Between the Lab and Disaster: The Environmental History of Experimental Oil Spills in Canada, 1970–2000

by

James Wilt

A Thesis submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

Department of Environment and Geography

University of Manitoba

Winnipeg

Abstract

Marine and aquatic oil spills are one of the most visible and controversial socioecological issues of our time. Extensive scientific research has been conducted into the behaviour, fate, and effects of spilled oil in water and shorelines, directly informing response efforts during catastrophes like the *Exxon Valdez* tanker disaster of 1989 and the *Deepwater Horizon* blowout of 2010. However, there has been little study from a social sciences perspective of one of the most important scientific tools used to produce information about spills in Canada, especially in cold-water and Arctic environments: the experimental oil spill, or the controlled discharging of various volumes and types of oil into real-world conditions for the purposes of observing and testing response methods. This dissertation provides a detailed assessment of original scientific reporting about experimental spills conducted between 1970 and 2000—after which they were largely phased-out in the Canadian context—and argues that the findings from this experimental work continue to have important resonances today concerning the perceived ability to effectively respond to spills if and when they happen. Specifically, it demonstrates that this experimental work constituted the active materialization of what Rosemary-Claire Collard and Jessica Dempsey's (2022) have described as the "future eco-perfect," which appeals to an imagined future of science and technology overcoming conflicts between resource extraction and socioecological impacts. It examines five interlinked case studies about the siting, timing, oiling, production of "new natures," and scientific uncertainty in experimental spills. While acknowledging the tremendous capacities of scientific knowledge production in understanding socioecological issues, it suggests that this experimental work significantly overstated the degree of control and response potential in many real-world spills, and downplayed or even ignored an array of unknowns and complexities. It concludes by recommending increased caution to be exercised on the issue, and a re-politicization of oil spill risk in the context of oil industry expansion.

Acknowledgements

This dissertation would not have been possible without the exceptional and patient supervision of Dr. Jonathan Peyton, who provided consistent guidance and support throughout. I am also deeply grateful for Dr. Fabiana Li and Dr. Nicole Wilson, who served on my committee, and Dr. Anna Zalik, who served as external reader; everyone involved in this process offered invaluable feedback that shaped the dissertation in major ways. Dr. Warren Bernauer has also provided regular support and opportunities, which have been greatly appreciated. I would also like to thank the many librarians and archivists who helped locate materials for this research, especially at the University of Calgary, Library and Archives Canada, and the National Science Library. Many thanks to all family and friends who supported me throughout this process, including my partner (Emily), parents (Brenda and Garth), and cats (Stokely and Muggsy). This dissertation draws on research supported by the Social Sciences and Humanities Research Council, along with fellowships from the Clayton H. Riddell Faculty of Environment, Earth, and Resources and the Centre for Earth Observation Science (CEOS).

Table of Contents

Introduction

The diesel spill was *supposed* to be simple to clean up. It happened close to shore, well within range of a potentially efficient response. Marine vessels constantly used the waters as part of a broader "marine highway" stretching from Alaska to the mainland United States via British Columbia's coastline, creating a reasonable expectation of sufficient organizational capacity. And the spill itself was "only" 110,000 litres, or under 100 tonnes: far less than the 10,000 tonnes that spill response organizations in Canada are legally required to be prepared to respond to "within prescribed time standards and operating environments" (Transport Canada 2019). The national spill response regime that response organizations belong to had even been rebranded as "world class" only a few years prior in the wake of an expert panel review and introduction of new measures in anticipation of increasing tanker traffic carrying Alberta bitumen to Asian markets (Heiltsuk Tribal Council 2017, 27).

Yet these factors mattered little when, in October 2016, the *Nathan E. Stewart*—a tug connected to an oil-carrying barge, both owned by Texas-based shipping giant Kirby Corporation—ran aground and sank near Bella Bella, off the central coast of British Columbia, in the heart of Heiltsuk territory. A Transportation Safety Board of Canada (2018) investigation concluded that the grounding was caused by worker fatigue, a single-worker bridge, and a lack of availability and deployment of navigational alarms (53); the second mate who fell asleep on watch prior to the disaster had only slept for an estimated 17 of the previous 72 hours, "equivalent to a normal nighttime sleeper who had missed 1 night of sleep" (*Professional Mariner* 2018; Transportation Safety Board of Canada 2018, 21). In contrast to the trumpeted vision of an efficient and effective clean up, the response was instead "disorganized, chaotic and ineffective … with little to no recovery of product" (Heiltsuk Tribal Council 2018, 42), leading to many costly delays and miscommunications. Equipment eventually provided was "inadequate and the window to deploy the equipment safely had closed due to tide and weather conditions" (Heiltsuk Tribal Council 2018, 42). High winds and tides quickly overwhelmed and broke apart booms intended to corral the oil for recovery (Pawson 2016). Government and industry responders ignored Heiltsuk first responders and failed to provide guidance or adequate protective equipment, resulting in the suffering of acute health impacts from diesel exposure (Heiltsuk Tribal Council 2017, 42; Heiltsuk Tribal Council 2022). This itself continued a long-standing pattern of neglect that included failing to ever consult Heiltsuk about a waived pilotage requirement for Kirby despite the company "operating as an oil tanker and Heiltsuk's expressed concerns about oil tankers in Heiltsuk waters" (Heiltsuk Tribal Council 2017, 25).

The socioecological harms of the spill have been catastrophic and ongoing for the Heiltsuk Nation. Governments have refused to support an environmental review of the impacts, leaving Heiltsuk without a clear sense of potential short-term ecological damage and longer-term legacy effects. Fishing and harvesting marine species in Gale Passage—including manila clam (*Lajonkairia lajonkairii*), northern abalone (*Haliotis kamtschatkana*), red sea urchin (*Mesocentrotus franciscanus*), and herring (*Clupea pallasii*) spawn on kelp (SOK)—have been a vital foundation of Heiltsuk society for millennia (Heiltsuk Tribal Council 2017, 32). Many of these harvesting sites have remained closed in the years since the spill "due to lack of information about the future health of our marine resources" (Heiltsuk Tribal Council 2022). The Heiltsuk Nation's Dáduqvḷá Committee—formed to "assess and adjudicate the Spill in the context of Heiltsuk laws, known as Ǧviḷás" (Heiltsuk Tribal Council 2018, 5)—concluded that "the Spill was an assault, not only to our sacred place, but to our way of life and everything that we hold dear and makes us Heiltsuk" (Heiltsuk Tribal Council 2018, 17), explicitly connecting it to the long history of European colonization and genocide such as the *Indian Act*, potlatch ban, and residential schools (Heiltsuk Tribal Council 2018, 23). In March 2024, Heiltsuk hereditary chief Harvey Humchitt Sr. told the International Maritime Organization in London, UK:

> The NES spill's impacts on Heiltsuk are interconnected and go beyond damage to our economic and food security, breaching our Ǧviḷás and harming our connection to territory, the learnings of our next generation, and our cultural and governance practices. The spill has caused a sense of disconnection and loss that many Heiltsuk people have compared to mourning the death of a loved one. (Heiltsuk Tribal Council 2024, 1)

The Dáduqvḷá Committee, however, equally emphasized the continued resistance and resurgence of Heiltsuk to "persistent external assaults on the essence of who we are" (Heiltsuk Tribal Council 2018, 24) such as the 2016 diesel spill. Centrally, this included the use of an alternative legal order seeking genuine restitution through a process of identifying, acknowledging, addressing, and overcoming a problem (Heiltsuk Tribal Council 2018, 45). Applying this legal order to the *Nathan E. Stewart* disaster, the Dáduqvḷá Committee issued a series of concrete recommendations to Kirby Corporation and governments that included participation in ceremony, dedicated funding for restoration and compensation, and implementation of policies to reduce spill risk. Until Kirby had acknowledged harms and fulfilled its requirements, the Dáduqvḷá Committee determined that the company should be indefinitely banished from Heiltsuk waters (Heiltsuk Tribal Council 2018, 46).

