conducted intensive applications of insecticides and nematicides, notably utilizing DBCP, which had severe health consequences for workers and inhabitants all around the Golfito division (Thrupp 1991; Mora Solano 2014). In the final decade of the banana enclave, Black Sigatoka disease, caused by the pathogen *Mycosphaerella fijensis*, prevailed in areas previously inhabited by *Mycosphaerella musicola*, which required significant investment in chemical control (Thrupp 1988; Marquardt 2001b).

In the 1980s, Costa Rica confronted a debt crisis which had a significant impact on the country's agricultural sector. The growth of the state during the previous decades had relied upon low-interest, dollar denominated loans that became unserviceable when US monetary policy sparked skyrocketing interest rates. The measures requested by the International Monetary Fund (IMF) as a condition to restructure the loans had an early and strong conditioning effect on the country's economic policies (Edelman 2019). As a result, the State implemented two rounds of structural adjustment (1985-1988), which prioritized agriculture for the export of the so-called non-traditional, or ‘neoliberal’export crops (Vargas Solis 2015; Castro-Vargas and Werner 2023). Subsidies and market facilitation programs promoted new crops deemed to earn more foreign exchange than untransformed or commodity crops (glossed as traditional exports) due to their niche, “high value” attributes.

In this context, two significant events re-configured the plantation economy in the Térraba-Sierpe delta: the emergence of a plantation within the plantation, shifting from banana cultivation to oil palm; and the development of the pineapple agroindustry in the middle basin of the Térraba river, created by the transfer of knowledge, inputs and varieties from Hawaii to Costa Rica (León-Araya 2020; Clare Rhoades 2008). Although UFCo closed its banana plantation in 1984, making an apparent departure from the region, its institutional and ecological presence would continue (Royo 2004; Cano 2017). Even hough UFCo had experimented with oil palm on its banana plantations since the 1930s, the company only initiated larger scale cultivation from the 1970s onwards under the management of its partial subsidiary, Palma Tica (Clare Rhoades 2011; Abarca 2016). As stated by UFCo in 1987, banana production had become an "unproductive activity," due to both agronomic (i.e. plant pathogens and pests) and economic reasons (e.g., increasing pesticide management and labour costs and unrest, including a three-month strike in 1984) (Compañía Bananera de Costa Rica 1987). Through oil palm production, the company found the means to continue extracting value from land and nature, while reducing the total number of workers needed, and largely eliminating permanent contracts.[5] In addition to oil palm take-off, the development of the pineapple agroindustry in the southern Pacific region of Costa Rica was supported by the granting of State subsidies, namely Tax Credit Certificates (CATs in Spanish) to companies such as Del Monte, through its subsidiary Pindeco. The installation of Del Monte inaugurated a large-scale pineapple production system, that would, later on, expand to the Caribbean and the Northern region of the country.

The emergence of these neoliberal crops in the Southern Pacific occurred during the decline of the banana enclave. Oil palm and pineapple monocrops germinated in the biotech-chemical-patchwork crafted by UFCo, a set of conditions developed through a historical and global process, which involved biotechnology experimentation to create new varieties (e.g. pineapple MD2 and compact oil palm), and the setup and calibration of tropical technological packages (Clare Rhoades 2011; León-Araya 2020; Castro-Vargas and Werner 2023). Therefore, one can argue that oil palm plantations were built upon the remnants of the banana occupation, as material and symbolic legacies of that industry. The degraded and contaminated soils were repurposed to support oil palm growth, through the

[5] In the Caribbean basin, Standard Fruit Company resumed banana production under a different structure, by withdrawing from direct production and implementing a process of contract farming (Montero Mora and Viales Hurtado 2014). The company introduced the Cavendish cultivar in the 1950s, which exhibited resistance to Fusarium oxysporum, and employed box packaging to avoid fruit bruising, as the fruit was more fragile (Ellis 1983; Marquardt 2001a). Although contract farming had been present in the global banana industry since its emergence, it became dominant in the 1960s, shaped by the close ties between large domestic capitals and multinational agro-exporters (Striffler 2001).

use of agricultural machinery to remove the accumulated synthetic twine from the soil and the use of fertilisers to counteract soil degradation. Additionally, the agricultural know-how and experience gained from the banana industry were leveraged to optimize plantation management and achieve high productivity.

Neoliberal crops reshaped spatial, labour and socio-environmental relationships.[6] Both oil palm and pineapple monocrops manifest different political economic relations as flexible production networks that mix variegated schemes of land ownership, contract farming and labour requirements. Although it is beyond the scope of this article to analyse tenure relations associated with both crops, it is important to emphasise that their expansion created greater complexity in agrarian dynamics. For instance, the pineapple industry in Costa Rica exhibits stark regional differences in terms of production and land tenure. In the Southern Pacific region, Del Monte dominates as the main pineapple producer and controls large tracts of land, both through direct employment and outsourced contract workers. In the Caribbean and Northern region, there is a wider diversity of companies producing pineapple on small to medium-scale farms that sell to large companies, which control the marketing of the product (Carazo and Aravena 2016; Obando Campos 2020). Moreover, in the Northern part of the country, proximity to the Nicaraguan border plays a significant role, as contractors and migrant labour are central to regional production dynamics (León-Araya and Montoya Tabash 2021). In sum, neoliberal crops have rearticulated inherited regional dynamics related to class, gender, race, ecologies and labour, including specific labour risks and barriers to union organization.

Whilst these monocrops emerged, the closure of UFCo's banana plantation was catalogued as an emergency in the Southern region (Arias Mora 2007). To address the potentially acute regional economic crisis, the state promoted agricultural cooperatives of small producers, which failed to achieve financial sustainability over the course of several productive projects (Guillén Araya 2020). In 2001 and 2014, two land occupation processes were carried out by former banana workers, peasants, and people from other rural areas of the country on former UFCo lands in Palmar Sur (Hernández González 2018; Mora Calderón 2022). Former banana farms, Finca Térraba and Finca Chánguena, turned into land occupations by *parceleros/as*.[7] Since the 2000s, the Térraba-Sierpe delta has become a fragmented and constantly changing waterscape where oil palm, banana and rice plantations coexist with occupied *parcelas* and the wetland's conservation area.

[6] The legacies and possible futures of the plantations have been referred to as plantation afterlives, building on Saidiya Hartman and post-slavery black geographies (Hartman 2008; Bruno 2022). Plantation afterlives explores the potential outcomes of the plantation system following the dismantling or modification of its production methods, which have often resulted in economic and environmental devastation (Peano, Macedo, and Le Petitcorps 2023).

[7] Inhabitants of the former banana plots (referred to as parceleros/as in Spanish). They originally were agricultural workers or peasants who migrated from other regions of the country to work in the banana enclave. After several processes of proletarianization and peasantization, the separation was blurred. Striffler used the term peasant-workers based on a similar context in Ecuador (Striffler 2001)

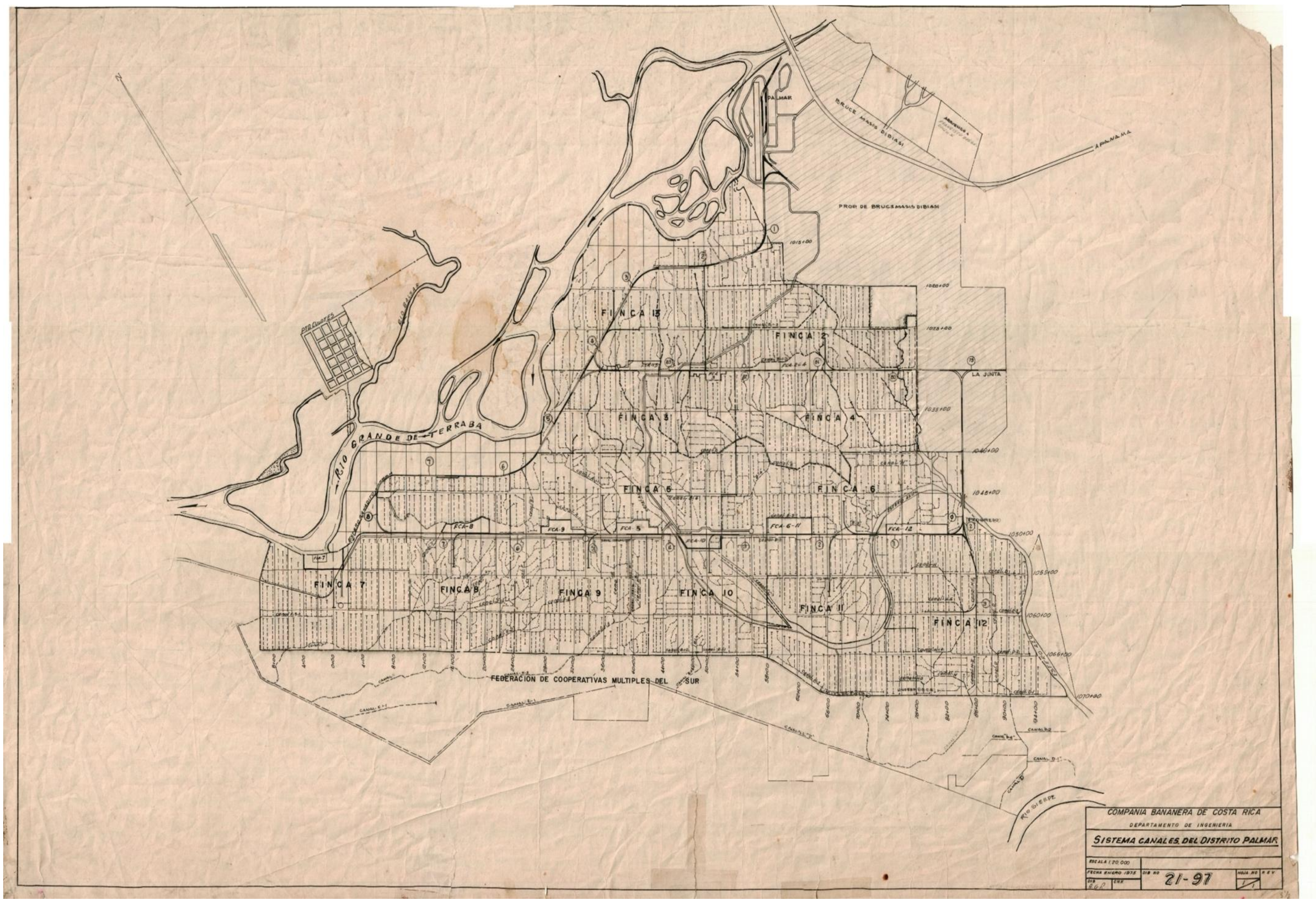

Figure 3. Irrigation canals system in Palmar Sur. Source: Compañía Bananera de Costa Rica (1975).

4.4 Shaping the Delta: Reconfigurations of the plantation amidst the legacies of the banana enclave

The floods in a plantation-made waterscape

> Don Beto Muñoz, the former head of UFCo's mechanical workshop and later president of Palmar Sur's community aqueduct, shows me the floodgates - a rehabilitated structure of the water system installed during the banana plantation's operation. He explains that their malfunctioning has increased flood risks, since state institutions have not been able to properly maintain the system. Don Beto, born in 1938, recalls that a significant flood in 1955 led UFCo to build a dike on the Térraba river: "In all that section, on the bank on this side of the river, they built a dike and the water never entered until the company abandoned it or destroyed it themselves. The floodgates and other infrastructure were removed by the company when they left, causing chaos whenever the river rises. I don't know if they did this out of malice or what." Over the past two days, we have been examining maps and reviewing the water infrastructure built in the 1950s by UFCo, including the deviation of the Térraba river, the system of canals through the farms, and the estuaries mechanized by the company, such as the Blue Estuary (*Estero Azul* in Spanish). In spite of the far-reaching significance of the UFCo's hydrological modification of the delta, little information is available, making it difficult to reconstruct their interventions.

Since pre-Columbian times, the delta's strategic position between the coastal and inland areas and the richness of its alluvial soils has made it a crucial area for territorial control. The Térraba river was the main communication route for Indigenous populations until the 1950s, when a road was opened that eventually became the Inter-American Highway in 1976 (Albertazzi 1993). The delta has always been affected by periodic floods, which have shaped its sedimentation patterns. These floods led to the development of collective water planning mechanisms, such as drains or dikes, that allowed elites of chiefdom societies to exercise centralized control over agricultural production (Corrales 2018). Soil fertility was a key factor for agricultural production, and maritime access allowed the transport of commodities. These two factors made the area particularly attractive to UFCo, in addition to the inexistence of *Fusarium oxysporum*. However, the biophysical characteristics of the terrain required the development of an irrigation and drainage system (Albertazzi 1993; Cano Sanchiz 2017).

Settling the banana plantation demanded massive investments in land preparation to produce a high-yield landscape as determined by agronomic sciences (Ellis 1983; Soluri 2021). In the early 20th century, scientific literature recommended the construction of more advanced drainage, trenching, and irrigation systems to maintain optimal soil humidity levels, particularly in regions with extended dry seasons. Drainage was seen as an essential practice, despite the substantial capital investment it required, to prevent the development of Fusarium Wilt disease (Viales-Hurtado and Montero-Mora 2010). As Ellis (1983) described, the cultivation area of banana plantations in Central America was "covered with a network of primary and secondary drainage canals that drain water into a main channel that flows into a nearby river (...) the entire system is a formidable display of hydraulic engineering, a capital cost which is only justified by the fact that, in the long run, it makes an enormous contribution to maintaining high levels of production" (p. 85).

Between 1938 and 1955, UFCo abruptly transformed the waterscape by deforesting extensive areas of the tropical jungle. During this process, workers uncovered stone spheres previously hidden by sediment and vegetation in the delta and removed them from the area, symbolising UFCo’s dominance over the accumulated layers of the delta's history (see Fig. 2). A team of engineers and scientists then developed a water system comprising square trenches to drain the wetland. In 1955, the Térraba river overflowed, owing to the surge of hurricane Katie in the Caribbean sea, causing what locals refer to as "*la llena*" - a dramatic river rise that floods absolutely everything in its path (Meza 2021). The tragedy of the 1955 floods remains etched in the collective memory in the waterscape (Villalobos 2006; Ortiz and Léiva Léiva 2018). As Don Beto Muñoz recalled: “*La llena* swept away what was there, imagine that in Cortés the buildings had two floors, so people [i.e., UFCo’s middle- to high-ranking officials] could live upstairs, but the water rose so high, too high, that it took them out of there.” Following the devastating effects of *la llena*, compounded by the challenges of crop diseases, UFCo temporarily halted operations in Palmar Sur (Royo 2004).

UFCo resumed banana production in the region in the 1960s, after undertaking a significant transformation of the waterscape. This transformation involved the design of a complex management system for the Térraba river, which included the construction of a dike and floodgates. According to Don Beto: “They came here and started to build a dike splitting the mountain, because at that time there was no road [Interamerican highway], and they extended the dike as far as *Estero Rompido*.” The newly implemented system partially diverted the upstream waterway through a network of canals and artificial estuaries, which eventually discharged into the Sierpe river. This infrastructure served a dual purpose, acting as a drainage channel during the rainy season and an irrigation connection during the dry season, which was controlled by the floodgate system (see Fig. 1). As Don Beto explained: “I had to rebuild those floodgates twice, they were four metres high, and when the tide emptied all the water that was swamped here on land, the floodgate would open using its own pressure and the water went into the river, and when the river came up, the same water closed it, so the river water could not enter, those floodgates were automatic closing gates, the water itself managed them.”

The waterscape was then transformed into a hybrid of the plantation's hydric system and its network of canals and the delta's geomorphology of estuaries and mangroves. Don Joaquín, a former UFCo worker who lives in Sierpe, explained that "[t]he company could not use the water of Sierpe River because this water is salt water, so they created a canal from the Térraba river and passed that canal to this side, and that canal came directly to reach the Azul Estuary here. But they also made some canals that went through the farms to take the water to where the irrigation pumps were, continuing on to the branches to take the water from the banana plantations, to drain the water, which they used to irrigate the towers and when it rained a lot, it came out through there." The water infrastructure also required careful management, with dedicated workers, as Don Félix recounted: "The banana company use to dredge from the Culebra River to where the bridge is now, going through all the banana farms, to where Azul Estuary began, they dredged all that so it wouldn't get saturated with sediment, because there was a lot of sediment coming down, a lot of ballast, so if that got aterrado [filled with silt], the water would rise and get into the banana plantations, so the company personnel dredged it to keep it deep, they used dredges that had very long arms with cables." Moreover, the deviation of the river connected the two main watersheds of the Térraba and Sierpe rivers, creating a new geographical configuration for the discharge of effluents through the set of canals and estuaries. This led to a change in the flooding pattern and the discharge of sediment and contaminants, from the Térraba river through the farms in Palmar Sur, and eventually to its waterways and estuaries that flow into the Pacific Ocean.

In 1984, when the UFCo aimed to cancel its contracts with the state[8)], a negotiation process took place between the two parties, resulting in two agreements and a settlement for the closure of the activity (Expediente Nº 10472 1990). In this negotiation, UFCo managed to sell the lands, the "improvements" on them, and the infrastructure to the government, plus compensation for dismantling the infrastructure. In short, UFCo "took advantage of its own breach" of the production contracts, as the Attorney General's Office statedby then (1985:6). Subsequently, UFCo dismantled part of the water infrastructure, including the famous floodgates, leaving the system incomplete for its proper functioning. As Guillén (2023) pointed out, the same workers who once sustained the plantation carried out the process of deliberate ruination, erasing the infrastructure such as the train, from the landscape. However, they did not restore the waterscape to its previous form in Palmar Sur. The diversion of the river and the irrigation canal, and its intricate network of waterways and estuaries remained.