In 2019, Kirby pled guilty to three of nines charges under environmental and shipping legislation for the spill, resulting in penalties of more than $2.9 million (*CBC News* 2019). However, Elected Chief Marilyn Slett described this as "a drop in the bucket for a multi-billion dollar company," suggesting that "this sentence does not represent true justice." In the years since, Kirby has refused civil liability and demands for compensation while governments have avoided conducting an environmental assessment of the spill or requiring that the corporation cover ongoing costs (Heiltsuk Tribal Council 2019; Heiltsuk Tribal Council 2021; Heiltsuk

Tribal Council 2022). As a result, the Heiltsuk Nation has had to fundraise and conduct its own independent environmental assessment—which Kirby and government bodies have withheld requested information from (Heiltsuk Tribal Council 2017, 8)—along with "conducting healing ceremonies, and supporting community members in the lingering grief and losses" (Heiltsuk Tribal Council 2022). In October 2021, on the fifth anniversary of the spill, Chief Slett said in a statement:

> Kirby Corporation has annual revenues of $2-3 billion per year. The BC government's own *Environmental Management Act*, enables the government to make them pay, and yet BC has declined to do so. The federal government also has a Ship Source Oil Pollution Fund reporting close to $410 million dollar surpluses, and a $1.5 billion Oceans Protection Plan, and yet nothing has been done. How is this possible? How can it be justified? (Heiltsuk Tribal Council 2021).

Chief Slett's invoking of the Oceans Protection Plan was especially resonant given the federal government had unveiled the plan less than a month after the *Nathan E. Stewart* spill, pledging to establish a "world-leading marine safety system" (Prime Minister of Canada 2016) including $45 million in funding for oil spill research through the Multi-Partner Research Initiative (Colley 2017). Only a few weeks after that, the federal cabinet controversially approved the expansion of the Trans Mountain pipeline (Trans Mountain 2016) and later nationalized the project and arranged enormous loans to complete its construction at a total cost of $34 billion, despite widespread opposition by Indigenous peoples and environmental activists (Thurton 2022; Stephenson 2024). Examining the timing of the announcement of the Oceans Protection Plan a few years later, a *National Post* article explicitly described it as a "bid to bolster the Trans Mountain pipeline" and "an effort to pacify concerns about the increased marine traffic caused by the pipeline expansion" (Snyder 2018). This claim appeared further supported when the federal government announced in 2018 that the Oceans Protection Plan would not proceed without the construction of the TMX and when it paused six new West Coast spill response bases due to legal challenges to the project (Knox 2018; Hunter 2018).

Such a critical irreconcilability—between the feckless effects of spill response and claims by state and industry of a “world-class” approach—has continued to manifest in the years since. For instance, several sizable spills have occurred in Canada’s East Coast offshore. In 2018, Husky’s SeaRose platform spilled 250,000 litres of oil during a major storm, but provincial regulator deemed that the pollution was “impossible to clean up” (McKenzie-Sutter 2018). Less than a year after the SeaRose incident, about 12,000 litres of oil spilled from the nearby Hibernia offshore platform, but responders call off efforts after a few weeks as “the oil had become so diluted that it can no longer be recovered or dispersed” (*Canadian Press* 2019). In 2020, almost 20,000 litres of diesel leaked from a storage tank near Rankin Inlet, Nunavut, eventually spilling into Hudson Bay; local officials deemed it was “not recoverable due to the difficult and almost impossible situation with the ice cover and the tides” (Tucker 2022). Yet politicians, regulators, and industry have maintained that it is possible to effectively respond to marine and aquatic oil spills when they happen.

For instance, Trans Mountain (2015) refers to the capacity of the Western Canada Marine Response Corporation, which was involved in the *Nathan E. Stewart* response: “Their ability to effectively manage and direct spill response procedures within the first few hours after response activation significantly reduces the negative impacts oil can have on the surrounding environment.” The Impact Assessment Agency of Canada’s (2021) environmental assessment report of the Bay du Nord offshore oil project also described a straightforward response process: “The proponent indicated that in the unlikely event of a blowout, spill response measures would be undertaken in a safe, prompt, and coordinated manner. These response measures could include containment, capping, drilling a relief well, application of dispersants, mechanical recovery, and shoreline protection operations, as applicable" (iii). These pledges assure that spills can be addressed in a predictable and efficacious manner, rejecting the concerns of many Indigenous peoples and environmental organizations about spill threats and skirting the demonstrated gross inadequacies of recent spill responses. One can easily discern such certainty and obfuscation in statements such as Prime Minister Justin Trudeau's 2019 second approval for the nationalized Trans Mountain pipeline expansion:

> Our top priority is making sure there's no spill in the first place. But we know we need to be prepared for anything. After ten years of cuts under Stephen Harper, we've reinvested in the Canadian Coast Guard. With new vessels, new environmental response equipment, and new stations on the west coast – including the re-opening of the Kitsilano coast guard base – our professionals have never been more ready to respond in the unlikely event of a spill. (Liberal Party of Canada 2019)

This throughline has even been present in agreements struck between Canada and the Heiltsuk Nation since the spill, such as the renewal of a memorandum of understanding about spill response in mid-2024, with the federal fisheries and oceans minister asserting that "increasing marine preparedness and response in Heiltsuk Nation's territory by expanding the role of their Marine Emergency Response Team strengthens Canada's ability to respond to environmental incidents off the West Coast" (DFO 2024). Yet Chief Slett's questions from 2021 have remained unanswered, even in a more general sense about the spill itself. How *is* it possible that such devastation can occur in the wake of a small spill and in the context of a supposedly "world class" regime? How *can* such failure or mistakes be understood? What accounts for the material discrepancy between claims and realities of oil spill response in Canada? Such questions are even more important since the start-up of the Trans Mountain Expansion Project in mid-2024, increasing West Coast oil exports by up to 50 million litres per day in its opening months of operation (Hack 2024).

This dissertation argues that a major source of insights into these concerns can be found in historical oil spill research conducted in Canada, particularly the once-ubiquitous approach of *experimental oil spills*. Specifically, a central claim of this dissertation is that past experimental spill research serves as a key element of the foundation for present-day confidence in the ability to respond to marine and aquatic spills. Politicians and industry do not explicitly reference these residues, but the scientific findings continue to provide an important base of scientific confidence and legitimation required to rebuff opposition to oil industry expansion. As a result, it is important to return to original scientific publications about these experimental spills to understand their concrete aims, practices, and outcomes. However, this extensive body of scientific work has not been recognized or analyzed in critical approaches to oil spills.

To be sure, a sizable body of critical scholarship and commentary has emerged in recent years scrutinizing the claims of oil industries and states to efficacious oil spill response. One strand of this general critique is that spill response is a form of politically expedient busywork that actually does little, if anything, to improve the situation. Andrew Nikiforuk (2016) contends that marine oil spill response "creates little more than an illusion of a cleanup," noting that Transport Canada estimated that responders could only recover 10 to 15 percent of oil from the ocean in a large spill incident. In these assessments, a concerted "response theater" distracts from the reality that most oil spills simply cannot be cleaned up: at least, not in terms understood by the public (Nikiforuk 2016).

A closely related critique is the argument that spill response does actually do some amount of work, rather than only being a PR exercise, but tends to merely relocate the oil to less visible and contestable locations. Rob Nixon's (2011) application of his renown "slow violence" thesis to the *Deepwater Horizon* blowout is emblematic of this approach. Drawing on the work of Anne McClintock (2010), Nixon (2011) argued that the widespread application of chemical dispersants to the spill "operated as an image dispersant" and that "by dissipating the slicks without actually removing the oil from the ecosystems, BP was able to soften the imagery of disaster" (273). Focusing on the production of scientific knowledge about the spill, particularly via the technique of "toxic thresholds"—or what Max Liboiron (2021) has dubbed a "threshold theory of pollution"—David Bond (2022) emphasized that response to the BP disaster centred a logic that "protecting the environment was all about preventing crude oil from making landfall" as "federal agencies … sought to protect the environment they already knew how to protect" (78). These arguments demonstrate how oil spill responders can consciously designate certain socioecologies, usually those well out of sight or mind for most, as sacrifice zones to prevent more dire environmental and political consequences from manifesting, at least in the short-term.

Yet another strain of critique focuses on the structural unknowability of spills altogether. Anna Zalik (2009) identified legislation that restricted access to rigs in the Mexican Gulf as providing industry "the advantage of rendering spills and environmental practice largely invisible" (563), a theme that Hannah Appel (2019) similarly applied to Equatorial Guinea's offshore industry whose hard-to-reach location "forestalls the risks attached to visible spills" (58). In this sense, siting extraction offshore and tightly controlling access to platforms must be understood as a conscious "infrastructural choice intended to minimize the political risks of visible, accessible production" (Appel 2019, 20). A similar investigation of spill reporting in Nigeria described the feeling of an "epistemological vertigo" that "floats in a miasma of ambiguity and untruth" and constitutes "a sort of political economy of ignorance and distortion" (Watts and Zalik 2020, 790).

Other independent research has turned up unreported or understated spills in the Eastern Canadian offshore (Fraser and Ellis 2008) and Saskatchewan (Kerslake 2016), studies that Angela V. Carter (2021) cited as evidence of the country's oil-producing provinces becoming "fossilized – perilously outmoded and resistant to change under the sway of fossil fuels" (5). Sean Kheraj's (2020) recent study of federally regulated pipelines in Canada was remarkably the first "comprehensive statistical analysis of such incidents," and clearly demonstrated that "onshore oil pipeline spills have been a regular occurrence in Canada since the mid-twentieth century" (163). An investigation by Julia-Simone Rutgers (2024) in Manitoba similarly found that the province's spill data lacked transparency and consistency, with the oil industry left to self-regulate. Most exhaustively, Kevin Timoney (2021) examined more than 100,000 spills across North America and concluded that "most spills are never seen by the public, and most spill effects are never documented" (7). However, as Timoney (2021) stressed, "failure to find impacts should never be construed as absence of impacts" (49).

These related threads of critical spill analyses offer valuable insights that can help start to answer the questions posed by Chief Slett. However, these assessments do not meaningfully engage with the extensive scientific work that has primarily *produced* the confidence that manifests in regulatory documents, politicians' statements, and spill contingency plans in Canada. By ignoring or marginalizing such practices, conclusions about spill response effectiveness can border on the conspiratorial: that politicians and industry know that responders cannot clean up spills and *therefore* develop strategies of distraction, intentionally site offshore rigs in certain locales, and manipulate disaster imagery to suit their particular state projects and accumulation strategies. We cannot rule out such outcomes in every instance, particularly given the extensive literature on the oil industry's decades of involvement in promoting anthropogenic climate change denialism (Oreskes and Conway 2010; Dembicki 2022).

At the same time, decades of scientific research into oil spills and response have indicated that technologies like skimmers, chemical dispersants, and in-situ burning can in fact work effectively *in suitable conditions*. Rather than outright rejecting this scientific work as busywork, the key to gaining a better understanding of the mechanics of this contradiction requires entering "through the back door of *science in the making*, not through the more grandiose entrance of ready made science" (Latour 1987, 4; emphasis added). Put another way, it is necessary to closely examine the *material practices and processes* of scientific knowledge production about spills and their response. And while spill scientists have conducted such research in many settings—actual spill sites, indoor laboratories, outdoor tank facilities, and enclosed mesocosms—by far the most important scientific practice used to generate these findings in Canada has been the *experimental oil spill*.

'A Pollution Dunkirk'

Oil spill science started in earnest in Canada in the wake of the catastrophic *SS Arrow* tanker spill in early 1970, which spewed more than 10 million litres of thick Bunker C oil into Chedabucto Bay, Nova Scotia, contaminated more than 240 kilometres of shoreline, and killed thousands of birds (Watkins 1971; Owens 1971, i; Ministry of Transport 1970, 17). Despite the prior disasters of the 1967 *Torrey Canyon* tanker grounding in the UK and 1969 *Santa Barbara* blowout in offshore California,—along with heated debates about oil drilling and transportation in the Great Lakes (*Globe and Mail* 1969; Hess 1970), British Columbia coast (*Globe and Mail* 1971; *Globe and Mail* 1972), and Northwest Passage (Grant 2010, 351; Coen 2012)—federal transport minister Don Jamieson told a highly critical House of Commons that "there was no past experience on which to draw for successful techniques because 'this is the first serious oil spill to occur in waters as cold as those to be found, at this time of year, off the Canadian east coast'" (Sanger 1970).

The *Arrow* response was frantic, highly improvised, and in many respects a significant failure. Government scientists called off the aerial application of dispersants due to toxicity concerns (Waring 1970; Hart 1971, 135), burning the oil failed due to insufficient thickness and near-freezing temperatures (*Globe and Mail* 1970; Sanger 1970), and skimmer deployment happened too late to be of much use (Ministry of Transport 1970, 18). Responders cleaned less than one-quarter of contaminated shoreline, with a narrow focus on tourist sites or community beaches. The federal "Operation Oil Task Force" assured on the first page of its report: "We would like to underscore indelibly to you and to all those who may read this report that this is not a success story. It is the story of a pollution Dunkirk" (Ministry of Transport 1970, 1). The Royal Commission report similarly concluded that "the ARROW incident exposed the Canadian public to the fact that Canada was completely unprepared for a major oil spill" (Hart 1971, 189). By far the greatest focus during and after the disaster to better make sense of and prepare for major spills was the essential role of *scientific research*.