Upon acquisition of the UFCo lands, the state took over the ruined irrigation system. Despite its non-operational condition, the system still required costly and careful

[8)]Around twenty-one contracts were signed between the Government of Costa Rica and the Chiriquí Land Company, UFCo and the Compañía Bananera de Costa Rica, known as law contracts, a confusing category that generated internal debates within the State (Procuraduría General de la República 1987). The following contracts are the most commonly referenced: Nº3 of 1930, Nº30 of 1934, Nº133 of 1938, Nº1126 of 1949 and Nº1842 of 1954 (Procuraduría General de la República 1984).

maintenance, such as drainage of the canals and dredging of the estuaries. Although the state was now to manage the system, it did not benefit from any technical documents or background information. For whatever reason, no transfer of this material, including hydrogeological studies and blueprints upon which the irrigation system was developed, occurred upon the company's departure (Ministerio de la Presidencia 1985). When I consulted state institutions about these studies, officials and technical staff had no knowledge of them, even in inter-institutional spaces for climate disaster management. As an officer from the Institute of Rural Development (INDER in Spanish) expressed, "These eyes will probably never see those studies" (INDER, interview, 2020). In addition to managing disasters "blindly," the responsibility for the system has been shifting from one government institution to another ever since, generating confusion regarding institutional competencies (SENARA, interview, June 2020; Mayor of Osa, interview, June 2020). By 2022, in the former banana district of Palmar Sur, about 20% of the land was occupied by Palma Tica and the rest was fragmented between cooperatives and *parcelas*, while great uncertainty about land ownership prevailed (Mora 2022). For instance, an internal process was initiated within the government to analyze the ownership of some of the former UFCo buildings, and whether they belonged to Palma Tica as an inheritor of the company or to the state. Questions of ownership have concrete implications, given the diffuse and ambiguous responsibility for the maintenance of the irrigation system, which crosses through these disputed land holdings.

During the land occupation process, *parceleros/as* used the ditches of the former plantation to demarcate land among themselves. These waterways not only divided the land into individual plots, but also connected them to one another through the seasonal flowing waters of the Térraba river. As Anahí, a leader from *Chánguena por Siempre*, described: "This is all connected, because these waterways, all these are ditches and everything is like that, all the *parcelas*, all the farms are the same, then all those waters where they go is to the Sierpe river, and everything that you put here on the land is going to be washed [run-off] and will flow there."

In October 2017, tropical storm Nate (later Hurricane Nate) provoked a massive *llena* in the delta, comparable to the one in 1955. Although the *llena* was triggered by a climatic event, it should be understood as a socio-natural disaster, where its causes and consequences were closely interconnected and shaped by histories of colonialism and capitalism (Meza 2021). The flooding in Palmar Sur resulted in a catastrophic situation that required rescue operations using boats from Sierpe. Many people were forced to flee their homes and seek refuge in shelters, while crops were destroyed and the majority of farm animals perished, leaving behind a devastating aftermath. Julián, who joined a rescue team to help those affected, explained: "It was striking to see this, it was like a sea. Everything was flooded in Finca Chánguena and Finca Térraba. Here the water reached about one or one and a half meters high, but it had a lot of current, so it was difficult and dangerous to move around."

The *llena* put in sharp relief how the deteriorated water infrastructure inherited from the banana plantation endured in the socio-spatial configuration of the delta. Uncertainty and confusion swamped the plots as the flood waters receded. No clarity existed over which institutions were responsible for the irrigation and drainage system, how the system was to be managed, who could benefit from it, and what residents could expect. The floods also revealed the outsized role of the oil palm plantation, despite its relatively small territorial extent. The spatial corporate occupation of the oil palm plantation, following the vertically integrated banana plantation, was drastically different as it brought in occasional contract work, a reduced labour force[9)] and processing that did not involve packaging[10)]. This had allowed Palma Tica to operate below the radar, but the floods stirred up the socio-ecological impact of this discrete spatial occupation. Ultimately, the *llena* exposed how historical land seizure and land use dynamics along the basin accumulated over time. These dynamics not only materialized in episodic socio-natural disasters but they also encumbered any sort of recovery, which will be discussed in the following sections.

Plantations remade: New processes of sediment accumulation

> We walk along the outskirts of Del Monte's pineapple plantation in Buenos Aires de Puntarenas. The soil is clayey and has a fiery reddish colour. Jairo, a former pineapple worker, describes the legal complaints they made in the early 2000s, in response to the environmental degradation caused by pineapple production. "You know, by then [2001] we exposed that each hectare of cultivated pineapple represented two tons of sediment loss per year through run-off, and that has continued without control, and if you multiply it by the number of years that the company has been here, it is already too much sediment, and in big storms like the last one that happened during those hurricanes [Tropical Storm Nate], everything goes there, because not only does it pull up what the river has carried, but it also drags more, right." Our attention moves to the horizon of the plantation, where we see nothing but short-pointed pineapple plants in bare soil, offering no respite from the burning sun.

Buenos Aires in Puntarenas is located upstream of the delta. While the southern-south region of the area had maritime access in the context of the banana enclave, this area,

9)Estimations indicate that in banana monocrop the ratio was one worker per hectare, compared to one worker per ten hectares in oil palm plantations (Clare-Rhoades 2011, Picado 2016).

10)The enclave maintained large workforces in packing, mainly women, so both men and women had jobs. The gendered division of labour in the oil palm plantation operates differently, where women's share consists of occasional work collecting palm fruits from the soil (coyolear in Spanish) (for an analysis about gendered working in oil palm plantations see Ojeda 2021).

situated approximately 70 km from Palmar Sur, remained relatively isolated until the development of terrestrial infrastructure. The construction of the Inter-American Highway in 1963 paved the way for the entry of the import-substitution industrialization policies in the Southern region, a major state effort towards agricultural diversification, promoted through different mechanisms such as agricultural credit schemes (Rovira 2000; Vargas Solis 2003). This strategy incorporated technological interventions without transforming the pre-existent dynamics of agrarian capital accumulation and land grabbing (León-Araya 2008). In the Southern region, the main shift consisted of the broadening of pesticide use beyond UFCo's banana plantation. As César, from Boruca Indigenous Territory, strongly affirmed: “With the highway the agrichemicals entered”. Pablo, from the council of elders from the Indigenous Territory Térraba similarly portrayed this: “I witnessed the entry of agrichemicals in the region, I remember how [State] institutions started to distribute packs of agrichemicals”. As a result, regional forms of agricultural production were gradually eroded or modified (Granados and Matarrita 1981; Muñoz Calvo 2018).

While the oil palm plantation was built in the interstices of the decadent banana enclave, over its degraded soils and ruined infrastructure, the pineapple plantation took over areas that had been previously used for other agricultural activities such as rice cultivation and livestock, as well as some forested areas (Muñoz 2020). To prepare the land, Palma Tica contracted machinery and operators to remove synthetic twine and applied a combination of biotechnology and chemical inputs, including herbicides and fertilizers, which enabled the company to maintain continuous production without rotation or fallow. However, the intensive use of fertilizers and subsequently elevated concentration of nitrates in the wetland resulted in eutrophication, particularly in the lagoon located upstream of the Sierpe river (Hernández et al 2022). Seemingly, the large-scale pineapple production system developed by Del Monte to pursue high yields, was extremely dependent on chemical inputs, particularly herbicides[11]. Indeed, the herbicides bromacil, diuron and ametrine, have been detected downstream in the Wetland Térraba-Sierpe, some 80 km from the middle basin, and despite the abundant flow of the Térraba river (Picado Blanco 2014). In the case of bromacil, our study detected it in Térraba river and Wetland Térraba-Sierpe even after its banning in 2017 (Chapter 5, included in Appendices).

Throughout the Térraba basin and the delta, informants repeatedly raised concerns about the sedimentation of the river, particularly since the 1980s. In the middle basin, in Volcán de Buenos Aires, interviewees associated the arrival of Del Monte with the beginning of soil degradation. For Don Esteban, who was born in 1930, when the pineapple plantation arrived in the 1980s, people worried about the consequences that soil erosion could have

[11] Pineapple plantations employ a technology package highly intensive in pesticide use related to certain specificities of the monocrop including year-round production, land use practices (e.g. cultivation based in total vegetation removal) and plant characteristics (i.e. bromeliads are less dependent of soil characteristics and more dependent on external inputs).

downstream: "We started to get concerned about it when we saw the magnitude of sedimentation, we thought by then 'all that water that goes over there, what might be happening over there?' I imagine that probably when the river reaches the floodplains it is swallowed up by the ground [is buried by the huge amount of sediment]."

Downstream, in the mouths of the delta, as commercialisation of *piangua* was just beginning in the 1980s, red sediment appeared in the mangrove. Carlos, President of the *piangüeros/as* association APREMA, explained: "In the 80s, capitalism entered, *piangua* began to be bought, *piangua* began to have a value, before that, *piangua* wasn't worth anything, people just didn't buy it". However, the take-off of *piangua* sales coincided with the upstream surge of pineapple cultivation, which manifested in the mangrove as the sudden presence of red sediment, according to *piangüeros/as* from the three main associations present in the area (APREMA, interview, January 2020; ASOPEPIPESACBT, interview, January 2020; Asociación de Piangüeros Ecoturísticos Agropecuarios, interview, June 2020). As Jacinto, a *pianguero* from Boca Zacate, made clear: "Well, the problem is Del Monte because the red soil that it throws falls into the mangrove and just with that the *piangua* no longer survives".

The past consequences of the banana enclave on the mangrove were visibly evident in the high rates of mangrove deforestation, but river sedimentation from pineapple plantations, in contrast, had a more attenuated impact, gradually leading to the disappearance of *piangua* in the mangrove areas influenced by the Térraba river (e.g. Boca Nueva). As Alejandro Camargo (2023) has argued, sediment in deltas has a two-fold character, while being essential for the reproduction of human and non-human life, an excess can result in numerous socio-ecological disruptions. Physical sciences studies found that the transformations in upstream land use dynamics and sediment fluxes had an effect on the mangrove geomorphology of Wetland Térraba-Sierpe (Krishnaswamy, Halpin, and Richter 2001; Acuña-Piedra and Quesada-Román 2021). The high loads of sediment carried by the Térraba river, combined with the effects of currents, tides, and waves, have been crucial factors in the modification of the coastline, including mangrove die-off in some of the Delta's mouths (e.g. Zacate mouth) (Silva Benavides et al. 2015).

Sediments and flows reverberate in the flooding episodes discussed above, intertwining risks and concerns. Informants were keenly aware of the loss of river depth due to excess sedimentation, and the clogging of canals, constantly mentioning these changes. In the areas surrounding the wetland, for instance, in the town of Sierpe, people from the tourism sector pointed out how the excess sedimentation had obstructed navigation in certain areas of the wetland and had affected biodiversity. The flooding inundated accumulated deposits of sediment and pesticides from old and recent plantations, and the breakdown of water infrastructure, together comprising material legacies of historic state and corporate neglect. As Julián explained: "And with the issue of the pineapple plantation, we have felt that it is affecting us a lot, with the sedimentation of the river, which is getting shallower every day, and with nothing we suffer the floods due to the overflowing of the river, the Palma Tica company also, the way they work in the oil palm, how they arrange the leaves, they don't maintain the canals nor do they keep them clean, all that has affected us with the floods, these companies, well, they have really harmed us."

This latent threat is exacerbated by the renewal practices of the palm plantation, when producers desiccate palms after 25 years by applying herbicides (e.g. glyphosate), in order to start the production cycle again. As Melissa, a *parcelera* who lives close to the oil palm plantation, explained: "Last year [August 2020] the dead palms were there, and to make things worse, it was also the time of the rain [rainy season], if the river had gone out, imagine that… they have already been rotting, because they were not removed, Palma Tica just left them there and little by little, with the rains and everything, they have been rotting under the sun." The management system of production cycles might aggravate the consequences in case of flooding, since these giant dead palms can be swept away by the current, raising the vulnerability and anxiety of *parceleros/as* in relation to the llenas.

Meshed riverine lives

> From the Boruca Indigenous Territory to the Sierpe River, the winding path of the watershed was drawn by the run of a snake, according to local oral tradition. This serpent was the offspring of a Boruca indigenous woman who had fallen in love with a snake. When the serpent was threatened, it fled to the Delta, while its sister remained concealed underground in Boruca. Whenever it thunders, the two serpents are communicating along the river.

The Térraba river is known as DíCrí in the Borucan language, meaning abundant water. For Indigenous people[12)], the river has represented sustenance, livelihood, and a primary means of transportation, through which they travelled to the delta to exchange foods and bring supplies. Don Mauricio, a long-time river navigator from the council of elders of the Curré Indigenous Territory, explained: "We are aware of how much we depend on the river, in the past, the river used to be the main way to walk, and then, came the road [Interamerican Highway]. Our elders taught us how to navigate the river, such as going around a particular whirlpool three times to get to Palmar." César, shared a similar perspective: "Transport here used to be by river to the sea, they used to take food for a month, to exchange and then they brought things from the mangrove, from the river, salt. But now the flow has decreased so drastically that sometimes it is possible to cross it walking, the spirit of the water is going to manifest itself in a way that will make people care, so that they can see that it is still alive".

[12)]Brörans inhabit the Térraba Indigenous Territory and Borucas the Rey Curré and Boruca Indigenous Territories.

Once teeming with shrimp and fish, including *mojarra*, the Térraba river has transformed from a river of green waters to a brown-coloured one where people avoid bathing due to fear of contamination. Bröran Indigenous people consider the Térraba river a living being protected by their grandmother Tjer that has fallen ill, which led them to file a court action to declare the river a subject of rights (Bröran leader, interview, March 2019). Although the court rejected it, this was one action of a wider process defending the river, including the decades-long struggles against a large-scale hydroelectric project (i.e. PH Diquís) and the land recuperations of disposseessed Indigenous Territory. One of these recuperations is the 450-hectare San Andrés farm, as Mario, from the council of elders from the Térraba Indigenous Territory explained: "The most fertile part of the territory is the river's lowlands, but we were displaced from there, the river bank is a living wellness and if the indigenous people are there, it will come back to life." The river reflects a devotion to life, but rather than a cheerful one, it reflects a challenging and disputed life, as Mario continued: "Our childhood was a battered childhood, a very hard one, the river is life, but a battered life, we have to respect the river, but we shall not trust in it." The struggle for life embodies the complexity of life itself, and how interdependence might also represent a union of sorrow and belonging.

In Volcán de Buenos Aires, a community neighbouring the pineapple plantation, inhabitants described the drastic change following the settlement of Del Monte. The company obtained water concessions for irrigation of River Volcán, a micro-basin of the Térraba river basin, which allowed the company to dredge the river and construct retaining walls. The community that 'once had revolved around the river' lost its social cohesion (Don Esteban, interview, March 2019). As Miguel, a local member of the Southern region organization Ríos Vivos, explained: "When I was a child, there were many lagoons there, it was a place for migratory birds, there were turtles, deer, those were places where fish were born, but they drained everything to plant pineapples." By 2019, the organization Ríos Vivos estimated that Del Monte utilized 98% of the river's flow, which in turn illustrates how land grabbing can facilitate water grabbing (Ríos Vivos, interview, March 2019).

The sense of loss of Volcán river, combined with other factors such as the increase of illicit drug trafficking in the Southern Region, has led to an upsurge of violence in Volcán, according to Violeta, also from Ríos Vivos. For her, the deterioration of local rural livelihoods in Volcán has pushed young people into drug-related activities, which she synthesized as "dry rivers, full prisons". Criminalization was also perceived as an instrument to silence complaints about environmental degradation and water contamination. The fear of reprisals for carrying out acts of denunciation was repeated all along the basin, manifested in different ways according to each particular setting. In the Térraba Sierpe Wetland, which constitutes an important entry point for illicit drug trafficking and storage (Wrathall et al. 2020; Devine et al. 2021), social tension pervades the still waters of the wetland. Exercising any kind of mention or observation, in a waterscape where conservation policies, unfortunately, create favourable conditions for the circulation of illicit drugs, poses a considerable threat. Indigenous Territorieswere not exempt from the threat of possible repercussions. As Pablo explained: "You begin to see how something that used to feed you, starts to disappear and then, for defending the river they put a price on our heads, whenever you raise your voice, they take you to jail". These examples illustrate how a similar pattern of alarm, distress and frustration is expressed in multiple ways.

The deterioration of the delta, and thus of the mangrove, has had repercussions for *piangüeros/as* who rely on *piangua* extraction as their main source of livelihood. In Zacate Island, they carefully traced recent transformations in the mangrove and how it has affected the health and abundance of *piangua* and other wetland organisms. Erika, a *piangüera* from a family living for many generations in Boca Zacate, complained: "When the rainy season comes, and the chemicals that the companies throw into the rivers start to wash away [run-off], you see that the fish die because it kills the fish too, and then you cannot take out enough fish or *pianguas*, so you have to look elsewhere, let's say, far away from there, to avoid the damage from the pineapples". She and her family recounted how the piangua disappeared in specific areas of the mangrove, where they used to extract it. In Boca Nueva and Boca Brava, for example, and particularly after the flooding caused by Hurricane Otto in 2016, the *piangua* "comes out dead", or "only the shell comes out". The combined results from climate events, sedimentation and pesticide exposure were clearly assessed by them, as Erika's mother, Gaby, reflected: "as [the river] runs off from the top to the bottom, then all the chemicals come down as the floods come down, that's how the chemicals come down, and then everything gets complicated. So it comes from something, everything comes from there."