An estimated 100 scientists worked on the response effort in various capacities, rendering the region a "new scientific laboratory of sorts" and working to "derive the maximum amount of scientific information from the incident to add to the world's storehouse of knowledge" (Waring 1970; Ministry of Transport 1970, 13). Experts concluded through this response and subsequent investigations that the federal state had to massive escalate its funding of the scientific study of oil spills as an *anticipatory* measure for future spills. The Operation Oil Task Force, led by

Patrick McTaggart-Cowan, head of the Science Council of Canada, was particularly emphatic about this point, writing in the introduction to its report that "our final plea is for the support of ongoing research into the problems presented by spills of petroleum products" and that "unless Canada carries out the work specific to cold and Arctic environments no one else is likely to do it for us" (Ministry of Transport 1970, 4).

The three decades that followed the *Arrow* disaster and other major spills of the era saw an explosion in state-led oil spill science in Canada, particularly in the country's North and cold-water offshore environments. This work closely tied to the specific priorities, ambitions, and projects of the federal state in developing so-called "frontier lands" in the Arctic and East Coast offshore. Taking place largely under the leadership of Pierre Trudeau, this extensive scientific work was connected with significant shifts in the country's energy policy in response to the "oil price revolution" of the 1970s and towards greater federal state direction and control of oil exploration and production, especially through the formation of Petro-Canada in 1975 and the National Energy Program (NEP) in 1980 (EMRC 1980). In order for such a state project (Jessop 2016) to succeed, particularly given increasing ecological consciousness and Indigenous resistance to large-scale resource projects, states had to invest significant resources in spill research and response preparation.

Many hundreds of experiments, studies, and reports have been conducted over the decades about a vast range of issues relating to spills to improve such security. As recommended in the Operation Oil Task Force, this research was tightly intertwined with the oil industry, with the work directly anticipating and preparing the way for planned resource extraction and transportation in the Canadian Arctic and East Coast. The problem that quickly arose, however, was that oil spills are *extraordinarily difficult* to study. Spills are the product of unexpected failures of oil tankers, offshore rigs, pipelines, trains, storage facilities, and other vessels (see Appendix B and C for a list of some of the largest spills in and connected to Canada). These incidents can result from any number of overlapping factors: severe weather, navigational errors, equipment failures, human blunders, or even freak accidents; a "peculiar" example of the latter occurred in 1973 when a storage tank on Ellesmere Island was "ruptured when a wandering polar bear swatted it with a paw," spilling an estimated 7,500 litres of diesel oil (O'Malley 1974). Spill experts have anticipated certain areas and regions to experience higher spill risk than others due to the specific siting of offshore platforms or the routing of pipelines, tankers, and trains, but countless complexities can undermine even the best laid plans. Along with merely detecting and responding to spills effectively, this means that in most cases, scientific studies generating reliable data are nearly impossible to conduct.

A major planning document prepared by the Arctic Marine Oilspill Program (AMOP) summarized this issue as the "rather random occurence [sic] and nature of accidental spills," with "no guarantee that useful spills will occur within a satisfactory time frame, or have suitable characteristics which will permit the most important problems to be solved" (AMOP 1979, 8). This lack of predictability severely impedes the ability for scientists to develop baseline data, testing priorities, and sampling procedures for any given situation (Passow and Overton 2021, 110). The same AMOP (1979) report wrote: "One of the major shortcomings of work on accidental oilspills is the lack of experimental control. Because spills are unexpected, valuable information prior to the discharge and during the initial stages is frequently unavailable or, at best, incomplete. This makes the planning of any scientific experiments extremely difficult" (8).

Timing is a particular challenge. What Matthew T. Huber (2013) has described as "the biophysical attributes of oil itself—its dense energy, its liquid propensity to flow, its chemical composition" (xix) results in its rapid spreading, evaporation, and integration into sediments and organisms, with the spilled oil shifting and transforming as soon as it escapes. These dynamics are especially relevant when there are sizable delays in the identification of a breach, such as the 1974 spill of almost 2 million litres of diesel at a NORAD radio base in Saglek, Labrador, which failed to be noticed for 33 hours (O'Malley 1974). However, even in cases of rapid detection and dispatching, by the time responders arrive at a spill the oil will have changed significantly from its original form, rendering it difficult to even locate (Bond 2022, 14).

Further, the immediate priority in such situations is to dedicate available resources to limiting the spread and impact of the oil, not necessarily to produce usable scientific data that can assist with future response efforts. This prioritizes "response over science in the competition for resources" (Owens et al. 2024, 3), making it "difficult to coordinate, or even mount, a coherent scientific study" (AMOP 1979, 8). Shoreline spill expert Ed Owens (2022) has remarked that response efforts can be too effective in some cases, explaining that: "Where we have data, we often just clean things up and that doesn't help the science. It helps the environment but doesn't give us a picture." In many other situations, Owens (2022) noted, active spills have been improperly documented and reported to identify its source, or lack baseline environmental data that enable rigorous comparison of oil concentration and effects. For example, while the *Kurdistan* tanker spill of 1979 provided the first large-scale opportunity to study the behaviour of oil in pack ice, later studies argued that its approach was insufficient. One wrote: "Unfortunately, most of the direct observations of ice oiled from the Kurdistan were made weeks after the spill occurred. Without details of the oil/ice interaction immediately post-spill, quantitative conclusions of oil fate cannot be made" (S. L. Ross Environmental Research and D. F. Dickins Associates 1987, 3).

The massive amount of scientific work conducted in the wake of the 2010 *Deepwater Horizon* blowout in the Gulf of Mexico may appear to challenge this claim of "spills of opportunities" being inherently difficult to study, with billions of dollars from settlements and penalties dedicated to scientific research (Goss 2020) and a review of the first decade of research describing it as triggering a "renaissance in oil spill science" (Kujawinski et al. 2010, 246; see also Bond 2022, 90–92). However, many aspects of the disaster were highly unique in character and fairly limited in applicability to most spills in the Canadian context, including the massive volume of oil spilled, its continuous duration over three months, relatively close proximity to land, environmental conditions, depth of the blowout, and inaugural use of subsea dispersant injection (SSDI) at the wellhead (NASEM 2020, 170; Passow and Overton 2021, 110). The type of oil spewed into the ocean was also light and low-sulphur in nature, vastly different from the diluted bitumen that is increasingly being exported by tanker in Canada (Passow and Overton 2021, 111).

There also remain significant uncertainties about the long-term fate and impacts of the oil due to immense challenges in studying such an expansive incident; for instance, a study published a decade after the spill indicated that working assumptions of oil spread were far too narrow, and that "large areas of the GoM were exposed to invisible and toxic oil that extended beyond the boundaries of the satellite footprint and the fishery closures" (Berenshtein et al. 2020, 1). Another recent report cautioned that studies into biodegradation capacities at *Deepwater Horizon* "face limitations because each provides only snapshots of a complex and changing landscape, and in aggregate they suggest as-yet undiscovered processes or methodological inconsistencies" (NASEM 2020, 50). Attempted estimates of the fate of oil spilled during the blowout exemplifies this complexity, with one (French-McCay et al. 2021) reporting that about

40 percent of the oil evaporated and another 40 percent ended up in the water column, at least partially degraded, while another (Passow and Overton 2021) reported that 25 percent was recovered or burned, 5 to 15 percent evaporated, and 60 to 70 percent "spread and weathered within the Gulf of Mexico"; however, "the fractions of the oil that entered food webs and were lost at sea are unknown" (113). Uta Passow and Edward B. Overton (2021) wrote that in the case of *Deepwater Horizon*, "biodegradation varied greatly between different environments, and reliable estimates of the total amount of oil fully biodegraded or metabolized are lacking" (118). More generally, they summarized:

> All these research efforts notwithstanding, making accurate budget calculations that include the ultimate fate of all of the spilled oil is nearly impossible, with limited agreement even on the total amount of oil spilled (MacDonald 2010). Furthermore, because of the immense size of the impacted area, it was difficult to efficiently track the oil during the 87 days of the spill, with direct measurements of certain specific processes and pathways missing or insufficient, and with newly released oil continuously mixing with weathered oil that was released earlier (Joye 2015). Tracking efforts were further complicated by the chemical complexity of oil and natural gas and the weathering processes, combined with the biological complexity of organisms and ecosystems, in the physically dynamic Gulf of Mexico. (Passow and Overton 2021, 110)

As "real" as accidental spills are it has proven extremely difficult to produce useful and generalizable scientific information from them. This reality has led to the promotion of much smaller tests in highly planned, methodical, and controlled laboratory-type environments located at universities, oil industry and government facilities, and even ad-hoc and specifically designed settings. The AMOP planning document from the late 1970s framed such research as offering a "very cost-efficient, quality-controlled option," claiming that "because of the opportunity for preplanning and on-going experimental control, the approach is particularly attractive for solving very specific problems" (AMOP 1979, 7). For example, a frequent site of spill studies in the 1980s and early 1990s was a large outdoor concrete test basin located on Esso property in

Calgary, Alberta, which included high-powered refrigeration units capable of forming ice sheets to test the behaviour of oil and response technologies within Arctic-like settings and had the ability to generate waves with a series of large paddles (Brown and Goodman 1987, 4; MacNeill et al. 1985, 463; Fingas 1998, 4; NIST 1994, 39; Lamb 1990). Other important laboratory facilities for spill testing have included scientific contractors like the Kanata, Ontario-based Arctec Canada (Purves 1978; Whittaker 1987, 391) and the Waterloo, Ontario-based Energetex Engineering (Energetex Engineering 1978; 1980). The Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) in New Jersey has also served as a key site of Canadian spill research over the decades (Solsberg et al. 1976, 45–46; Borst 1983; Technical Services Branch 1984, 52–53; Fingas and Decola 2006).

However, as with many other scientific problems, laboratory environments also face significant limitations. AMOP (1979) identified several broad issues including challenges of understanding and accurately modelling the real-world environment, an inability to extrapolate results, and that laboratories are "not suited to the solution of field operational problems" (7–8). Many other specific problems have been identified ranging from the problem of "side-wall effects" that "unnaturally enhance dispersion" (Yuan et al. 2018, 447; COAATF 1986, 128), to issues of water composition and residues from previous testing influencing results (NASEM 2020, 209; Merlin et al. 2021, 4), and a "general lack of correlation" found between laboratory findings and the "open-sea environment" (COAATF 1986, 128), meaning that "results achieved routinely under laboratory and mesoscale conditions cannot be easily duplicated in the field" (Swiss and Vanderkooy 1988, 2). Concerning dispersant testing, for instance, Merv Fingas (2002) has noted that there are "no standard testing procedures" for measuring effectiveness, and that influential factors such as salinity and mixing energy may vary significantly, meaning that "tests may not be representative of actual conditions" (2). As a result, Fingas (2002) cautioned that "results obtained from laboratory testing should therefore be viewed as representative values only and not necessarily reflecting what would take place in actual conditions" (2).

Studies of microbial biodegradation have encountered similar issues. Given that many environmental factors can shape the potential for biodegradation of oil—temperature, nutrient availability, type of oil, local microbial populations—researchers have been able to "achieve excellent results during degradation of petroleum hydrocarbons under laboratory conditions yet exhibit dissatisfactory results in field-scale tests" (Xu et al. 2018, 5). For instance, a laboratory test successfully demonstrated the addition of nutrients to a sandy beach ecosystem, but a "similar treatment was ineffective" in the field, leading researchers to conclude that "while laboratory studies avoid the dynamic and unpredictable nature of sandy beaches, they cannot adequately simulate field conditions" (Lee and Levy 1989, 479).

Spill scientists developed and popularized the experimental oil spill—or the intentional discharge of oil into real water bodies—out of this tension between accidental spills and laboratory work (see Appendix A for a full list of experimental spills referred to in this dissertation). The AMOP (1979) planning document described: "Planned oil discharges combine many of the advantages and eliminate many of the disadvantages of laboratory work and spills of opportunity. An experimental spill is a well-directed, problem-solving tool which allows good experimental control in the real environment" (8). While extremely diverse in specifics, this field experiment became the dominant means of generating reliable information about the fate, behaviour, and effects of spilled oil at close to full scales between the early 1970s and 2000. At least 40 of these spills took place during this span, involving a wide range of volumes of oil, research objectives, and locales. Experimental spills took place in oceans, bays, lakes, rivers, and other water bodies across the country, especially in the Arctic and East Coast offshore. Many experimental spills were specifically located close to where real-world spills were expected to occur due to increasing oil industry and shipping activities: in thick multi-year ice in the Arctic Archipelago (Corcoran 1979, 1), in the "outer reaches" of Conception Bay, Newfoundland (Gill and Ryan 1979, 498), and the St. Lawrence River (Coupal 1976, 1; Grenon et al. 2001, 1467).

Researchers regularly framed these efforts in extremely explicit terms: planners selected the East Coast offshore for dispersant testing in the early 1980s as it was a "cold saltwater environment where petroleum development appears to be imminent" (Gill and Ross 1982, 258). Likewise, a small experimental spill in 1984 near Halifax was sited on a "low-energy sandy beach" near Halifax as "further exploration and possible future production in this region pose a threat to the Nova Scotian coast, a portion of which consists of low-energy coastal systems, including beaches and salt marshes" (Lee and Levy 1987, 411). Ideally, this method combined the *realism* of accidental spills with the *control* of laboratory studies. For example, the prospect of "realistic field conditions" and "realistic open ocean conditions" underpinned the work of the Newfoundland Offshore Burn Experiment (NOBE) of 1993, including the viability and harmful byproducts of a full-scale burn in such a setting (Ferek et al. 1997, 3; Environment Canada et al. 1993, 1-2). The NOBE was also directly tied to real spill management, with the *Exxon Valdez* spill involving in-situ burning of an estimated 60,000 to 100,000 litres of oil, and Environment Canada scientists speculating that as much as 50 percent of the spilled oil could have been burned within just two hours if used (*Oil & Gas Journal* 1993, 29).