In Palmar Sur, *parceleros/as* have been dealing with the overlapping and synergistic consequences of the different monocrops located both proximately and distantly, combined with the diverse legacies from the banana enclave. Four decades following the banana enclave's closure, the soil remains burdened with layers of copper sulphate and synthetic twine, posing significant challenges for agricultural cultivation. Moreover, disputes and doubts have arisen among *parceleros/as* regarding the application of pesticides. The awareness of the interconnectedness through their waterways turns an apparently individual decision into a collective matter, as Alejo, a *parcelero* trying to start up his plot after a lifetime of labouring in the fields, outlined: "It is complicated because if I throw something in my ditch, then I might contaminate other plots." These dilemmas have generated heated debates and conflicting positions, and the question of how to deal with plantation legacies. In this regard, Anahí, who held a coordination role within several organisational spaces in *parcelas*, stated her position:

> Well, when they planted bananas here, they [*parceleros*-men] were seeing how they were growing bananas, right, with all the agrochemicals of bananas. There is even a banana plantation here now. So, they kept that habit, the company left them a pesticide 'chip' [programmed mindset], as my partner says. And I understand, it is easier to take a herbicide and spray it all around than to manually cut down the weeds, right? That is harder, even more with the sun that we have here. But for the sake of what? If we don't change that mentality, we will continue destroying the little bit that this land can offer us (...) So we want them to change that mentality that the United [i.e., UFCo] left them, left us, in the banana plantation everything was chemical [pesticides]. And now the oil palm plantation, everything is chemical, right? The aircraft [aerial spray] sometimes passes there fumigating and sometimes you go along the road and all that chemical that the aircraft throws down, you receive it because almost all along the road there are oil palms, and it continues like that from here to Sierpe, they fumigate and they are not careful about it. Everything goes through the air. So, uh, that part of it, it is a struggle, I feel it is very, very hard and very strong. I don't know when we are going to finish with this.

Upon taking the land, *parceleros/as* faced the agricultural challenges of contaminated and exhausted soils, including the diseases and pests triggered by the banana monocrop, and the dependence on agrochemicals, as well as the symbolic legacies of the enclave. Victor García, a well-known social leader involved in southern popular struggles since the early 1970s, shared his reflections on the matter: "In this region, there is a Unitera culture [from UFCo], people talk about *quemantes* [herbicides], it is a culture of fumigations, of agrochemicals, here the banana culture is fierce, and that is a legacy of UFCo." Although the land movement revived expectations of a transition towards agrarian justice in the Southern region, the movement faces these inner and intimate subjective challenges. Victor referred to the difficulties related to local resignation and feeling of powerlessness, and how it derived from the dependency that UFCo generated, through their near-total control of the basic conditions of inhabitants' everyday lives. Li & Samedi (2021) have argued that foreclosed agrarian futures constitute corporate harm in the interplay of corporate occupation and abandonment. Occupation in its banana enclave form compromised the capacity of engaging in agricultural practices that might slip away from plantation logics. As Victor suggested: "This area has a strong agricultural vocation, so its people are closely linked to agriculture or to the land and livestock. Yet, most of our people have been labourers and hence farmers who were more labourers than farmers, I mean, maybe I am wrong about this, but here, with the banana enclave, this culture of labourer was generated."

The concepts of 'plantation' and 'plot', have been put into dialogue by black feminist scholars, to reflect on the legacies of the plantation beyond the plantation, and the possibility of challenging them and imagining other futures, even from plot-lives conditioned by plantation logics[13] (McKittrick 2013; Goffe 2022). In *parcelas* in Palmar Sur, one of these legacies has been the lack of a sense of belonging, as Victor explained: "There is no rootedness here, the largest amount of fertile land was part of the banana enclave, but the ones who were here were all labourers and no one put down roots, there were all uprooted, in the Southern region, there is a problem of identity…We have to make a conscious effort to generate that, to see if, in 30 or 40 years, people will feel more encouraged and say, yes, this land is our land." In that sense, the pesticide-chip mindset that Evelin described, goes beyond whether *parceleros/as* use pesticides or not. Confronting or undoing that mindset speaks to *parceleros/as*' migrations in search of a livelihood, a longing for land stemming from histories of dispossession, a desire for a dignified life, and a disciplined yet persistent hope.

4.5 Conclusions

Plantations extend beyond their formal territorial and historical boundaries, permeating waterscapes in tangible and everyday ways. When Del Monte sought to establish a pineapple plantation in Palmar Sur, its move stirred up accumulated layers of the banana enclave, and recent experiences with pineapple through the residues and sediment that settle downstream. The interconnectedness of harm in the waterscape is well described by Carmela, a *parcelera* concerned about the implications of pineapple expansion: "When the soil is ploughed, everything mixes, the poison mixes, we are in a time bomb. The wind carries everything away and drifts the chemicals. We don't want the pineapple to expand any further". Her reflections underscore her acute awareness that her *parcela* sits atop the stratified remains of the banana plantation in the soil, the implications of bare-soil practices in pineapple production, and what the combination of these layers might represent.

The extended scope of plantations is not merely rhetorical; it is a concrete reality with far-reaching implications for subjectivities and livelihoods. As I have argued in this chapter, plantations are relational spaces that produce waterscapes over time while remaking

[13] Sylvia Winter's essay "Novel and History, Plot and Plantation" published in 1971, used the concept of 'plots' to refer to the small parcels that planters gave to slaves to grow their own food. Katherine McKittrick (2013) built on her work to analyse the black geographies of dispossession, taking the plantation concept to cities and linking it to the present. She argued that the plantation produced black rootedness in place as a strategy of survival for black people in the Americas. Even though the plots were concessions within the plantation, they constituted spaces to reproduce a life that could defy plantation logics. She then proposed to think of the plot-and-plantation "as a new analytical ground that puts forth a knowledge system, produced outside the realms of normalcy, thus rejecting the very rules of the system that profits from racial violence, and in this envisions not a purely oppositional narrative but rather a future where a corelated human species perspective is honored" (2013:11).

landscapes. Capitalist accumulation in the Southern Region was made viable both by UFCo's build-out of major hydrological infrastructure in the 20th century and that infrastructure's ruination as the company formally left the area, while also seeding the oil palm boom to come. The plantation's hydro-logic still determines the spatial composition of the Palmar District: a land divided into quadrants, and plots, crossed by a grid of waterways. *Parceleros/as* wrestle with these legacies on a daily basis: as contract workers on nearby palm oil plantations, as cultivators who generously use pesticides on their plots, and as organizers who seek to change this "chip" or mentality of pesticide use that plantations instil.

The *llenas* lay bare the institutional abandonment and vulnerability of those fishing and cultivating in the delta as they stir up plantation effluents in watercourses made and abandoned by its capitalist logics. Fertiliser-intensive oil palm production system and the lack of adequate ditch management clog irrigation canals, while excess sedimentation from the aggressive soil stripping practices of pineapple production obstruct waterways for transport and disrupt mangrove ecosystems far downstream. The delta materializes the ever-changing configurations of agrarian capital in and through plantations, as effluent flows of sediment and pesticides accumulate in and through the knotty roots of mangrove forests. The extended boundaries of the plantation transcend the binary notion of inside and outside, encompassing not only the enduring legacies of the plantation but also the areas of overlap where one plantation ends and another begins. The uncertainty surrounding the source of pesticide exposure is a manifestation of this intricate overlap. The movement of pesticide residues across the Térraba River and delta, and the subsequent socio-ecological interactions and disruptions, expose how the environmental fate of contaminants is part and parcel of a dynamic waterscape, too easily glossed as a sink. The *llenas* uncover what has accumulated over time, what had runoff through the waterflow and how socio-ecological relations had been affected. Even though the banana enclave conditioned people's lives, it was not a homogenous and monolithic process, and *parceleros/as* opposition to pineapple expansion reflects how corporate occupation did not fully determine their subjectivity.

Conclusions

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This research project originated from collective inquiries among scientists, activists, farmers and others who have long been concerned about the pervasive presence of pesticides in Costa Rican agriculture, rural communities, and vegetables and fruits for domestic consumption. After spending many years immersed in debates over pineapple expansion, I constantly felt that we were reaching a dead end. Through this research, I have attempted to understand the reasons behind these circumstances as part of a broader and longer-term process. The idea of working in the southern Pacific, after having been mainly focused on the Northern Caribbean, arose to examine more closely the banana enclave and the transition towards pineapple and oil palm plantations. Through each empirical chapter, I sought to comprehend why and how pesticide-contaminated waterscapes have been and continue to be produced in Costa Rica.

In Chapter 2, I examined how the pesticide registry reform process in Costa Rica is characterized by a precarious maintenance of hegemony through regulation by impasse. Rather than being a failure or absence of regulation, this approach involves continuous strategic reworking by various social, economic, and political forces, along with state managers, in maintaining regulatory gridlock. The contest to shape the asymmetrical structures of the state manifests as a complex, highly technical, and bureaucratically intricate process. Additionally, the influence of extra-national norms and interests, combined with past political settlements, gives rise to novel regulatory arrangements. The shifting composition of transnational capital further impacts the dynamics of competition and cooperation within the regulatory dispute. The outcomes of regulation by impasse are not only institutionally challenging but also ecologically and socially detrimental. 1800+ pesticide registrations in Costa Rica exist in a state of administrative ambiguity, even for those responsible for managing the process, as the article shows.

These registrations, which have not been brought into compliance with the Auditor General’s 2004 mandate for registry reform, remain officially categorized as "irresolutely valid." Consequently, widely used substances, approved without risk evaluations and restricted or banned in other countries, continue circulating through the country's ecosystems and impacting farmers, farmworkers, and communities. Despite positioning itself as a global leader in conservation, Costa Rica faces deepening contradictions between environmental protection and capital accumulation. The tenuous achievement of environmental governance through prolonged regulatory disputes reflects the increasingly frayed hegemony that sustains the country's development model.

In Chapter 3, I argued that pesticides are not merely inputs in crop production but integral to maintaining capitalist agriculture's ecological regime. This distinction is crucial for understanding how the regime is maintained over time, the role of pesticides in stabilizing it, and the potential for transformative tensions and contradictions. Pesticides exhibit a dual dynamic in relation to capital accumulation. They stabilize profit-making in capitalist agriculture by converting “waste” of extractive industries into inputs, and by exploiting organisms' vulnerability to biocides. However, as chemical fixes, pesticides are deeply intertwined with the biotechnical strategies developed by capitalist agriculture to overcome socio-ecological limits. The massification of biotech fixes, such as new cultivars, hybrids, and genetically modified organisms within monocrops, disrupts ecological relationships that are continually restabilized through a "patchwork" of chemical and biotech solutions.

In Costa Rica's southern Pacific region, the complex interplay of monocrop-plot production, pesticide use, and chemical exposure poses challenges in unravelling their interconnected impacts. The globalization of the agrochemical industry and the availability of generics have made pesticides more accessible to small farmers, who experiment with compound combinations and share strategies. These plots bear the remnants of toxic and synthetic legacies, conditioning the livelihood possibilities associated with reclaimed plantation lands. Smallholder agriculture in these areas relies on specific pesticide practices using legacy compounds from the post-World War II synthetic boom, all while grappling with limited public support and the consequences of chemical- and pathogen-riddled soils. The dilemmas in the plots show the importance and necessity of historicity, since it is not possible to understand the challenges in this type of agrarian process, without trying to comprehend where they come from and how they developed over time.

In Chapter 4, I showed how plantations extend beyond their formal territorial and historical boundaries, permeating waterscapes in tangible and everyday ways. I trace plantation extensions over time, in the legacies of the banana enclave in Palmar Sur, and space, in the effects of upstream plantations on the delta's socio-ecological relations. The hydrological infrastructure built by the United Fruit Company (UFCo) in the Southern Region shaped the Palmar District and laid the groundwork for the subsequent oil palm boom. *Parceleros/as*, who work as contract laborers, pesticide-using smallholders, and organizers struggling for change, have grappled with the legacies of this infrastructure, and other banana enclave legacies like the prevailing pesticide mindset. Moreover, periodic, devastating floods, or llenas, reveal the institutional neglect and vulnerability experienced by those in the delta as plantation soil practices and effluents clog waterways, disrupt ecosystems, and impede transport due to excessive sedimentation. Seeing plantations through the delta shows how the extended boundaries of plantations blur the distinction between inside and outside, encompassing enduring legacies and overlapping areas between plantations.The opposition to Del Monte's proposed pineapple expansion by *parceleros/as* in Palmar Sur not only sheds light on how these issues inundate life in the delta, but also hints at the possibility of something escaping the interplay between corporate occupation and abandonment—like a timid wink of hope.

In Chapter 6, included in Appendix 1, I evaluated the environmental exposure and biochemical responses of the mollusk bivalve *Anadara tuberculosa* in relation to the presence of pesticide residues in the Térraba-Sierpe wetland. The findings suggest a plausible association between pineapple cultivation and the observed impact on the wetland aquatic environment, based on the geographical distribution of these substances and their utilization in pineapple production. Furthermore, the study supports the potential to evaluate biomarkers in *A. tuberculosa*, particularly GST and ChE activities, to investigate pesticide effects in coastal systems potentially affected by pesticide contamination, as they showed differential responses in the sampled sites. However, the analysis also identifies potential issues and paths of investigation to define the baseline values of such biomarkers. Future studies should focus on biomarker responses in *A. tuberculosa* at low salinities to further assess the potential of this species as a bioindicator, as this chapter demonstrates the wide salinity range to which it is exposed in the wetland area. The differential responses depending on the reproductive state or the measurement of biomarker responses over time, in caged organisms exposed *in situ*, should be considered.

Returning to my main research aim, the different lenses I have applied in this thesis have allowed me to understand the production of pesticide-contaminated waterscapes, such as the Térraba-Sierpe delta, as a confluence of the following: the chemicalisation of agriculture developed in Costa Rica in the long twentieth century, the plantation legacies and their expanded boundaries in terms of time and space, a precarious pesticide regulation shaped by sedimented histories, i.e. regulation by impasse, and its interaction with global networks of pesticide production and distribution, and the dispersion of pesticides from agricultural crops to aquatic ecosystems. While there is still a long way to go on this subject, my personal concerns as a researcher that motivated this study have found roots to understand the "why" behind pesticide pervasiveness. This has been quite healing, since we deserve to delve into our past and carefully observe the present to locate ourselves, in this place, in this world.

5.1 Research contributions

The combination of disciplines and standpoints is one of the contributions of my research, which functioned as a mirror, similar to mirror statistics. In other words, the unavailable or unclear information on a topic was possible to obtain from another field of knowledge or by taking a different approach to access it. In countries like Costa Rica, where there is great uncertainty and a lack of information regarding imports-exports, regulation, registration, and use of pesticides, this was definitely key within the research framework. Faced with the sectorization, suppression and fragmentation of information, being able to participate in such diverse spaces expanded the observation and access to the subject. For example, topics related to governance and regulation, studied within the social sciences, are being discussed in spaces related to agronomic and environmental sciences, both within and outside of academia. From these spaces, a detailed and constant citizen evaluation of pesticides is carried out, addressing specific pesticides, their evaluation criteria, restriction or prohibition, socio-environmental hazards, etc.

The study in ecotoxicology allowed meto reflect in detail on the technological package used in each crop, agricultural practices, as well as the dynamics of land use. Analyzing the relationships between pesticides and the human-environment closely allowed me to ground specific observations and analyses regarding pesticides. The dialogue generated between this perspective and the other analytical lenses used in the research created a mirror between the upper and lower parts of the pesticide production and distribution chain. While studying the regulation of pesticide registration, for example, I could contrast which substances were being used but not detected due to the lack of analysis protocols (e.g., mancozeb, glyphosate), or which substances were detected in water monitoring despite being prohibited (e.g., bromacil).

Environmental science and social science methods can enrich and complement each other. For instance, key informants collaborated to identify sampling sites, plan the logistics of the sampling campaigns, and carry out the samplings. This is particularly important because certain estuaries in the wetland are quite difficult to access due to tides and other coastal factors. It was also interesting to observe how sampling generated an enriching debate about pesticide exposure. Although I had already interviewed several people before conducting the sampling, focusing specifically on something related to the topic (extracting sediment with a dagger, observing the difference between the water in one estuary or another, etc.) facilitated the connection between environmental exposure and personal, everyday experiences and observations. Similarly, it was curious how, through the sampling, a bridge was formed between shellfish gatherers or *piangüeros/as* and smallholders or *parceleros/as.* The areas of the plots and the mangrove, despite their proximity, often operate as separate worlds. Moreover, during the interviews, I had noticed a gender gap in the *parcelas* in relation to the wetland, as it is mostly men who have explored or have a better understanding of the latter. Taking this into consideration, I decided to invite some women *parceleras* to participate in the sampling campaigns. This opened up an exchange about life experiences in the mangrove and in the plots, which in turn sparked conversations about how what happens in one place is connected to broader spaces. In this way, the sampling campaigns served as a connector between places, life experiences, and everyday life in a larger human-environment. With these examples, what I am trying to illustrate is that the combination of methods generates a very enriching feedback, which is itself an outcome.

Many studies in both environmental science and social science are designed based on knowledge gaps. As a matter of procedure, I conducted the exercise of identifying these knowledge gaps, such as the lack of studies on political ecology in wetlands or the larger focus on the Caribbean region of Costa Rica compared to the South Pacific, among others. While it is important to locate the contribution we aim to make and give it a sense of meaning, there is a thin line between this and an excessive drive for "innovation." It is crucial to consider what questions are important and why, even if they are outdated or considered obsolete depending on your geographical standpoint. At the beginning of my doctoral research, I received multiple comments suggesting that the topic of pesticides was outdated in political ecology or that it was not cutting-edge in ecotoxicology compared to the study of emerging contaminants, to name a few examples. However, despite the criticism, I decided to continue with the research, driven by stubbornness or *necedad* akin to Silvio Rodríguez's song. Looking back, not only do I have no regrets, but I would advocate for cautious consideration that the driving force behind our research should not be to achieve innovative interventions at the frantic pace of neoliberal academia.

From the perspective of feminist geographies, key reflections have been made in analyzing the operations, logics, violence, risks, and possible strategies to counteract neoliberal academia (Mansfield et al., 2019; Manzi et al., 2019). Part of this work has been to propose and build a slower academia, with conscious and supportive feminist mentorship (Curran et al., 2019; Mountz et al., 2015). Thanks to the collaboration with my co-supervisor, Dr. Werner, who has been actively involved in these debates, I have been able to learn and practice alternative ways of working in academia. This has involved thinking and writing together, honouring and attending to life circumstances in contrast to the head-on-a-stick ideal of a detached intellectual work that displaces us spatially and affects our bodies and lives (Hawkins et al., 2014). It also means giving importance to how we do things, not just the end product, among other examples. Particularly, Dr. Werner's notion that there is some sort of limit to the reach and achievements of our academic work, and that exceeding this limit leads us to work unethically and gradually enter into the realm of abusive, extractive, or exploitative practices, has deeply influenced me. This study not only allowed me to learn about a different way of conducting research but also provided an example to follow: that it is possible and essential to engage in committed, self-critical, and reflexive scholarship both theoretically and in practice.

Theoretically and empirically, my research contributes to various debates on the political ecology of pesticides, political ecologies of water, critical agrarian studies, environmental governance, critical state theory, and tropical ecotoxicology. In terms of the political ecology of pesticides in Costa Rica, it engages with the work of Lori Ann Thrupp and Ryan Galt, which is explored throughout the thesis, with a particular emphasis in Chapter 4, where the intensive use of pesticides in banana monocrop and domestic agriculture is analyzed, respectively (Galt, 2014; Thrupp, 1988). Inspired by both studies, I examine the chemicalization of agriculture in Costa Rica from different perspectives, bridging the analytical gap between monocrops and *parcelas* through a relational conceptualization of the delta. The dissertation delves into the agrarian conditionings derived from plantations in Costa Rica while shedding light on new political and economic configurations of the pesticide complex. Regarding political ecologies of water, it provides a biochemical lens to Swyngedouw's conceptualization of waterscape production, materializing temporal and spatial analysis through specific human-environment relations, such as sedimentation and socio-ecological disruption owing to pesticide contamination (Swyngedouw, 1999). It complements plantation studies by examining classic questions about what constitutes a plantation, applied to a stylized analysis of different forms of plantations and how they manifest in the delta. In terms of environmental governance and critical state theory, the dissertation offers elements to question the boundaries of the state in relation to civil society and the business sector, as well as their connections to global production networks. It reinforces previous work by Jansen (2017) analyzing tensions within the business sector, and by Fletcher et al. (2020), León Araya (2021) and Ramírez Cover (2020), and others, on neoliberal environmental governance and the Costa Rican sustainable development model. Finally, in the field of tropical ecotoxicology, it contributes to tropical ecotoxicology studies by bringing a preliminary analysis of pesticide contamination in a coastal ecosystem in the South Pacific, and applying a battery of biomarkers for the first time to the native tropical species *A. tuberculosa* (as far as I am aware)(Gunnarsson and Castillo, 2018). The study also aims to influence a more critical ecotoxicology that incorporates elements of social sciences in its scientific practice, including research design, methodology, and analysis of results.

Both toxicology and ecotoxicology have played a controversial role in determining thresholds of toxicity and risk, often from problematic and non-reflexive perspectives (Boudia and Jas, 2014; Liboiron, 2021; Romero, 2022). While I share these concerns, I believe that in countries like Costa Rica, where pesticides are omnipresent in multiple and complex ways, from our food to socio-ecological communities, this sceptic distance and relativisation about the convenience to research pesticide exposure and its effects or actions to intervene in the regulatory landscape, is not so straightforward. The biased determinism of regulatory sciences is tricky, yes, but if one lives next to a plantation, works on it, or has their community's water contaminated by pesticides, the uncertainty or lack of information is equally or even more problematic. In this context, I consider it is important to conduct research that contributes to characterizing the problem in order to take actions or measures.

5.2 Future Research

The contributions and findings of this thesis open an avenue for future research. Once I publish everything that is presented in this dissertation in scientific journals, I will write other essays, articles or chapters, based on the extensive information that came out of my fieldwork and is not presented here. Furthermore, stemming from my research, I will go deeper into this topic, working on a research project at the Department of Geography, University of Zurich, from May 2023 to December 2026. This project, titled "Making herbicide markets: Interactions between production restructuring, agriculture, and the environment in Latin America and Asia," aims to analyze chemical herbicides as specific drivers of economic and ecological change by examining the transformative role of emerging-market generic production networks in relation to farming practices and environmental impacts in Latin America. Its specific objectives are: (1) to understand the process of herbicide market formation considering chemical dependence on legacy compounds, declining effectiveness, and environmental feedback loops; (2) to contextualize these environmental challenges within global production networks for key synthetic herbicides, with a focus on the connections between Latin America and Asia; and (3) to conduct in-depth studies of selected herbicide "assemblages" in the global South, with a particular emphasis on how the distribution and agricultural use in the "last mile" reflect and reshape environmental challenges and economic strategies in Latin America. Through this project, I will have the opportunity to delve deeper into understanding the commercialization and use of pesticides, both in Costa Rica and by taking a Central American perspective, in relation to what occurs upstream in production networks in countries like India and China.

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Lens IV: Biochemical interactions

Appendix 1:

Tracking pesticides from upstream river waters to wetland fauna in the Terraba-Sierpe National Wetland:

An ecotoxicology study of *Anadara tuberculosa*

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Abstract

Costa Rica's agriculture system heavily relies on the use of pesticides. As pesticides can easily reach aquatic ecosystems, this study identified and quantified pesticide residues in water and sediment samples in the Térraba-Sierpe National Wetland and influenced areas. Additionally, a battery of biomarkers was evaluated in the bivalve mollusc *Anadara tuberculosa*, including glutathione S-transferase (GST), cholinesterase (ChE), catalase (CAT), lacatate dehydrogenase (LDH), ethoxyresorufin-O-deethylase (EROD), and lipid peroxidation (LPO) activities. Statistically significant differences were determined compared with those in a control site ($p<0.05$) Results evidenced the presence of pesticides in the Térraba river waters and the northern Térraba-influenced wetland area, with diuron, carbendazim, diazinon and ethoprophos appearing at highest concentrations. Considering the geographical distribution of these substances and their utilization in pineapple cultivation, the findings suggest a plausible association between this agricultural activity and the observed impact on the wetland aquatic environment. Furthermore, the study supports the potential of A. tuberculosa biomarkers, particularly GST and ChE activities, to investigate pesticide effects in coastal systems potentially affected by pesticide contamination, as they showed differential responses in the sampled sites. We recommend that future studies focus on biomarker responses in *A. tuberculosa* at low salinities to further assess the potential of this species as a bioindicator and set baseline values.

6.1 Introduction

Contemporary agriculture entails intensive agrochemical use. According to the UN Food and Agriculture Organization (FAO), the average global use of pesticides per unit of cultivated land increased from 1.12 to 1.81 kg ha^{-1} between 1990 and 2020. However, a recent study by Shattuck et al. (2023) has suggested that FAO's estimates might underestimate pesticide use due to poor data quality and gaps in country-specific information. In the past decade alone, global pesticide use has increased by 20% in terms of volume, with low-income countries experiencing a staggering 153% rise (Shattuck et al., 2023). Despite the increase in pesticide use per hectare, agricultural productivity has not seen a corresponding rise, indicating a potential decline in the effectiveness of these substances. Moreover, only a limited number of countries have successfully reduced the overall intensity of pesticide use, as decreased insecticide use has often been offset by increased herbicide and fungicide use (Haggblade et al., 2017; Schreinemachers and Tipraqsa, 2012). Globally, herbicides constitute the largest proportion of pesticide use at 49%, followed by insecticides (18%), fungicides (14%), and fumigants (19%) (Atwood and Paisley-Jones, 2017).

Costa Rica's agriculture system heavily relies on the use of pesticides, indicating a strong dependence on these chemical substances (De La Cruz et al., 2014; Echeverría-Sáenz et al., 2018; Galt, 2008; Schreinemachers and Tipraqsa, 2012). The elevated pesticide use in Costa Rica, along with Colombia and Mexico, can be attributed to the dominance of export-oriented crops and their extensive land utilization (Schreinemachers & Tipraqsa, 2012). Although pesticide usage is also significant in domestic agriculture, certain export-oriented monocultures are particularly notable (De La Cruz et al., 2014; Galt, 2014). For instance, banana monocrop employs an average of 76 kg of active ingredient (a.i.) per hectare per year, while pineapple cultivation utilizes around 47 kg ai ha^{-1} year^{-1} (Bravo et al., 2013). Over the past two decades, studies have identified pesticide residues from these crops in different environmental water sources, including drainage canals, packaging plant effluents, streams, rivers, and coastal lagoons along the Caribbean region and to a lesser extent in the Pacific region (Echeverría-Sáenz et al., 2021; Gunnarsson and Castillo, 2018). These findings have been related to adverse impacts on biota, such as incidents of fish mortality and alterations in the structure and species richness of macroinvertebrate communities (Castillo et al., 2006; Diepens et al., 2014; Echeverría-Sáenz et al., 2018).

Most imported pesticides used in the country have the potential to reach aquatic ecosystems. Notably, 98% of these imported pesticides have been classified as acutely toxic to fish and crustaceans, with 73% exhibiting toxicity risks for amphibians (De La Cruz et al., 2014). In freshwater ecosystems, diuron, ametryn, pyrimethanil, flutolanil, diazinon, azoxystrobin, buprofezin, and epoxiconazole were among the most frequently detected pesticides between 2009 and 2019 (Echeverría-Sáenz et al., 2021). This presence of pesticide residues in aquatic ecosystems raises significant concerns regarding their adverse effects on the surrounding environment. For instance, studies have documented sub-lethal effects in native fish species, such as *Astyanax aeneus* and *Parachromis dovii*, at environmentally measured concentrations (Jiménez et al., 2021; Mena et al., 2023).

The behaviour of pesticides in tropical ecosystems, characterized by high biodiversity and unique climatic conditions, is a subject of ongoing debate in the field of ecotoxicology. Understanding of the environmental fate, bioavailability, and impacts of pesticides on tropical species and ecosystem dynamics is essential but remains limited (Gunnarsson and Castillo, 2018). Tropical ecosystems possess distinct ecological conditions that can significantly influence the behaviour and fate of pesticides in water and sediment (Carazo-Rojas et al., 2018), as the coexistence of multiple pesticides in aquatic environments introduces the potential for complex interactions with other environmental change drivers, leading to synergistic effects (Polidoro and Morra, 2016). Furthermore, studies have indicated that certain contaminants, such as arsenic, exhibit higher bioavailability and toxicity in tropical soils compared to temperate regions (Alves et al., 2018). Thus, it remains a matter of debate if ecotoxicological data developed based on temperate species should be applied to assess ecological risks in tropical regions (e.g. Diepens et al., 2014). Additionally, the existing toxicity dataset, predominantly derived from temperate species, is insufficient to explain specific ecological events observed in tropical ecosystems, such as fish mortality events. Consequently, it is crucial to consider the interplay between toxicity data and other environmental factors when assessing the ecological risks of pesticides in tropical regions (Polidoro and Morra, 2016).

Climate change, through variations in environmental drivers of change such as temperature, ocean acidification, or sea level, can alter the transport, environmental fate and behaviour of pollutants (Noyes et al., 2009; Bogdal and Scheringer, 2011; Gilman and Jenssen, 2011), making them more available for organisms (Kibria et al., 2021). Increasing temperatures increased the toxicity of pesticides in fish (freshwater and marine) (Patra et al., 2015); eel, (Ferrando et al., 1987); and rainbow trout (Patra et al., 2015). Tropical areas are predicted to markedly suffer the effects of climate change stressors, leading to increasing bioavailability of pesticides and adverse effects on the biota. In many tropical countries, fish, crustaceans and mussels are an important source of animal protein. Thus, not only ecosystems but also human health and local livelihoods might be under a rising risk.

All this considered, this research addresses the need for studies on pesticide presence and effects in tropical ecosystems. While previous research has predominantly examined pesticide impacts in freshwater systems, there is a lack of knowledge concerning the persistence and effects of both old and contemporary pesticides in wetland environments and associated biota (Cuevas et al., 2018). Moreover, most of the studies have focused on the Caribbean region. To bridge this gap, this study aimed to identify and quantify pesticide residues in water and sediment samples collected from the Térraba-Sierpe

National Wetland located in the Southern Pacific region. Monocrop plantations, including oil palm, banana, and rice are located within the influence area of the wetland, while upstream of the Térraba River, there are extensive pineapple plantations (Cortés Muñoz and Montero Solís, 2021).

Furthermore, we evaluated different biomarker responses in the bivalve mollusc *Anadara tuberculosa*, commonly known as *piangua*, in different areas affected by pesticide pollution. Biomarkers are molecular, biochemical, cellular and physiological indicators of contaminant stress measured in organisms, either resident or exposed in situ in a specific location. They are used in the monitoring programmes of Regional Seas Conventions and more recently in the EU Marine Strategy Framework to identify the impact from substances or combinations of substances not previously identified to be of concern, study trends and identify regions of decreased environmental quality (Wernersson et al., 2012). Environmental risk assessments increasingly use biomarkers as sensitive biochemical indicators of sublethal pesticide exposure (Mohr et al., 2012). Common enzymatic biomarkers responsive to pesticide contamination include the neurotransmitter acetylcholinesterase activity and the oxidative stress enzymes catalase and glutathione S-transferase and lipid peroxidation (Jemec et al., 2007).

Pianguas are commonly found in the intertidal muddy flat sediments of mangrove swamps, at depths of up to 15 cm, specifically in areas where the aerial prop roots and mangrove tree canopies provide habitat (McKenzie and Stehlik, 2001; Stern-Pirlot and Wolff, 2006). Although more research is needed to understand their biological functioning and ecological interactions, efforts have been undertaken to consider them as a prospective biomonitor and sentinel bivalve species (Aguirre-Rubí, 2018). Moreover, *A. tuberculosa* constitutes a key species within the wetland, since its extraction is the main source of livelihood for local populations (Arias Bogantes, 2017).

By conducting an analysis of pesticide presence, quantification, and their potential impacts on the biochemical responses of *A. tuberculosa*, this research seeks to advance our understanding of contamination dynamics in the Térraba-Sierpe National Wetland. The findings will not only contribute to the scientific knowledge in the field of tropical ecotoxicology but also hopefully provide valuable insights for future research and conservation efforts.

6.2 Materials and Methods

Study area

The Térraba-Sierpe National Wetland (HNTS in Spanish) is a protected area since 1994, managed by the Conservation Areas System (SINAC in Spanish) from the Ministry of Environment of Costa Rica (Fig. 1). It has an approximate area of 33,030.8 hectares and is considered one of the most important wetlands both nationally and internationally,

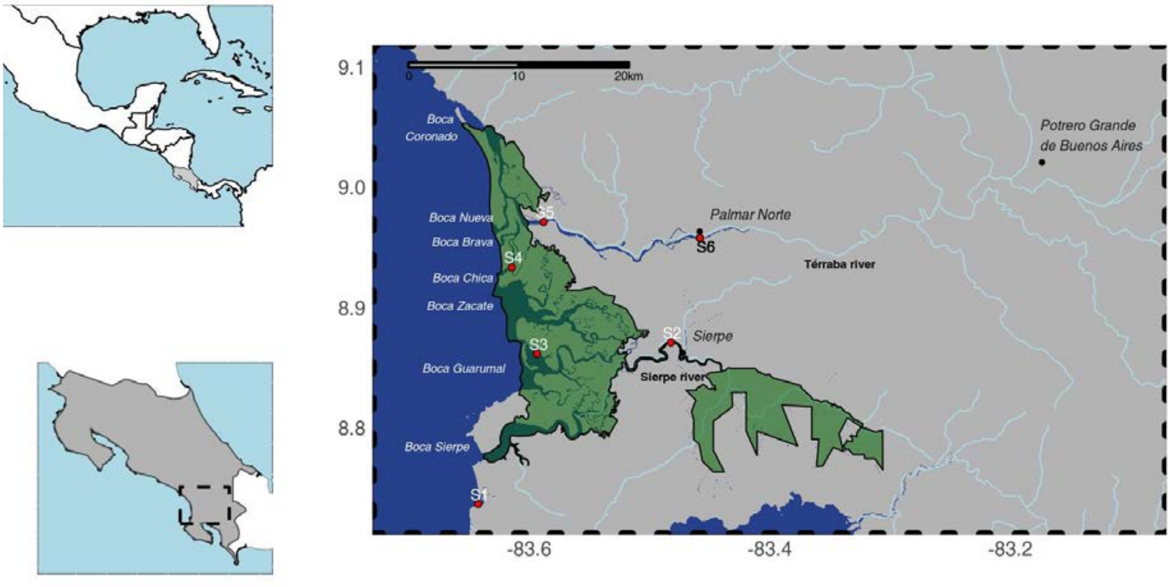

Figure 1. Study area and location of sampling stations in the Southern Pacific Region: Boca Ganadito (S1), Ajuntaderas (S2), Boca Guarumal (S3), Boca Chica (S4), El Rompido (S5) and Térraba River in Palmar Norte (S6).

recognized as a RAMSAR site since 1995 (Picado, 2015). Despite this recognition, it faces serious management weaknesses owing to multiple factors, including the lack of implementation of the management plan, insufficient human and financial resources, absence of monitoring and pollution control, and the existing tension between agricultural land uses and conservation interests (CGR, 2011).