Studies in laboratory and at accidental spill sites continued alongside this field work, often complementing it, and identifying new issues or questions to address. But it was this extensive experimental spill work that primarily contributed to Canada becoming one of the leading global authorities on oil spill science and response—particularly in cold-water and Arctic environments—with Environment Canada hosting an annual technical seminar on Arctic and marine spill response since 1978 that convenes experts from around the world. This experimental work has also resulted in Canadian leadership and coordination in international spill research, with Environment Canada personnel managing large and complex collaborations between industry and other states such as the US and Norway, including the NOBE of 1993 and In-situ Treatment of Oiled Sediment Shorelines (ITOSS) in Svalbard, Norway, of 1997. Experimental work itself became a domain of expertise.

However, this approach to generating scientific knowledge about spills was phased out in Canada by the end of the 20th-century, replaced by smaller-scale research in laboratories, outdoor tank facilities, and mesocosms (Environment Canada et al. 2013, 56; Witt O'Brien's et al. 2013; Markusoff 2017; Meyer 2018). In 1990, a *Calgary Herald* reporter wrote that "few, if any, saltwater ports around the world will let anyone tip a few barrels to see how it will react to an inventor's latest whim," and quoted an Esso researcher working at the company's outdoor tank test facility in Calgary: "These are the `90s. You don`t just pour oil into harbors anymore - even for research" (Lamb 1990). The extensive planning work required for one of the last major experimental spill efforts, in 1999, provided a window into the factors contributing to this transition, with the shoreline study on the St. Lawrence River preceded by considerable public outreach and local communities described as "very sensitive to the quality of their environment and tend[ing] to resist any project that could affect that quality" (Grenon et al. 2001, 1467). It took experiment planners a year-and-a-half of site selection, contingency planning, and public forums to "sell the project to the local authorities and citizens" and minimize "any confrontations that could jeopardize the experiment" (Grenon et al. 2001, 1467–68). While successful, this process exemplified the resource-intensive and politically sensitive quality of intentional spillage for scientific gain. Another small set of spills took place in the St. Lawrence River in 2008, but there has been little else of its kind in the years since.

Although attracting national and international media attention (Semeniuk 2019; Ogden 2018; Williams 2019; Davis 2018; McSheffrey 2018), recent spills conducted at the Experimental Lakes Area (ELA) near Kenora, Ontario, in 2018 and 2019 were of a much smaller and more controlled nature than the experimental spills of the early 1970s to 2000; the same goes for the discharges planned for the $45 million Churchill Marine Observatory, which opened in August 2024 after significant delays (Semeniuk 2024). Spill scientists working to conduct field experiments akin to earlier experimental spills off the coast of Newfoundland in August 2023 had to postpone the project due to having "encountered challenges regarding logistics and stakeholder alignment" (Brosseau 2023, 2). Significant experimental spill work has continued elsewhere, notably the Joint Industry Program on Oil in Ice that took place between 2006 and 2009 in Norway's Barents Sea (Sorstrom et al. 2010). Yet the centrality of the experimental spill in the field has appeared to have ended in the Canadian context.

Experimental Spills and the 'Future Eco-Perfect'

Due to this prospect, it may seem peculiar to return attention on this long-gone scientific era. However, these experimental spills continue to have major bearings on contemporary understandings of marine and aquatic spill behaviour and outcomes. In a webinar hosted by ExxonMobil and the American Petroleum Institute, Arctic spill expert David Dickins (2022)—who has been involved in much of the experimental spill research work in Canada—explained:

> Most of what we know about how oil behaves in ice comes from these very small number of historic experimental spills. Now, these spills are increasingly more difficult to execute, especially in North America. When I say "more difficult," I

> could say almost impossible, in terms of getting permits to do the type of spills we did in the 1970s. (56:25–56:45)

Similarly, in another webinar as part of the same series, shoreline spill expert Ed Owens (2022) reflected on large-scale experimental spills such as the Baffin Island Oil Spill (BIOS) and Svalbard trials in the following way:

> In essence, there's some good lessons that we have learned. Those lessons are based on good data. I know techniques have changed: analytical techniques are more sophisticated these days. But that doesn't mean to say that that data that was collected back in the 1980s and 90s isn't still good data. It was collected with a very rigorously thought out sampling plan to make sure that the results are still today scientifically and statistically valid. It would be really hard to reproduce any more of these types of experiments. It takes a lot of effort, a lot of money, and you've got to find somewhere to do it. (45:00–45:50)

Given that limits of studying real-life spills and simulating spills in laboratory conditions still exist, these experimental spills retain considerable influence on the perceived possibilities and probabilities of spill response, including in cold-water and Arctic environments. Spill scientists developed considerable confidence that large-scale response approaches like in-situ burning and chemical dispersants through these trials. This claim has been repeatedly demonstrated during catastrophic large-scale spill events, such as findings from the BIOS project of the early 1980s playing a "key role" in the shoreline response to the *Exxon Valdez* disaster of 1989 in Alaska (Owens 1993), and the NOBE of 1993 providing data about in-situ burning that was applied during the *Deepwater Horizon* response (NOAA 2012). About the decision to start burning the oil a week after the start of the 2010 blowout, *CBC News* (2010) reported that BP's conclusions were "based on a 1993 experiment that the Canadian government organized off Newfoundland's east coast," with an Environment Canada manager saying that the experiment "showed a controlled burn can be successful as long as the oil is contained." Findings produced by this experimental work migrated to new spill sites in entirely different regions and countries.

Like with the regular return of scientists to spill sites to evaluate the long-term fate of oil—such as the *Arrow* and BIOS shorelines in Canada, the *Exxon Valdez* site in Alaska, and the *Metula* site in southern Chile—such scientific continuities can be thought of as complex afterlives of scientific work in the years and decades that follow its creation, especially when such methods have largely been replaced or phased-out. To understand the present-day contradictions of spill response, then, it is necessary to return to the original scientific research that produced these findings. Spill scientists themselves advocate for such a return. Take, for example, BIOS project lead Gary Sergy's (1986) description that the experiment's conclusions "can be applied to decisions about the use of chemical dispersants on an oil slick approaching an arctic coastline" and "provide no major ecological reasons to prohibit the use of chemical dispersants on oil slicks in nearshore areas typified by the experimental site" (1). Almost four decades later, in response to an ExxonMobil spill researcher's comment about industry needing to improve communication methods and understandings of group psychology, Dickins (2022) noted:

> I think that's why it's important to go back to some of these older experiments like BIOS, because there were lessons that came out of that project that are just as applicable today and really could aid in that communication process. If you even mention now thinking about using dispersants in shallow water, you're viewed as slightly crazy. But BIOS demonstrated that the environmental impacts of using dispersants nearshore even could be better or certainly no worse than allowing the oil to come up on the beach. So there's an awful lot to be learned there. (1:22:25–1:23:05).

Far from being stranded in the past, these studies and findings are essential to understand in their granular details, offering an important opportunity to help provide more robust answers to the types of questions raised by Chief Slett.

While still small, there is a robust and growing body of scholarship about the history of oil industry activities in the Canadian Arctic, including by Andrew Stuhl (2016; 2024), Paul

Warde (2018), Stephen Bocking (2019), Warren Bernauer (2020), and Matthew Farish and Leah Fusco (2024). However, with the exception of a short Greenpeace report about Arctic oil exploration that briefly mentioned a brief span of spill experiments in the mid-1970s (Nikiforuk n.d.), there has been no attention paid to this history of experimental spills outside of the scientific community itself.