From an ecosystem perspective, HNTS consists of two different hydrological systems. One is influenced by the Térraba River basin to the north, characterized as an intertidal estuarine wetland with a landscape classified as a flooded forest due to tidal influence. The other is related to the Sierpe River basin, with a permanent and extensive swampy area (Mora, 2013) and the largest mangrove coverage in Central America. According to Costa Rican legislation (Decree No. 35803-MINAET based on RAMSAR Convention categorization), it encompasses five types of wetlands: marine, estuarine, lacustrine, riverine, and palustrine (SINAC-UNDP-GEF Wetlands Project, 2018; Ramsar Convention Secretariat, 2016).

Regarding the estuary's geomorphology, it has seven mouths: Boca Coronado, Boca Nueva, Boca Brava, Boca Chica, Boca Zacate, Boca Guarumal, and Boca Sierpe (Fig. 1). Due to the wetland dynamics, salinity values change spatially and temporally according to various factors such as rainfall patterns, atmospheric phenomena like El Niño or La Niña, and geomorphological changes. The northern zone influenced by the Térraba River exhibits characteristics of a partially mixed estuary (during the dry season from December to April) or a salt wedge estuary (during the intermediate and high flow seasons from May to November). The central area has a greater marine influence with a vertically homogeneous or mixed estuary. In the southern area, a partially mixed estuary is present with balanced contributions of the Sierpe River and the tidal regime (Picado, 2015).

Field monitoring

The field monitoring was designed considering different issues described as follows: a) the existing anthropogenic contamination gradient from the Térraba and Sierpe rivers to the wetland's estuaries; b) the suitability of *A. tuberculosa* as native bioindicator species; c) the lack of studies analyzing the effects of pesticides in tropical estuaries with a salinity range of 10–30 ppm; and d) the need to compare both hydrographic basins against to a reference site to assess the potential behaviour and effects of contamination gradient.

Based on these criteria, sampling took place in 6 sites covering the North and South areas of HNTS, as well as the Sierpe and Térraba aquatic systems (Fig. 1). Site 1, considered a control was located at Boca Ganadito (outside HNTS), Site 2 was located in Sierpe River, Sites 3 and 4 were in Boca Guarumal and Boca Chica, respectively, and Sites 5 and 6 ran upstream Térraba River. All Sites were sampled for sediment and water characterization, while *A. tuberculosa* sampling took place in coastal Sites 1, 3, and 4, where they organisms are present. Site 1 corresponds to the reference site, selected due to its location at a greater distance from agricultural plantations and proximity to protected areas.

Water and surface sediment samples (5-10 cm) were collected at the study sites using opaque bottles and a Van Veen grab sampler of 0.025 m^2, respectively. The samples were transferred to pesticide-free containers and protected from light. Sediment containers were closed and stored at 4 °C until they arrived at the laboratory.

Four sampling campaigns were carried out during the 2019–2021 period, one during the dry season (March), two during intermediate periods (April and May), and one during the rainy season (August) for chemical characterization. Specimens of *A. tuberculosa* (n= 15) were sampled in situ (sites 1, 3 and 4) during the rainy and dry seasons. Organisms were kept in polystyrene refrigerators in a cool place until they reached the laboratory (IRET-UNA). Once there, they were depurated in seawater-filled aquariums under controlled laboratory conditions.

An additional sampling was designed and performed for extra knowledge of the area of research in the rainy season (August), covering the upstream area of the Térraba River in Potrero Grande .

Chemical characterization

Physicochemical parameters were measured at every sampling site. A calibrated Hach®, HQ40d multi-probe was used to record temperature (°C), conductivity (µS cm-1) and dissolved oxygen (DO, mg L^{-1}). Pesticide residues were measured in surface water samples collected at the six sampling sites following a standardized methodology already described (Mena et a., 2023). Briefly, the samples were extracted by solid phase (SPE), using Isolute ENV + 200 mg cartridges (Biotage). Gas and liquid chromatographic techniques were used for the identification and quantification of pesticide residues, with: 1) gas chromatography with mass detector (Agilent 7890A/5975C), using a BPX35 column; temperature 80 °C (1 min), 15°C min^{-1} 180 °C (5 min), 2°C min^{-1} 200 °C, and 12°C min^{-1} 300 °C (11 min); carrier gas, helium; gas flow, 1.78 mL min^{-1}; injected volume, 2 μL; and reading mode, SCAN and SIM; 2). Liquid chromatography coupled to a triple-quadrupole mass spectrometer (Waters ACQUITY UPLC H-Class with a TQ-S micro MS), using a ACQUITY UPLC BEH C18 column, temperature 45°C, solvent A H2O-CH3OH 95/5 0.1% formic acid, solvent B NH4-MeOH 0.1% formic acid, flow 0.4 mL min^{-1}, and injected volume 2 μL.

Biochemical responses characterization: biomarkers analysis

Twenty-four hours after this depuration, the organisms were dissected, and the digestive glands and foot, subsampled flash-frozen with liquid nitrogen and stored at -80 ºC prior to tissue homogenization. For biochemical analyses, a pre-tested methodology was applied (Mena et al., 2023). Briefly, samples were homogenized in appropriate phosphate (K2HPO4 / KH2PO4) buffers. After homogenization samples were centrifuged at 10,600 rcf, 4 °C for 5 min and the supernatant was used for Cholinesterase (ChE) analyses. All biomarker responses were normalized by protein content. For this, protein concentration was measured in each sample with the Bradford method (1976). Exposure to pesticides was measured by ChE activity following the method of Ellman et al. (1961), adapted to microplate by Guilhermino et al. (1996). Briefly, samples were exposed to a reaction mixture containing the synthetic substrate, acetylthiocholine (1 mM) and the conjugate 5,5′-dithiobis (2-nitrobenzoic acid) (DTNB) (0.1 mM); the reaction was measured at 415 nm for 10 min and expressed as nanomoles of substrate metabolized per minute per milligram of protein. Phase II of pesticides detoxification metabolism was measured by glutathione S-transferase (GST) activity was measured according to Habig et al. (1974), exposing samples to a mixture containing 1 mM of 1-chloro-2,4-dinitrobenzene (CDNB) and 1 mM of reduced glutathione (GSH). The reaction was monitored at 340 nm for 3 min; activity was reported as nanomoles per minute per milligram of protein. Lipid peroxidation (LPO) was measured by the thiobarbituric acid reactive species (TBARS) assay (Oakes and Van der Kraak 2003) and expressed as nanomoles of TBARS per milligram of protein. Oxidative stress was determined by the measurement of catalase (CAT) activity was measured according to the method of Aebi (1974) as the decrease in absorbance at 240 nm due to H2O2 consumption. The reaction was followed for 20 s and expressed as micromoles of substrate metabolized per minute per milligram of protein.

For all measured organisms, we considered the reproductive state by differentiating between mature reproductive females in contrast to other individuals.

Statistical analyses

General linear models (GLMs) and Tukey's post-hoc tests were used to assess relationships of biomarkers with reproductive state and size, as well as differences in size or reproductive state across sites. Similarly, differences in biomarkers between sites and seasons were assessed by GLMs. All analyses and visualizations were carried out in R software for statistical analyses version 4.1.2 (R Core Team, 2021).

6.3 Results

Physico-chemical characteristics

Physico-chemical parameters characterized the different sampling sites during each season. During the dry season, S1, S3, and S4 samples showed seawater characteristics, while S2, S5, and S6 showed freshwater characteristics. Meanwhile, in the rainy season, all sites showed lower conductivity values, with S4 fully transitioning from marine to freshwater. Additionally, turbidity was higher in the Térraba River (S4, S5, and S6) during the rainy season, as indicated by the attenuation coefficient.

Chemical characterization

Overall, 16 different compounds were detected in the water samples, with 12 of them being present in the Térraba River (Fig. 2). Diuron and carbendazim showed the highest concentrations (0.6 and 0.53 µg/L detected in S6 and S4, respectively). Organophosphates such as ethoprophos and diazinon were found all along the Térraba river during the rainy season, all the way to Boca Chica (S4). The rainy season showed a higher presence of pesticides, compared with the dry season and intermediate period.

Table 1. Physical-chemical characteristics of water samples from Boca Ganadito (S1), Ajuntaderas (S2), Boca Guarumal (S3), Boca Chica (S4), El Rompido (S5) and Térraba River in Palmar Norte (S6), during rainy and dry seasons.

	Dry				Rainy			
	Conductivity (µS cm^{-1})	OD (mg L^{-1})	Attenuation coefficient (m^{-1})	Water temperature (ºC)	Conductivity (µS cm^{-1})	OD mg L^{-1}	Attenuation coefficient (m^{-1})	Water temperature (°C)
S1	56670	4.6	1	25	30600	5.62	5.67	26.35
S2	8.8	5.57	3.78	25	130.7	4.88	5.67	26
S3	52900	5.11	2.83	30.1	37900		3.4	27.6
S4	54400	7.85	2.43	30.2	1334	6.62	21.25	25.2
S5	3480	7.23	2.43	30.6	162.9	7.7	42.5	25.2
S6	164	8.54		25.5	137.6	8.26	28.33	25.5

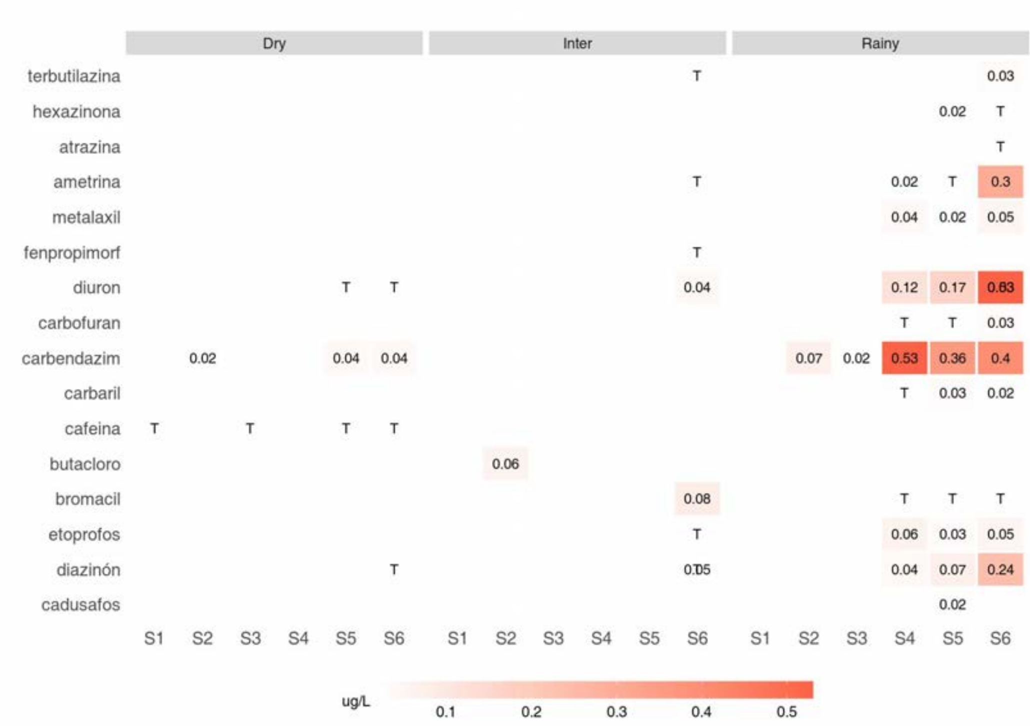

Figure. 2. Concentrations of measured pesticides in Boca Ganadito (S1), Ajuntaderas (S2), Boca Guarumal (S3), Boca Chica (S4), El Rompido (S5) and Térraba River in Palmar Norte (S6) during rainy and dry season. Values are expressed as $\mu g \cdot L^{-1}$. T: traces detected.

The last sampling upstream of the Térraba River (Fig. 3) showed very similar compounds to those detected downstream, with the highest concentrations of diuron, carbendazim, diazinon and ametrine in Quijada River, a tributary to Coto River, which flows into Térraba River.

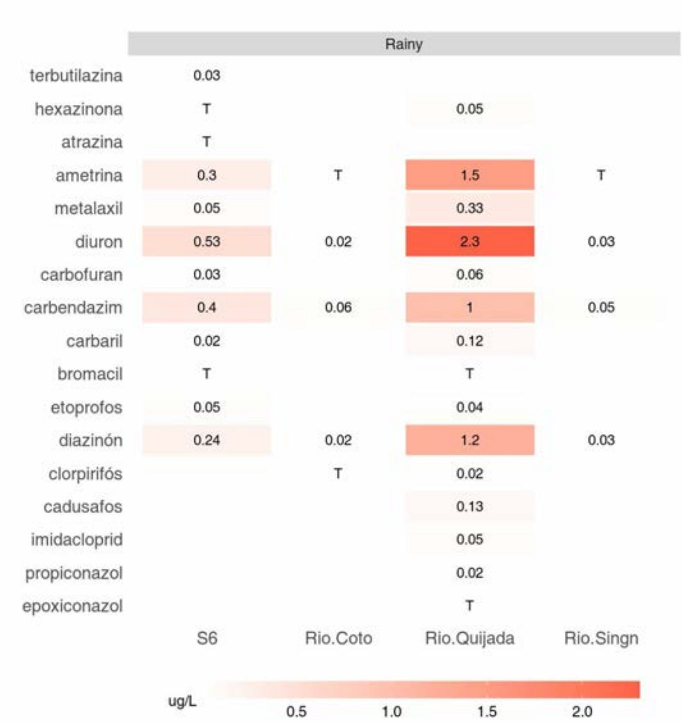

Figure 3. Detection of chemicals in water samples at Térraba River in Palmar Norte (S6), Rio Coto River, Quijada River, and Singri River during rainy season. Values are expressed as $\mu g \cdot L^{-1}$. T: traces detected.

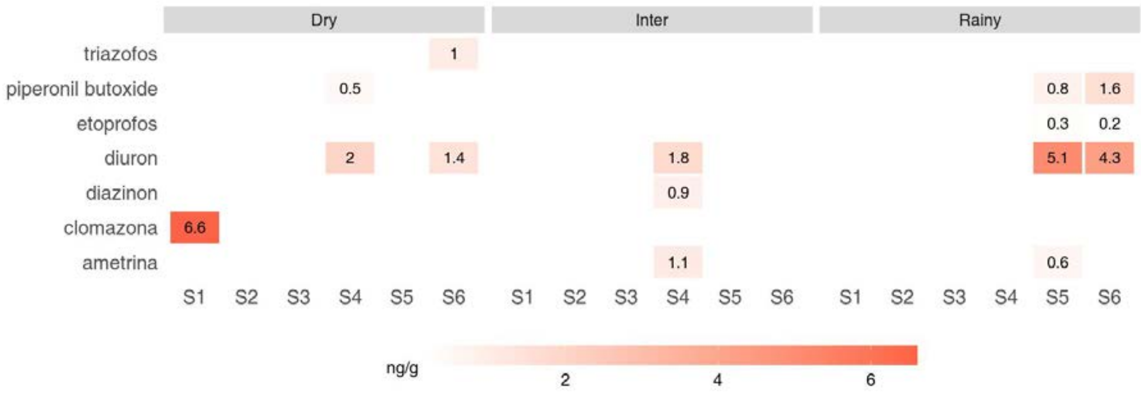

Figure 4. Chemical concentrations in the sediment at Boca Ganadito (S1), Ajuntaderas (S2), Boca Guarumal (S3), Boca Chica (S4), El Rompido (S5) and Térraba River in Palmar Norte (S6) during rainy, intermediate, and dry season. Values are expressed as ng g^{-1}. T: traces detected.

Sediment samples showed the presence of six different pesticides in Térraba River during all seasons (Fig. 4). Diuron and piperonil butoxide appeared both in the dry and rainy seasons, while triazophos and ethoprophos were only detected in the dry and rainy season, respectively. As an exception, clomazone was detected in the control site (S1) during the dry season. This compound was only detected in one of the sub-samples analyzed.

Biological condition

There were differences in size and reproductive state across sites and seasons. reproductive females were not found in S1 during the rainy season, but they were found at a frequency of 40% in dry season samples. This difference was also detected in S3, in which reproductive females increased 5% from the rainy to the dry season. Contrastingly, the presence of reproductive females showed no difference between seasons in S4 (Table 2).

Regarding size, GLM showed a statistically significant relationship with site and season (p-value < 0.05), with organisms being larger in the dry season and smaller on average in S1.

Table 2. Number of mature females per site and season. MF represents mature females, while Other refers to all other individuals.

	Dry		Rainy	
	MF	Other	MF	Other
S1	6	9	0	15
S3	4	11	3	12
S4	2	13	2	13

Biochemical responses: biomarkers

Results of enzymatic activities and lipid peroxidation measured in biological samples of *A. tuberculosa* can be found in Fig. 4. All biomarker responses except catalase enzymatic activity showed lower values during the rainy season than during the dry season, for sites S3, S4 and the reference site S1. Nevertheless, during the rainy season, no significant induction of biomarkers was observed compared with the control site.

Regarding the dry season, higher GST enzymatic activity, EROD enzymatic activity, LDH enzymatic activity and lipid peroxidation were observed in S4 compared with the control site. These higher values were significant for GST enzymatic activity ($p < 0,05$). This indicates the activation of the xenobiotic detoxification metabolism in organisms from site 4. Additionally, there was a significantly lower ChE activity during the dry season on sites 3 and 4 ($p < 0,05$) and on site 3 ($p < 0,05$) for EROD enzymatic activity compared to those in the control site.

Reproductive state only showed a statistical relationship with ChE. Interestingly, although ChE was lower in mature females, the differences among sites were consistent in all organisms. There was no statistically significant relation between any of the biomarkers and the individual length.

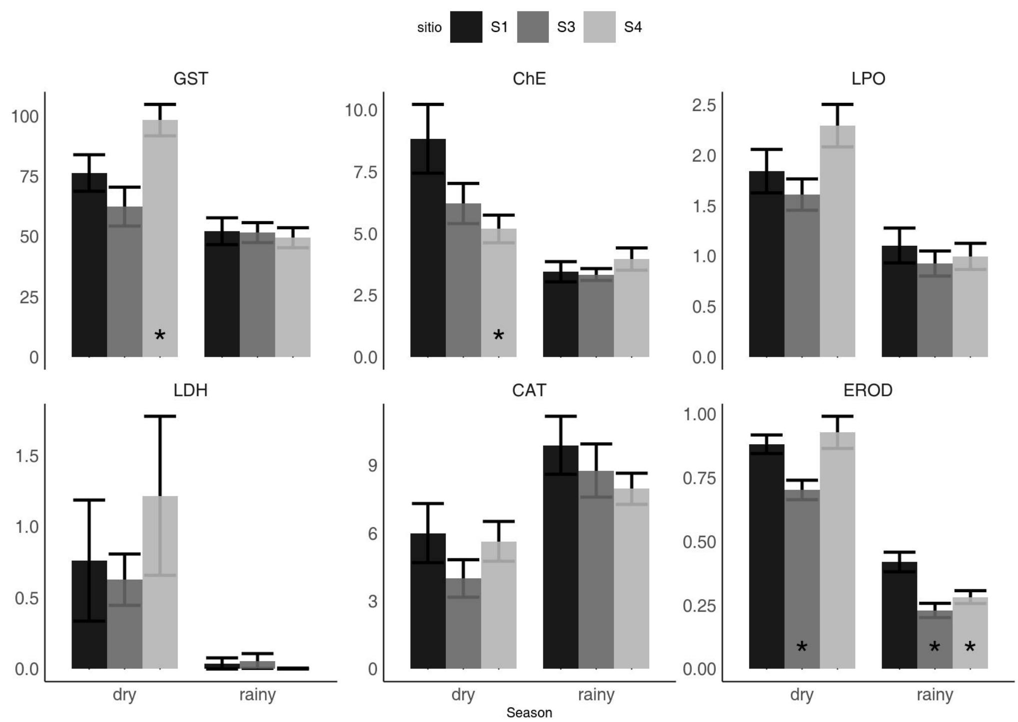

Figure 4. Biomarker analyses including glutathione S-transferase (GST), cholinesterase (ChE), catalase (CAT), lacatate dehydrogenase (LDH), ethoxyresorufin-O-deethylase (EROD), and lipid peroxidation (LPO) activities. The asterisk indicates a significant difference ($p < 0.05$) with the control site (S1).

6.4 Discussion

The results presented in this study evidence the presence of pesticides in the water of Térraba river and subsequently in HNTS, particularly in the northern Térraba-influenced area. The gradient of concentration from sampling station S6, S5 and S4 suggests that the water from the Térraba River constitutes one of the main sources of contamination in the wetland. The majority of identified pesticides (62.5%) are associated with pineapple production, including those detected at higher levels, namely ametrine, diuron, carbendazim, diazinon, ethoprophos and metalaxyl (Castillo et al., 2013). Despite the seasonal differences in measured environmental concentrations in water, which were more in the rainy season, pesticide residues were also detected in the sediment samples during the dry season (Fig. 3), indicating the accumulation of certain chemicals in the environment. These results also exhibit a pattern of distribution concentrated in the sampling stations within the Térraba influence area, with the exception of a detection of clomazone in S1, possibly derived from a rice cultivation located in the surrounding areas.

The presence of the diuron stands out in both water and sediment, which coincides with other studies in the Caribbean region in Costa Rica that have detected this herbicide with higher frequency and levels compared to other pesticides (Mendez et al., 2018; Rämö et al., 2016). Diuron tends to primarily accumulate in pineapple soil (52%-96%) and additionally is mobile and persistent, explaining its off-site presence from the pineapple plantation located upstream approximately over 70 km away (Mendez et al., 2018; Moncada, 2004). The high chemical concentrations detected upstream near Potrero Grande, an important node of pineapple production after Buenos Aires de Puntarenas, are in accordance with the presence of pesticides detected downstream. Diuron is used in the pineapple plantation which surrounds the Quijada river, explaining the high concentrations detected (Fig. 2). Similarly, the fungicide carbendazim is used in rice exploitation, also present in Potrero Grande, Golfo Dulce and nearby areas of HNTS (Cortés Muñoz and Montero Solís, 2021; Fournier et al., 2019; Muñoz Calvo, 2018). A study by Fournier et al. (2019) showed the presence of pesticides in the waters draining into Golfo Dulce, a semi-enclosed bay on the southern Pacific, and highlighted the high contribution of Coto River to the overall input into the Bay (Lei, 2002). Similarly, our results show the flow of pesticides down the Térraba River through the wetland and into the sea, more specifically through Boca Chica.

Regarding biomarker responses, the clear seasonal difference in biomarkers and water characteristics should be considered when discussing these results, particularly in the rainy season, when Boca Chica showed hydrological differences compared to the other two sampling sites. The low salinities detected in Boca Chica, indicating the prominent share of river water, could be influencing biomarker responses in this site, therefore making difficult the comparison with the other two sites. Additionally, this salinity difference could be causing differences in reproduction as *A. tuberculosa* reproduction has been connected with high salinities (Vega, 1994). Organisms in Boca Chica did not show the change in the reproductive state found in the other two sites, which could be affected by the differences in salinity reported. However, as statistical analyses did not find a relationship between the reproductive state and any of the biomarkers studied except ChE. This difference in the reproductive state between sites should not affect our biomarker assessment. In the case of ChE, our analyses indicated that the detected response differences between sites applied equally to both reproductive state categories.

All this considered, the observed ChE activity decrease in Boca Chica during the dry season is consistent with the presence of ChE-inhibiting pesticides, such as ethoprophos, previously described to affect growth, reproduction and behaviour in marine organisms (Baldwin et al., 2009; Sandoval-Herrera et al., 2019). Similarly, increased GST activity has been previously related to pesticide exposure in bivalves and fish (Lerebours et al., 2023; Mena et al., 2023). However, it should be noted that ChE activity in bivalves has previously not been regarded as a suitable biomarker for pesticides because its activity shows seasonal variation, as observed in the present study (Damásio et al., 2010).

The significant inhibition of EROD enzymatic activity during the rainy season should also be remarked. A strong and significant decrease in EROD activities has been reported in bullhead, eel and rainbow trout exposed to organotins (van der Oost et al., 2003). It was unknown whether inhibition observed in field studies was due to pesticides, other factors, or a combination of both. Payne et al. (1996) suggested that complex mixtures of contaminants, other than pesticides, could be important sources of ACHE-inhibiting compounds in the aquatic environment; they provided preliminary evidence for ACHE inhibiting activity present in extracts of used engine oil and wood leachate (van der Oost et al., 2003).

Water scarcity can amplify the effects of water pollution by reducing the natural diluting capacity of rivers. Interactions between stressors may be exacerbated by climate change. For instance, warmer temperatures and reduced river flows will likely increase the physiological burden of pollution on the aquatic biota, and biological feedback between stressors (e.g. climate change and nutrient pollution) may produce unexpected outcomes.

6.5 Conclusions

Our findings suggest a plausible association between pineapple cultivation and the observed impact on the wetland aquatic environment, based on the geographical distribution of these substances and their utilization in pineapple production. Furthermore, the study supports the potential to evaluate biomarkers in *A. tuberculosa*, particularly GST and ChE activities, to investigate pesticide effects in coastal systems potentially affected by pesticide contamination, as they showed differential responses in the sampled sites. However, it also identifies potential issues and paths of investigation to define the baseline values of such biomarkers. Future studies should focus on biomarker responses in *A. tuberculosa* at low salinities to further assess the potential of this species as a bioindicator, as this study indicated the wide salinity range to which it is exposed in the wetland area. Similarly, the differential responses depending on the reproductive state should be further investigated. The measurement of biomarker responses over time, in caged organisms exposed in situ should be considered.

The significant inhibition of EROD activity as a biomarker and the no significant induction of biomarkers in areas with significant contamination by pesticides should be further analysed, since it might be showing the presence of contaminants that inhibits EROD activity, such as organotins, or antagonist effects in relation to the mixture of contaminants.

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Appendix 2

Triggering the apparitions:
Spectres of chemical seascapes

Maria Soledad Castro-Vargas
Diana Barquero Pérez

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Chemical geographies in the Anthropocene

Synthetic chemicals are intrinsic to the Anthropocene's landscapes (Figure 11.1). Industrialization represented a historical landmark, as itdevised the fabrication and dissemination of synthetic chemicals capableof disrupting living organisms. Since World War II, their manufacture expanded geographically and increased exponentially, pointing to a dramaticphase of the Anthropocene (Arcuri and Hendlin, 2019). The rising production of these substances is not only considered one of the main agentsof global change, but also evidences a clear imprint of the Anthropocene(Bernhardt, Rosi and Gessner, 2017).

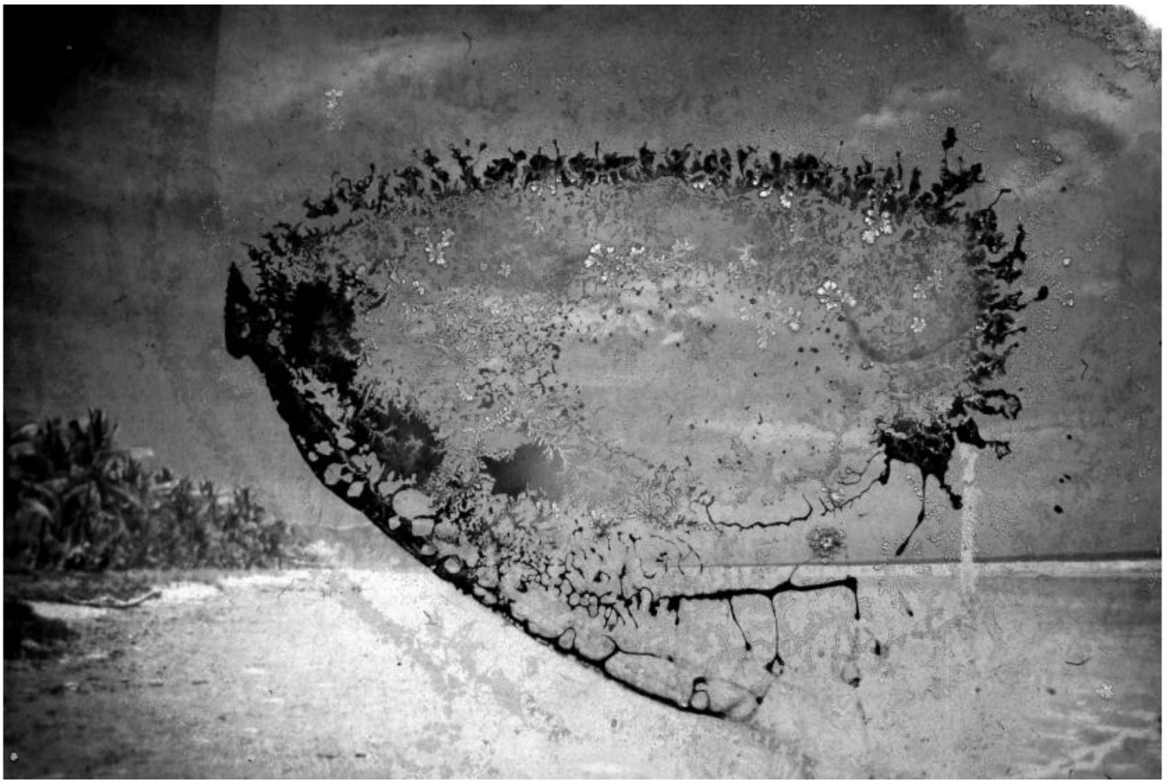

Figure 11.1 Altered photograph from Carlos Flores's personal photo archive, 2018.

During the past decades, contaminants of emerging concern (CECs)appeared in the scenario. CECs represent a novel environmental and healthrisk due to their adverse impacts (Naidu, 2016). Pharmaceuticals (e.g. Ibuprofen, tranquilizers, antidepressants), lifestyle compounds (e.g. caffeine,sweeteners, nicotine), personal care products (e.g. UV flters present in sunscreens and makeup, fragrances), drugs (e.g. cocaine, heroin), food additivesand hormones, among others are classifed as CECs. These compounds arepresent in marine ecosystems due to human activities, entering principallythrough wastewater. Nevertheless, there are major knowledge gaps abouttheir environmental impact, behaviour, effects, and their potential to bioaccumulate and biomagnify through the different trophic levels (ÁlvarezMuñoz et al., 2016) (Figure 11.2).

The presence of these substances in marine environments can be studiedfrom different perspectives. Environmental science disciplines, such as ecotoxicology, investigate the effects of contaminant exposure on all organismsin the biosphere, including humans. However, it is diffcult to determinehow the impact of a chemical substance can interact at

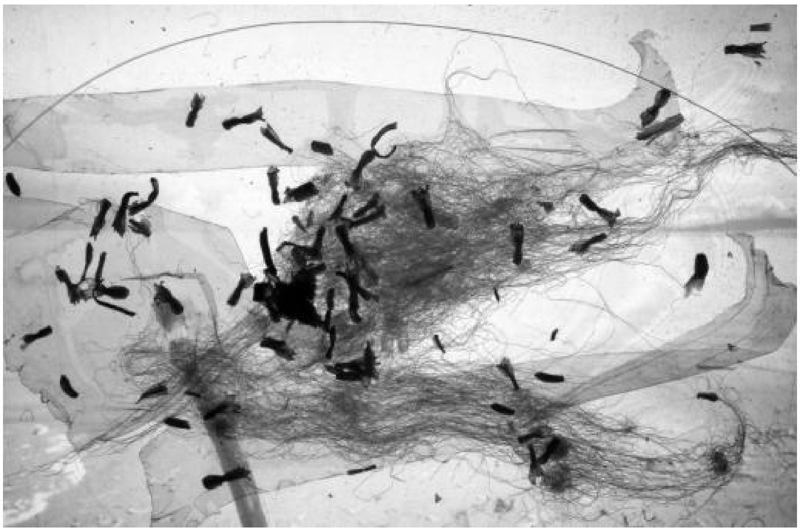

Figure 11.2 Altered photograph from Diana Barquero's personal photo archive,

a molecular leveland propagate at population and community levels. Furthermore, there is alack of understanding concerning the complexity of contaminant mixturesor "chemical cocktails" and their interaction with climate change stressors such as temperature, salinity and acidifcation (Stauber, Chariton andApte, 2016; Kaushal et al., 2018). In social science and humanities, there isan increasing interest in analysing the relationship between chemical substances and socio-natures, referred as the "chemical turn". From a chemicalperspective, questions have arisen about the ontology and metabolism ofthese substances between the living and more-than-living (Romero et al.,2017; Balayannis and Garnett, 2020). Chemical geographies gather different disciplines that share the common interest of thinking through syntheticchemicals: how these substances are embedded in the contemporary world(Romero et al., 2017) (Figure 11.3).

In an attempt to imagine the chemical geographies of the Anthropocene,we use the seascape to approximate evocations that the sea continuouslyawakens. The notion of seascape is broad and ranges from concrete conceptualizations in felds such as geographic sciences (e.g. spatial planning)to other more abstract elucidations, which understand seascape as a representation of the ideas we have constructed about the sea (Pittman, Kneiband Simenstad, 2011; Ingersoll, 2016). Our approach to the seascape concept brings

Figure 11.3 Altered photograph from Gonzalo Iglesias's personal photo archive,

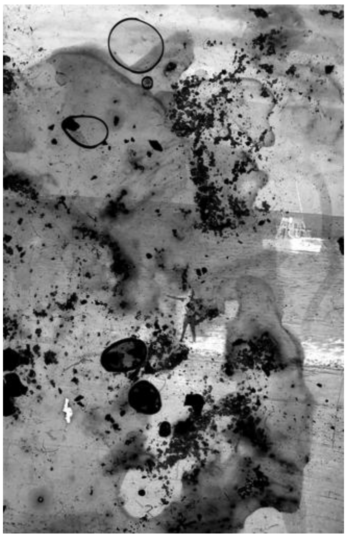

Figure 11.4 Altered photograph from Oscar Jara's personal photo archive,

into dialogue two contrasting stances. On one side, an anthropocentric perception sustained by human experiences and its subsequentlyimage production, in contraposition with the less perceptible relationshipsbetween chemicals and marine ecologies: the subterfuge of what happens ona non-perceptible molecular level. We draw near the debates about the Anthropocene that moves beyond its original conceptualization from physicalsciences, towards notions such as Capitalocene or Chthulucene that incorporate a myriad of capitalism in the web of life and the relevance of tentacular thinking in times of living and dying together (Haraway, 2016; Moore,2017) (Figure 11.4). Figure 11.4 Altered photograph from Oscar Jara's personal photo archive, 2018.