Methods and Theory

This dissertation aims to help fill this gap through a detailed analysis of experimental spills conducted in Canada between 1970 and 2000. Specifically, it used document and content analysis of approximately 100 scientific and technical reports that I collected from government and academic libraries and archives across the country, along with online sources. These reports were published about the planning, execution, and findings of oil spill research in the last three decades of the 20th century, with some also serving as synthetic or summary documents.

Hani Morgan (2022) has described document analysis as an "underused approach to qualitative research," especially in comparison to methods such as interviews and observation (64). It offers a range of specific benefits, including providing primary data about events that may have taken place decades ago, and also provides "stability of the data" that avoids directly influencing research subjects (Morgan 2022, 66). However, like with all forms of data, documents can be distorted, misrepresentative, or incorrect. Sharan B. Merriam and Elizabeth J. Tisdell (2016) have noted that "they may be fragmentary, they may not fit the conceptual framework of the research, and their authenticity may be difficult to determine" (183). In this study, document analysis provided a unique opportunity for a careful review of extensive scientific literature that researchers had not yet examined from a critical social sciences perspective. While conducting interviews with the scientists who worked on these experiments may reveal additional insights, this dissertation's research approach provided a means of understanding the scientific literature as originally conceived and reported. I further supplemented these documents with publicly available lectures that scientists have provided about this work, especially through the seminar series organized by ExxonMobil and the American Petroleum Institute about oil spill science and response.

It was not initially clear to me that experimental spills warranted a dedicated study. Between October 2022 and November 2023, I collected a wide range of reports and documents about oil spill science and research in Canada from institutions including the University of Calgary's Arctic Institute of North America collection, the University of Alberta, the University of Manitoba, the National Science Library, the Environment and Climate Change Canada Library, Library and Archives Canada, and the Glenbow Archives' Arctic Petroleum Operators' Association archival fonds. I had requested documents that appeared to offer details and insights into the historical production of spill science, located through online database searches of phrases such as "oil spill" and "Arctic spill." For all but the University of Alberta and Environment and Climate Change Canada libraries—which scanned and sent materials to me remotely—I travelled to each of the sites and scanned the entirety of each report that I had requested used a portable overhead document scanner hooked up to a laptop. This process allowed me to efficiently collect relevant materials without having to individually parse through each report on site. Once back in Winnipeg, I transferred the PDFs of the scanned reports to a portable hard drive, with the drive remaining in my office at all times. Since scanning, I have not shared the PDFs in any capacity and have exclusively used them for research purposes.

Over the following year, I began to conduct close readings of these reports, coding them with themes that emerged along the way; I conducted the initial phase of coding using NVivo, and later used QualCoder. At first, the major themes of interest appeared to be the scientific and technological genealogies of various response measures and focuses that industry had identified and tested throughout the era. Specifically, five major categories of coding through this process were: in-situ burning; containment (including booms and skimmers); dispersants; the issue of ice; and shoreline clean-up. This phase of coding included many subcategories for each measure and focus, such the particular complications of aerially applied dispersant and the planning of using ice trenches as a containment measure in the case of a massive Arctic blowout. However, upon development of an early draft of this dissertation along such lines, it became clear that the central tension and insight of this period was in fact the struggle to conduct scientific research itself, especially through the complex practice of the controlled experimental spill. This realization led to a second round of coding focusing on scientific practices and designs.

Through this process, I identified five new major categories of analysis specific to experimental spills: siting, timing, oiling, new natures, and scientific unknowns. While every spill design was distinct in some way, these analytical categories encompassed all of the work in some respect and allowed for effective comparison and synthesis of otherwise disparate studies. From this point, I worked to organize each of the categories into subsections of scientific work. In some cases, such as the "volume" section of the chapter on oiling, this involved writing up the case study in an effectively linear order, starting from the smallest spills and working up to the largest. In other cases, like the "emulsions" section of the chapter on new natures, I identified two opposite but intertwined processes of emulsion formation: one of which spill responders planned for in the form of successful dispersant application, with the other presenting a major problem due to formation of water-in-oil emulsions. Along the way, I supplemented this coded research with historical newspaper reporting from online databases that provided additional insights into some of the larger oil spill experiments. This reflexive process of broad document collection, reading and coding, and building case studies around identified trends of scientific practices points to the potential benefit of assessing scientific documents on their terms and through the priorities and perspectives of scientists themselves. To be sure, there are inevitably limitations of such a historical approach, with no ability to directly observe scientific work or trace the development of scientific knowledge from point of production to transmission and later usage. However, the approach nonetheless offers a wealth of insights into the design, execution, and findings of scientific work that we can usefully theorize by drawing on scholarship from the social sciences and humanities.

Theoretically, through a deep and extensive analysis of these materials, I argue this experimental spill work can be read as a materialization of what Rosemary-Claire Collard and Jessica Dempsey (2022) have theorized as the "future eco-perfect," which itself draws particularly on the work of Elizabeth Povinelli and other scholars of settler-colonialism and post-colonialism. Collard and Dempsey's (2022) concern was of a similar nature to this study: a question of how Canadian states could simultaneously produce extensive conservation plans and legislation to protect caribou habitat while approving resource extraction activities that destroyed it. The "hailing" of the "future eco-perfect" by what they term the "liberal environmental state" invokes an "abstract future" in which "the contradictions between colonial-capitalist growth and ecological degradation will have been resolved through technological innovation and managerialism" (1549). This hailing to a distant future has a depoliticizing effect similar to Tania Li's (2007) concept of "rendering technical, in which "questions that are rendered technical are simultaneously rendered nonpolitical" and experts functioning to "exclude the structure of political-economic relations from their diagnoses and prescriptions" (7).

Temporal management—or what they term "temporal fixes"—is central to this process, with past harms acknowledged but demarcated from, with the "late liberal strategy of deferral involves constant, confident gestures to an idealised future" (1550). Using the examples of failed caribou protection plans, Collard and Dempsey argue that state-mediated "busy, active work" like environmental assessments contribute to the "normalisation of a degraded environment" by constantly shifting and resetting baselines (1557), and the "perpetuation of an extractivist status quo" (1561). No matter how dismal past and even present conditions are, this conjuring of the "future eco-perfect" produces a captivating vision of linear progress towards a combination of "win-win laws and policies that achieve both capitalist growth and ecological sustainability, relying on science, technology and price signals" (1546). It is the fantasy of "sustainable development," a future that achieves perfect balance between capitalist growth and socioecological harmony, condensed into a forward-looking and conflict-erasing tonic for present-day worries.

There is much within this formulation to be effectively applied to the failings of marine and aquatic oil spill response, such as the Liberal government's pivoting from the catastrophe in Heiltsuk territory into the Oceans Protection Plan and spill response agreements with the Heiltsuk Nation while approving and later nationalizing the Trans Mountain Expansion Project that hugely increased oil exports off the West Coast. However, this dissertation aims to deepen and strengthen the concept of the "future eco-perfect" through a greater focus on scientific practice itself. Specifically, it will argue that the "future eco-perfect" is not merely an abstract discursive strategy cynically employed by industry and state to justify present-day resource extraction. Spill scientists have materially actualized the "future eco-perfect" through the *planning, execution, and reporting* of experimental oil spills over the decades. In particular, this has taken place through the production of small and highly controlled experiments that result in favourable outcomes, which are then extrapolated well beyond the testing conditions to suggest that equivalent results could be achieved in real-world spills.