A wide variety of blasted landscapes are spreading across the globe, affecting relations of life in diverse ways (Tsing, 2014). Degraded landscapesare unevenly distributed, as a consequence of the externalization of coststo sustain neoliberal lifestyles (Murphy, 2012). Pollution is one face of thegeometries of blasted landscapes. Synthetic chemicals have penetratedeverything. The contamination that confronts us is disruptive. On the otherhand, contamination binds us, it opens pathways to sustain other possibleencounters and belongings (Tsing, 2015). While it is crucial to defy and resistpollution, it is also meaningful to overcome troubled notions of purity. AsShotwell indicates, "purity practices – in ideology, in theory, in practice –work to delineate an inside and an outside; they are practices of defininga 'we'" (Shotwell, 2016, 13). Purity practices produce an idea of normativity, delimiting what is good and desired and what is not, which reinforceseparation and unevenness (Shotwell, 2016). Hence, it is not about accepting contamination and its consequences, it is recognizing that we live ina "permanently polluted world", with the contradictions and challenges itembraces (Liboiron, Tironi and Calvillo, 2018: 343) (Figure 11.5).

Engaging with the exercise of exploring how chemicals are embodied inseascapes we inquire the following questions: what do chemicals representbeyond their physical-chemical expression? In which way does the phantasmagoria enable us to understand the current chemical age and to re-imaginethe Anthropocene? This project responds to a collaboration between arts,political ecology and critical geographies, pursuing multiple stories andrelationships between chemicals and waterscapes in the production of socio-natures. In the active interplay contaminants have with sentient andnon-sentient parts of marine ecosystems, sea stories remain mysteriousand unanswered. CECs create dystopias not imagined before, of a seascapehaunted by our own ghosts (Figures 11.6 and 11.7).

Figure 11.5 Altered photograph from Gonzalo Iglesias's personal photo archive,

About spectres and phantasmagorias

A central part of our project deals with fear. Fear and discovery of something that haunts us, that approaches and pushes us towards death. It isthe recognition that something is not right. We cannot grasp it because it iselusive, intermittent and indeterminate. However, we know of its presence;in its furtive nature it leaves traces and vestiges of its appearance.

What are we afraid of? Death, the end of the world, the apocalypse. Latediscovery of occasioned destruction. We remember the image of WalterBenjamin's angel, with constant destruction appearing before his feet, in theunstoppable flight driven by the wind of progress (Benjamin, 2002). On hisway to the future, that we imagine with terror, this angel has realized thatthere is no further path, he has destroyed everything. Everything we produce, consume and use reappears. We sweep the dirt under the carpet and itappears in our throat (Figure 11.8).

In this gloomy scenario, we must converse with the spectres that arise. The spectres that appear from this destruction can teach us to live better. "If it—learning to live—remains to be done, it can happen only between lifeand death." (Derrida, 2006: xvii). What happens

Figure 11.6 Altered photograph from Soledad Castro's personal photo archive, 2018.

Figure 11.7 Altered photograph from Laia d'Armengol's personal photo archive, 2018.

in this dialogue betweenboth of them, not separately. For this to happen, the intervention of theghost is necessary. To talk about the ghost and with the ghost, in turbulenttimes loaded with political and ethical longings, must be driven and basedon respect for those who are here, who will arrive and who eventually willdie. This learning to live means to live in another way, "not better, morejustly" (Derrida, 1995: 12–13). It is then justice that mobilizes us to createan idea of the world that incorporates the dead (future and past). The ghostenables us to think about it. It wanders between the material and the immaterial, between the past and the future, disjointing the relationship between the two. This dislocation between material and immaterial appearsas capitalist spectrality, with the commodity fetishism and its abyss betweensymbolic value and real value (Figure 11.9).

Commodity fetishism, studied by Marx, has been re-appropriated underthe fgure of the spectre by Derrida and Benjamin. For Benjamin (2002),the phantasmagoria refers to the ideological concealment of capitalist society's commodities. Commons become fetishized when the exchange valueis disjointed from its use value, situating the value of the commodity as a spiritualized feature of itself. Therefore, the phantasmagoria shows thesesupposed fxations between the object and the symbolic meanings. We understand

Figure 11.8 Altered photograph from Daniela Mora's personal photo archive, 2018.

Figure 11.9 Altered photograph from Oscar Jara's personal photo archive, 2018.

CECs, which are residual elements of consumer goods, as arisingtraces of the spectre of the commodity. The ghost arises in the midst of thisdisplacement between the material and the symbolic. Its residue is a returnto its materiality, it is what remains of the object. This materiality pointsto the ghost but in its separation, in its carcass. In this way, the ghost isnot attached to the object, but corresponds to it. Just as when we observe acorpse, we cannot think about it without its previous animation, we cannotsee the contaminants without its phantasmagoria. This material carcass ofthe spectre in turn functions as a remainder upon death (Figure 11.10).

Apparitions from the Anthropocene: artistic procedure

The artistic procedure consists of a photographical archive from differentpeople about their experience with the sea. The archive was made in collaboration with persons from distinct latitudes who were invited to respond tothe following questions: how does the sea relate to your life? How could you synthesize in an image your relationship with the sea?

Figure 11.10 Altered photograph from Soledad Castro's personal photo archive, 2018.

Figure 11.11 Altered photograph from Sara Granata's personal photo archive, 2018.

The answer to these questions resulted in a series of digital photos, in some cases with little personal stories attached to them. It became crucial to convert the archive intophysical or material images. Hence, we transformed the virtual photographsonto slide-flm, which is a positive image in a transparent base. Afterwards,we altered the materiality of the flm by using various sources of CECs commonly employed in homes, such as coffee, sunscreens, pharmaceuticals andfragrances, among others. In this procedure, we display the materiality ofthe pictures with the traces of CECs as a way to interweave contaminantswith our symbolic construction upon the sea. The result was presented asa lecture performance, where the flms appeared and disappeared throughtime by using a slide projector as a phantasmagoria apparatus1. The fnalknot consisted of returning the altered virtual images to the involved participants, to bind the discourse between CECs, personal memories and blastedseascapes (Figure 11.11).

Conclusions

The phantasmagoria describes the apparent fxation of cultural productswith their symbolic meanings (Benjamin, 2002). The contemporary chemical merchandise functions as ways of solving health problems or enhancing productivity. These solutions become the spiritual value behind theconsumer products, which, although functional, also reveal a character of"semantic surplus value". They offer a chemically improved lifestyle in aFigure 11.12 Altered photograph from Sara Granata's personal archive, 2018. consumption. For Benjamin, phantasmagoria apparatuses project imagesover the real world, creating an undifferentiated unity. The symbolic surplus is undifferentiated from the materiality of the commodity in CECs,leaving not visible but existing polluted traces behind. These contaminants,conceived as necessary in capitalist societies, mark a sign and dictamen ofour time, our fetishes and needs. They reveal hidden emotions, desires andideals – unveiling in their rhythm of production and consumption, the voracity inherent to the Anthropocene era.

The process of destruction and alteration of the photographs seeks notonly to visualize the life and dynamism of chemical materials after their use,but also to unfold, through images, the phantasmagoria behind our gazeupon the sea. The appearance of the traces left by chemical spectres mutatesand deforms the bucolic anthropocentric images of a pristine sea that has already disappeared, or maybe never existed (Figure 11.12).

Note

1 Phantasmagoria apparatuses were a family of technical objects whose operationconsisted in projecting images onto the real world, so that both the real and theprojected image were confused, producing horror and astonishment in the eighteenth century.

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Appendix 3
Latin America in the Chemical Vortex of Agrarian Capitalism

Maria Soledad Castro-Vargas

Finn Mempel

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Abstract

Agri-food systems and their embeddedness in global capitalism play a key role in the environmental history of Latin America. In this chapter, we explore how the conception and use of chemical substances have been related with the development of agrarian capitalism in the region. Our analysis incorporates a chemical geographies lens, which describes an emerging interest in chemistry and chemicals in the study of the human relationship with the living and the more-than-living world. We do so by analyzing how agricultural items have increasingly been recast as carriers of chemical components to open up new circuits of capital accumulation and by investigating the incursion of industrial capital into pest management, leading to an increasing dependence on synthetic pesticides. We conclude that this industrial appropriation via chemicalization has left long-term legacies, but also highly dynamic processes, which have shaped agricultural landscapes, social relations, and socio-environmental health in Latin America.

Introduction

In this chapter, we explore how the conceptualization and use of chemical substances are related to the development of agrarian capitalism in Latin America. Our analysis incorporates a chemical geographies lens, which examines chemistry and chemical substances to rethink the human relationships with the living and more-than-living world. These insights seek to uncover how chemicals are embedded in the co-production of socio-natures (Romero et al. 2017).

Patterns of capitalist accumulation have determined particular configurations of the global food system, including their relationship to off-farm inputs, especially chemicals and fertilizers. Friedmann and McMichael (1989) conceptualize these temporarily stable configurations as distinct food regimes, a concept we deploy with respect to Latin America. During the first food regime (1870–1930s), Latin America constituted a source of cheap food and raw materials that supported the industrialization of Europe. The second food regime (1950s–1970s), characterized by United States (U.S.) hegemony, involved the mechanization and "chemicalization" of agriculture production through the imposition of industrial agriculture, and saw a movement of 'surplus' food from the U.S. to Latin America (Bernstein 2016). The contemporary food regime has been determined by the mechanisms of agricultural financialization that emerged in the 1970s, together with the structural adjustment programs of the 1980s that dismantled the state-led institutional arrangements built during the former regime. The role of the private sector became central, placing the state on a secondary plane supporting 'market rules' (Patel 2013; Werner 2021). Governments reduced social services and agrarian subsidies while they promoted non-traditional export agriculture. In contrast to the previous regime dominated by the U.S., the neoliberal policies of the World Trade Organization have yielded a multipolar political arrangement dominated by a small number of multinational corporations (McMichael 2020).

One can think chemically about the evolution of Latin America's role in global food regimes from various angles and relate to different aspects of agri-food value chains (see Figure 13.1). Our analysis explores how different types of industrial off-farm capital have

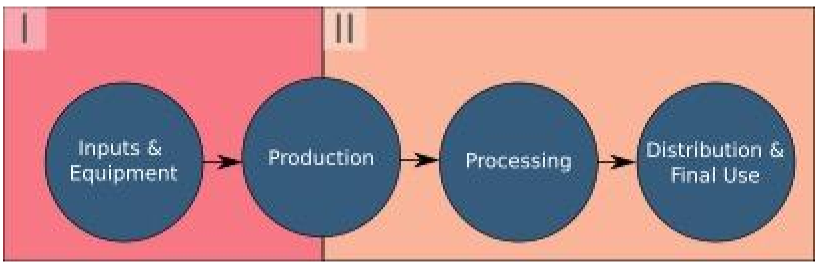

Figure 13.1 Industrial appropriation by off-farm capital. I. Inputs. II. Processing and final use.

appropriated agricultural production through chemicalization. Firstly, we examine how patterns of boom and bust relate to agricultural items' chemical properties, defining their appropriation in industrial circuits of accumulation through processing and final applications (section 13.2). We then analyze the role that pesticides have played in the development of industrialized agriculture in Latin America (section 13.3). It will become apparent, through our analysis, that the function of pesticides or the processing and final use of commodities transcend that of a mere material input or output. Rather, each of the nodes presented in Figure 13.1 constitutes a coupling between nested value chains in a complex network, through which industrial capital operates by transforming each node with possible effects on all connected parts of the network.

Commodity booms and the dynamics of sociometabolic circuits

Modern agriculture and the chemical gaze

Links between agriculture, food, and industrial chemistry have become ubiquitous since the early 20th century, accompanied by an emerging set of perceptual patterns, which Landecker has dubbed the "chemical gaze" (Landecker 2019). This gaze is a quintessential modernist approach to nature that dissects agricultural products and processing wastes into their biochemical components and creatively remakes them within industrial metabolic circuits. It thereby recasts agricultural products as substitutable carriers of matter.

A given configuration or alteration of these metabolic pathways is intrinsically linked to a mode of production and social relations. This becomes obvious when examining the Industrial Revolution and its dependence on colonized territories, slave labor, and rural dispossession enabling flows of cotton wool feeding the textile industry and cotton seed processed into vegetable oil and animal feed. The history of food and agricultural systems can then be read through the way in which these sociometabolic pathways have been initiated, altered, or rearranged over time and how these processes relate to broader social structures.

Industrialization, protectionism, and substitution: Rubber

An early example of the tight coupling between the chemical industry and agriculture was the rubber booms and busts in the Amazon region during the first food regime. Natural rubber became an increasingly important raw material through the scientific discoveries of various rubber solvents and, most importantly, the discovery of sulfur vulcanization in the 1830s (Guise-Richardson 2010). These advances in the chemical industry allowed for a diverse range of new applications for rubber and led to its ubiquity in the industrial world.

Brazil was the dominant source for wild rubber from the native Hevea brasiliensis, which in turn evolved into a mainstay of the country's economy, surpassed only by coffee in terms of export revenue (Dean 1987). This first rubber boom (1879–1912) was characterized by enormous wealth accumulation in the hands of rubber barons, the exploitative subcontracting of seringueiros, and the enslavement and brutal extermination of Indigenous communities. It would shape social relations in the regions for subsequent commodity booms (de la Rosa 2004). Plantation-style rubber cultivation in East Asia brought the first rubber boom to an end as new supplies and production methods depressed prices (Garfield 2011, 71–72).

The 1920s also saw the emergence of the Chemurgy movement in the United States. The movement's goals were threefold: to find new processing pathways for agricultural commodities in industrial products, to revive the domestic agricultural economy and to decrease dependence on imported items (Finlay 2004). Given the dependence on rubber imports from Brazil and East Asia for U.S. industry and the military, the movement pushed for a biomass-based rubber substitute. Hope was placed on the rubber extraction from the guayule plant, native to deserts in the U.S. West, and on the development of synthetic rubber from biobased alcohol.

When the U.S. was cut off from the East Asian rubber supply during World War II, the Rubber Agreement between the Brazilian Vargas government and the United States led to a second, short-term rubber boom (1942–1945) in the Amazon region (Garfield 2011, 226–27). The Chemurgy movement was ultimately unsuccessful in its advocacy for a biomass-based rubber substitute and, in the long run, petroleum by-products, such as styrene and butadiene, became the dominant feedstock for new synthetic rubbers. These began replacing natural rubber for many applications in the postwar period. More generally, the petrochemical boom, with its center in the U.S. Gulf Coast, became the basis of modern organic chemistry while Chemurgy's dream of biomass-based feedstocks was reduced to micro-level applications in the postwar economy and only to be revived decades later (Finlay 2004).

Evolving metabolic pathways in the post-war era: Soybeans

The demise of the first rubber boom coincided with the general collapse of the 19th-century wave of globalization, after World War I. Across Latin America, widespread adoption of import-substitution industrialization (ISI) policies followed, which sought to end dependence on the exportation of primary commodities and led to a net decrease in the region's share of global agricultural trade (Baraibar Norberg 2020, 79).

In the search for new markets for the large surplus of U.S. agricultural produce following World War II, the U.S. government and private companies sought new industrial applications for individual biochemical components of various agricultural commodities or their processing wastes. Some of these applications would become the basis of commodity booms in Latin America during the contemporary food regime. Soybeans, sugarcane, maize, or oil palms are grown not merely as food items, but as raw materials for a complex network of metabolic pathways, which expanded rapidly after the postwar era (Borras et al. 2016).

A good example of this development is the soybean boom across Brazil and much of the Southern Cone countries. Like rubber, soybeans first made their way into global industrial metabolic circuits in the first wave of globalization before World War I. Starting in the 1890s, Japan used its imperial enterprise in northeastern China to import soybean meal to serve as nitrogen fertilizer in its bid to rapidly intensify agriculture (Hiraga and Hisano 2017). Soybean oil, an excess product of soybean meal processing, would soon be shipped to Europe and North America, where it was embraced as an ingredient for margarine, shortening, soap and paints at a time of great demand for vegetable oils for industrial applications (Prodöhl 2013).

This separation into oil and protein fractions has remained the basis for the successful commercialization of soybean products and has generated other by-products, which have found their own applications (e.g., soy lecithin). After World War II, when the United States had become the largest producer of soybeans, soymeal became the excess product of oil extraction, since it had lost its prior role as a meat substitute in civilian diets during World War II (Prodöhl 2013; Du Bois 2018). After a series of breakthroughs in making soybean cake more suitable for animal diets by removing anti-nutritional factors (Barros Dourado et al. 2011), soybean protein rapidly evolved into a cornerstone of surging mass poultry and swine production systems in the U.S. and Europe.

The rapid expansion of large-scale export-oriented soybean production across Brazil, Argentina, Paraguay, and Bolivia has occurred in the contemporary food regime in a context of deregulation, and the general embrace of biotechnology and large agribusiness. However, as shown above, the soybean boom is a product not only of neoliberal policies, but also of the restructuring of industrial metabolic pathways since the postwar era, which has resulted in a dominant “industrial grain-oilseed-livestock complex” (Weis 2013) at the global scale. In the case of China, imported soybeans are a cornerstone of the recent surge in concentrated animal feeding operations. The radical transformation from net exporter to largest importer of soybeans was made possible by state-led agroindustrialization and an adjustment of China’s policies relating to self-sufficiency in staple crops. These have redefined soybean meal as an industrial rather than agricultural product (Schneider "B47"2017). The large biomass flows from Latin America to China mirror the reorientation of the former’s trade relations toward the Pacific for its other raw materials, particularly minerals.

The age of chemical versatility: Flex crops

The focus of capital accumulation in the “primary” sector of agriculture and mining, called reprimarización in Spanish, has become dominant since the beginning of the neoliberal wave. This shift inherited many metabolic patterns and industrial applications for cash crops from the postwar era. The new commodity boom began to feed into global industrial circuits, just as the U.S. agricultural surplus had been doing since World War II. However, the contemporary food regime also came with its own restructuring of these metabolic patterns. Since the late 1990s, the bioeconomy as a policy agenda has revived some of Chemurgy's earlier ideas to substitute fossil resources with renewable biomass sources. The use of renewable feedstocks has also become one of the principles of green chemistry, which aims to reduce the environmental impacts of the chemical industry (Anastas and Warner 1998).

While the Chemurgy movement had advocated for plant-based industrial applications mainly to reduce dependence on imports, the logic behind this new push for biomass-based organic chemistry has been quite the opposite. The chemical industry's hunger for plant-based feedstocks in the neoliberal era has resulted in a new coupling between the sourcing of agricultural items, financialization, and free trade ideology. The basic ingredients for metabolic pathways are increasingly sourced according to the comparative advantage of the production of certain crops, the quality of their biochemical components, and their respective maximum yields per hectare (e.g., corn for starch, soybeans for protein, oil palms for oil). The ever-increasing versatility of these flex crops in terms of their possible end-uses, mediated through the chemical industry, has also rendered them attractive objects of speculation through financial derivative markets and land deals (Oliveira and Schneider 2016).

The dynamic reconfigurations in metabolic patterns in the last decades have once again remade the boundaries between processing products as either waste or commodities. In the case of soybeans, the protein meal, which was mainly the excess product of oil extraction in the mid-1940s, became the economically most relevant component due to the grow in concentrated animal feeding operations, most recently in East Asia. While the oil component has long been important in industrial applications and as a cooking oil, its recent application for biodiesel fuel production through the chemical process of transesterification has further diversified its end-uses and greatly increased its value.

With the expansion of oil palm plantations, the increasing availability of a cheap and easily fractionated vegetable oil has positioned palm and palm kernel oil as extremely versatile raw materials in a myriad of metabolic pathways with different end-uses since the 1980s. In the case of personal care items, a shift in consumer preference towards plant-based ingredients led to a widespread application of palm oil to replace animal tallow as feedstock for synthetic surfactants. Tallow had often been locally available as processing waste from the meat industry, while oil palm plantations are concentrated in a limited number of tropical regions, including parts of Latin America.

Nutritionism and superfoods

Thinking chemically opens up additional perspectives on the evolution of nutritional science and dietary advice and their links with food marketing. Following Gyorgy Scrinis in his characterization of the ideology of "nutritionism" (Scrinis 2008), we can observe how a reductionist understanding of food to the biochemical or nutrient level has become dominant. Nutritionism has evolved from a mere focus on the quantification and sufficient intake of core nutrients (e.g. calories and protein) to include concerns over excess consumption and finally into a new form of functional nutritionism. This latest stage seeks to optimize health and bodily performance by emphasizing beneficial properties of ever more subcategories of biochemical components (e.g. omega-3 fats) for specific needs or conditions.

Through this focus, nutrients become isolated from traditional food items in the form of synthesized supplements or additives, but certain niche food items also become fetishized due to their biochemical composition in line with a belief in associated health benefits. This is particularly visible in the discourse on superfoods, which regularly uses specific health claims along with a focus on non-Western, 'authentic,' traditional, or Indigenous food items to open new niche markets (Loyer 2016). Latin American traditional and Indigenous food items, such as açai berries, chia seeds, maca, or quinoa have been at the forefront of this trend, which sits uncomfortably between ethical, environmentally conscious, fair-trade consumption culture on the one hand, and racist cultural essentialism and commodification on the other hand (Loyer and Knight 2018).

Latin America in the global pesticide complex

A brief history of synthetic pesticides

When analyzing food regimes from a chemical perspective, pesticides are a crucial element of this history, since they have facilitated the transformation of agrarian landscapes to the rhythm of capital accumulation patterns. The history of pesticides can be analyzed through three main phases: (1) Use of non-synthetic pesticides (prior to the first food regime); (2) the production of inorganic synthetic pesticides (during the first food regime); and (3) the production of organic synthetic pesticides (starting with the transition to the second food regime) (Zhang, Jiang, and Ou 2011). This last phase began with the development of dichlorodiphenyltrinchloroethane (DDT) during the World War II, which became available for agricultural purposes in 1945. It inaugurated an era of synthetic organic pesticides (Özkara, Akyıl, and Konuk 2016).

Four key aspects stand out in the history of pesticides. First, since the beginning of industrialized agriculture, pest control has been inextricable from, and has co-evolved with, chemical warfare ideologically, techno-scientifically, and organizationally (Russell 2001; Romero 2016). Second, science has played a crucial and ambiguous role, not only collaborating in the production and dissemination of these substances, but also by contributing to parameters and accepted ideas about their regulation (Boudia and Jas 2014). Third, the use of certain substances has been a cyclical process between their creation, the rise of concern about their effects and resistance-related issues, and their consequent regulation or prohibition. This has occurred in the case of insecticides with the shift from organochlorines to organophosphates and then to pyrethroids and to neonicotinoids (Davis 2017). Fourth, the intensive use of pesticides, their regulatory policies and socio-ecological effects have been historically and geographically shaped unevenly across the globe (Bertomeu-Sánchez 2019; Shattuck 2021).

From the circle of poison to the global pesticides complex

The institutional and technological groundwork for the second food regime lies in the Green Revolution, inaugurated in the 1940s when the Rockefeller Foundation launched a process of transformation of agriculture, seeking to develop varieties of high-yielding grains (Galt 2014). The concept of the "Green Revolution," first coined by William Gaud, described the results that the U.S. had achieved by funding developing countries for crop production, combining the use of fertilizers and agrochemicals with hybrid seeds, irrigation, and soil management techniques (Picado 2012). The U.S. government, with the collaboration of recipient governments and the World Bank, performed this large-scale philanthropic intervention, aimed to fight Communism (Patel 2013). The project was consolidated in the 1960s, when the agro-industrial production system was exported to the Third World by private foundations and international development agencies (Clapp 2012).

The relationship between global North and global South in terms of production, commercialization, and socio-environmental exposure to pesticides has been the subject of much debate. The circles of poison concept, introduced by Weir and Schapiro in 1981, described uneven relationships in pesticide geopolitics. It captured how particular pesticides are banned in the global North, but still produced for export to the global South. Due to the promotion of export-led agriculture in the global South, pesticides would then return to their manufacturing place as pesticide residues in fruits and vegetables (Weir and Schapiro 1981). Although 'circles of poison' constitutes an umbrella term relevant to a body of scholarship in political ecology and environmental justice, it is not in itself sufficient to explain the intricacy of pesticide networks. The concept of the 'pesticide complex' proposed by Galt (2008) emerged from these discussions, highlighting the need for new empirical data and global information about pesticide use, trade, regulation, exposure, and effects. This framework refers to "all aspects of pesticides' lifecycles from conception to environmental fate and arises from overlapping spatial patterns of pesticides in the world" (Galt 2008, 786).

The geometry of the pesticide complex has been rearranged due to three major shifts in the agrochemical industry in the first two decades of this century: First, a decrease in the number of new patents along with the expiration of old patents; second, the consolidation of the generics industry; and, third, the positioning of China as a global leader in the pesticide industry (Shattuck 2021; Werner, Berndt, and Mansfield 2022). Despite the increasing use of pesticides at a global level, the number of new patents for active ingredients (AIs) has steadily declined from 13 new patents of AIs per year during the 1990s to 7 per year in the 2010s (Haggblade et al. 2017). Additionally, the cost of research and the registration process for new AIs in pesticides is estimated to be more than $286 million, taking an average of 11 years until they are released to the market (Mcdougall 2016). Consequently, the pesticide industry has focused on the development of new pesticide formulations that mix off-patent AIs with co-formulants to respond to pest resistance. The boom in off-patent herbicide formulations and the fact that they are the most widely used type of pesticide across the globe, especially in the Global South, is referred to as the herbicide revolution (Haggblade et al. 2017).

While the global pesticide complex has penetrated into deeper layers of human and non-human lives, its causes and consequences are more indecipherable than ever. According to Shattuck (2021), three aspects stand out as a result of this continuously transforming process. First, pesticide use and dependence has increased, particularly in the global South. Second, its production core has shifted from the global North to the global South, with the predominance of China and India in the market. Third, although the current configuration of the pesticide complex touches more people, it is even more difficult to study due to lack of access to information, particularly for those most affected. China's rising centrality to the global food system, with its particular state-led participation in global markets, deserves attention (McMichael 2020). As Werner, Berndt, and Mansfield (2022, 14) point out, "in the new map of chemical ubiquity, middle-income countries are also principal producers, exporters, and end markets in a geography characterized by new south–south dynamics.". These large-scale market dynamics have transformed relationships between chemicals and socio-natures, into new spatial configurations and power relationships that require a hard look. Interactions between the state and agrarian capital and within each of these spheres deserve special attention to comprehend changes (e.g., regulatory tension in Costa Rica) (Jansen 2017; Castro-Vargas and Werner 2022).

Tracking the pesticide treadmill

Latin America and Asia have been the regions of the world where pesticide use has grown the most during the past decades. From the 2000s to 2015, the Latin American pesticide market grew from a value of $4 billion to $12 billion (Shattuck 2021). This dramatic increase has led to several problems, such as the pesticide exposure of workers and rural communities; the presence of pesticide residues in food, soil, and groundwater; and environmental degradation (Bertomeu-Sánchez 2019). Unfortunately, the issue remains understudied, resulting in a lack of knowledge about the use and effects of these substances (United Nations 2017).

The Green Revolution and its implications remain salient to our understanding of the contemporary pesticide complex for several reasons. First, the Green Revolution laid the foundations for the 'pesticide treadmill,' an ecological feedback loop that involves the disruption of agro-ecosystems with pesticide use, and the subsequent development of biocide resistance and pest resurgence, which results in a constantly increasing dependence to pesticides (Nicholls and Altieri 1997; Murray 1994). Second, the Green Revolution constituted an agri-biopolitics, understood as "a political technique that made certain populations of humans thrive alongside companion crops" (Hetherington 2020, 1). Third, from its early inception, the Green Revolution has been a violent process. Pre-existing colonial structures were re-organized and reformulated through development policies, providing the conditions for the expansion of the agricultural frontier, and displacing Indigenous peoples and peasants. This reinforced the racist, enslaving and settler colonial logic of plantations (Murray 1994; Hetherington 2020; Williams 2018). In short, the Green Revolution is best understood as a long, enduring process, with multiplate configurations, that continues to shape the present, as proposed by Patel when he asks when, exactly, was the Green Revolution (Patel 2013).

During the second food regime, Central American banana and cotton plantations were characterized by a very high use of pesticides that affected the socio-environmental health of rural communities and workers. Cotton cultivation during the twentieth century, promoted by U.S. development agencies using state subsidies, contributed to position Latin America as the Third World's leader in intensive pesticide use. Banana plantations abruptly transformed landscapes and the interaction among people, plants, and pathogens, developing a tropical-based production system, fully based on chemical inputs (Soluri 2005). From the 1940s to the 1960s, more than 12,000 workers each year applied intensively copper sulphate to combat Sigatoka disease. The fight against this fungus was arbitrarily dictated by techno-scientific specialists, at the expense of the health of workers or periqueros, so-called because of the blue tone of their skin from chemical applications (Marquart 2003). Later, in the 1960s and 1970s, the toxic nematicide DBCP produced by Dow and Shell, was broadly applied in banana plantations. Its widespread use led to severe health consequences, from permanent infertility to psychological trauma, for more than 30,000 workers. As Mora Solano (2014) points out, the environmental suffering of workers affected by DBCP is a direct consequence of production dynamics and it exemplifies how environment and bodies are inseparable. In both cases, the agri-biopolitics of the Green Revolution established a phytosanitary protection regime safeguarding certain plants for the abstract wellbeing of selected people, at the expense of the lives of others (Hetherington 2020).

In the contemporary food regime pesticide use intensified, due to the growth of global food market and the availability of fresh products all year round. Moreover, the number of pesticide users increased, since small-scale farmers not only began to participate in the export crop market, but also to incorporate chemical inputs in their own farming (Nicholls and Altieri 1997; Murray 1994; Galt 2008). Pesticides have become pervasive in agricultural landscapes, carrying with them logics of violence while also interacting with colonial and racist legacies. In Colombia, the use of the herbicide glyphosate for coca eradication campaigns demonstrates the persistent links between pesticides and chemical warfare, constituting an ecocide through instantaneous, structural, and slow violence (Meszaros Martin 2018). Furthermore, the regulatory process of glyphosate shows the agri-biopolitical nuances around its discussion, which have managed to separate health concerns of individual bodies from those of social and political bodies (Silva 2017).

Pesticide pollution has also constituted a mechanism of dispossession. For Camacho (2017), Martínez Sánchez (2019) and Hurtado and Vélez-Torres (2020), pollution represents a subtle and violent process that undermines social production and reproduction of daily life and, at the same, time re-signifies it. As part of this re-signification, communitarian feminism has consolidated the concept of the body/territory as a unity, which understands health and healing as a shared path. According to Cabnal (2018, 103), "defending the territory/body entails to assume the body as a historical territory in dispute with ancestral and colonial patriarchal power, but we also conceive it as a vital space for the recovery of life." Even though the global South holds multiple sacrifice zones, conceived as spaces of environmental suffering which are intrinsic to the logic of uneven development, these have also represented places to weave resistances into the administration of death (Olmedo and Ceberio De León 2021). Pesticide pollution both exacerbates other oppressions and injustices and extends and amplifies fields of struggle that have been established in the defense of life (Martínez Sánchez 2019).

Conclusions

In this contribution we have analyzed how industrial capital has increasingly appropriated agricultural production in Latin America through chemicalization. This process recasts plants, seeds, trees, and their products as carriers of chemical components, initiating new sociometabolic pathways and thereby new circuits of capital accumulation. Further, the incursion of industrial capital into pest management has increased the use and dependence on synthetic pesticides and propagated a model of input-intensive agriculture.

We have shown how this chemicalization has left long-term legacies, such as the industrial grain-oilseed-livestock complex and the pervasiveness of synthetic pesticides in Latin American agri-food systems. However, we have also pointed out highly dynamic processes, such as the shifting geographies of pesticide production and formulation as well as the ever-changing roles of chemical components derived from agricultural items and their fluid existence between waste, by-product, and commodity. These legacies and dynamics have shaped agricultural landscapes throughout Latin America by initiating commodity booms, favoring particular cash crops, and affecting social relations as well as socio-environmental health in rural communities.

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Appendix 4 - Supplementary materials

Interview guide

Guía de entrevista abierta – Agricultores en Palmar Sur

Categoría de análisis	Preguntas
Historias de vida	¿Cuál es su nombre completo? ¿En qué año nació? ¿A qué se dedica? ¿Hace cuánto vive en la zona? ¿Cómo llegó aquí? Profundización: ¿Cómo es la vida por acá? ¿Cómo fue que la gente llegó acá? ¿Qué hace la gente acá para juntarse?
United Fruit Company	¿Usted se acuerda de los tiempos de la bananera? ¿Cómo era en esa época? ¿Qué pasó después?
Agricultura y geografías químicas	¿De qué tamaño es su parcela?¿Le ayuda alguien en la parcela? ¿Por ejemplo, algún familiar o vecino? ¿Qué siembra? ¿Qué problemas ha encontrado en los cultivos? O, ¿cuáles han sido las mayores dificultades? ¿Cómo las ha enfrentado? ¿Qué ha hecho? ¿Qué productos usa? ¿Cada cuánto los aplica? ¿Cuánto dinero gasta (por cosecha u otra categoría de tiempo)? ¿Quiénes le han recomendado esos productos? ¿Qué indicaciones le dieron? ¿Sabe de dónde vienen los productos (CR o Panamá)?
Percepción del riesgo	¿Usted cree que hay contaminación alrededor con agroquímicos (en el humedal/río/canal/quebrada? Profundización: ¿algún lugar o momento en específico? ¿Le preocupa el tema de contaminación con agroquímicos? ¿Ha escuchado algo al respecto? ¿Cuál cree que es el origen de esa contaminación? ¿A quién responsabiliza? ¿Cree que usted puede hacer algo ante esa contaminación? ¿Se siente expuesto cuando aplica agroquímicos? ¿Usa protección? ¿Cree que puede afectar su salud o la de su familia? ¿Ha escuchado de gente que se haya intoxicado, enfermado, envenenado, etc.? ¿Le preocupa la contaminación residual o la exposición crónica o a largo plazo?