The empirical case for this argument will made through five case studies, broken loosely into two subsections. The first three case studies—siting, timing, and oiling—will demonstrate that experimental spill work has frequently taken place in *near-idyllic testing conditions* that has allowed for maximum knowledge, control, and response. A combination of scientific necessity, regulatory and permitting requirements, and community expectations materially shaped experimental conditions, with the spills often designed to *limit* potential socioecological impacts in many important ways. As a result, the findings frequently *understated* the threat of oil to socioecologies and *overstated* the ability to meaningfully respond to spills when they happen. Through this active production of experimental conditions, spill scientists *materialized* the "future eco-perfect," projecting forward future spill scenarios in which conditions would be maximally controllable and knowable. However, as the *Nathan E. Stewart* spill and many others like it have clearly demonstrated, spills often and *tend* to occur in dire conditions of storms, poor visibility, remote locations, and lack of ability to monitor spill behaviour. Industry and governments have extrapolated and universalized these experimental spills—and their resulting residues that linger today—to make highly questionable claims about real-world response.

At the same time, spill scientists materialized this "future eco-perfect" in experimental oil spills through actively downplaying, ignoring, and shearing off unresolved problems and uncertainties generated through the research work. Unlike the first subsection that explored the production of necessary and desired testing conditions, the following two case studies will examine the often-unwanted production of new natures and complications of scientific inquiry that had to be contained and bracketed out of consideration to maintain the coherence of the scientific claims to extrapolation. This process largely took the form of difficulties being noted in scientific reports in passing but rarely remarked upon or further investigated at any depth. While unknowns are a fundamental and driving part of any scientific inquiry, the desire by spill scientists, industry, and states to produce findings that could be expanded well beyond the particulars of a given experiment required certain elements to be de-emphasized in scientific reporting and even forgotten in the long term. In this way, the positive takeaways from the production of near-idyllic testing conditions were protecting from inconvenient obstacles to asserting scientific confidence.

This modification of Collard and Dempsey's (2022) concept of the "future eco-perfect" draws particular inspiration from science and technology studies (STS) and the history of science, especially from works focusing on the production of experiments and fieldwork. These approaches demonstrate that, at their most basic level, scientific experiments require a great deal of *work*. For example, Steven Shapin and Simon Schaffer (2011) argued that "the experimental production of matters of fact involved an immense amount of labour … rested upon the acceptance of certain social and discursive conventions, and … depended upon the production and protection of a special form of social organization" (22). Importantly, scientists have historically and contingently produced this experimental approach, with "nothing self-evident or inevitable about the series of historical judgments in that context which yielded a natural philosophical consensus in favour of the experimental programme" (Shapin and Schaffer 2011, 13). Such an argument of seeing scientific knowledge "as the product of a collective, as work, as *performance*" (Shapin and Schaffer 2011, xxxix; emphasis in original) does not diminish the capacities and significance of science itself. Like Ian Hacking's (1985) refrain that experimentation itself "has many lives of its own" (165), Andrew Pickering's (1995) case to replace the "representational idiom" of science—in which an external nature is merely observed—with a "performative idiom" that emphasizes agency and practice is above all a "recognition of science's material powers" (7).

Scientific research, and in particular the "paradigmatic scientific practice" of the experiment (Kohler 2002, 9), is an extremely creative, powerful, and productive array of methods and practices that scholars have to analyze on its own merits and claims. While scientific findings have certainly contributed vast benefits to capital, allowing for the development of many labour-saving technologies and product innovations (Braverman 1984, 155–167; Rose and Rose 1976, 14; Perelman 1978; Smith and O'Keefe 1980. 36; Rodney 1981, 174; Forman et al. 2023), it remains important to attend to the intricacies of scientific processes to understand how this knowledge was produced, stabilized, and transmitted. The case for such an approach was well-summarized in the introduction to a special issue in *Osiris* on the "entangled histories" of science and capitalism, with its editors arguing that "by studying these technical practices 'in action,' we can examine how seemingly natural, inevitable, or 'black-boxed' aspects of economic order or scientific knowledge were in fact the product of local cultures, personal interests, contested choices, and historical contingencies" (Rieppel et al. 2018, 14). Scientific work is often far more complex and uncertain than commonly regarded, a reality that is of particular relevance when involving powerful capitalist industries with potentially severe socioecological consequences (Oreskes and Conway 2010; Dembicki 2022).

This emphasis on the complex production of science appears especially fruitful in studies of *fieldwork*, when efforts to assert scientific control can be challenged by vast numbers of variables and unpredictable developments. Robert E. Kohler (2002) has documented how biologists developed laboratories and field research as "linked opposites, mutually supporting and defining" each other (11). At the same time, the "most obvious strategy for field biologists to achieve credibility—but difficult, because of the places where they work and the things they work on—is to become more like laboratory scientists" (Kohler 2002, 11). Similarly, while field studies are often heralded for their particularity in contrast to the uniformity of the laboratory, Scott Kirsch (2011) has historicized the development of "lab-like practices" by "fitting field sites with instruments, and extending specific controls over the conditions of nature in which their experiments resided" (81–82; see also Powell 2017, 55; Farish and Lackenbauer 2017). Stephen Bocking (2007) has also developed an inquiry into what he calls "disciplinary space," or "the territory in which the concepts and methods particular to a discipline are considered authoritative and relevant," with such space not merely existing in the abstract but "must be asserted" (Bocking 2007, 886). These analyses make clear that scientists do not merely *observe* in field studies but actively *produce* conditions (Livingstone 2003, 47; Robertson 2006; Li 2018).

Another fundamental aspect of scientific work—and of particular relevance to this study—is *uncertainty*. Unlike ignorance, or a lack of knowledge, uncertainty refers to a lack of knowledge *clarity* (Birkenholtz and Simon 2022, 154). Almost all scientific subjects involve some degree of uncertainty. Despite efforts to "isolate signal from noise," the "experimentalist can never, even in principle, exhaustively demonstrate that no disturbing effects are present" (Galison 1987, 2–3), such that "science, at least in part, is not about facts but about odds" (Tannert et al. 2007, 892). This reality does not in any way discount scientific processes: the underlying "probabilistic view of knowledge" instead aims to develop an "*appropriate* certainty" (Shapin and Schaffer 2011, 24; emphasis in original) through the scientific principles of reproducibility and replicability (NASEM 2019). Considerable scientific resources are dedicated to addressing such "epistemological uncertainty" (Tannert et al. 2007, 893).

However, major issues and challenges remain in the realm of scientific uncertainty. Most notably, there is a well-documented tendency of "opponents of public health and environmental regulations" like tobacco and fossil fuel industries to intentionally exploit and exaggerate scientific uncertainty to delay or rebuff tighter regulations on industry, including through the smearing of research as "junk science" (Michaels and Monforton 2005, 2–3; Castillo 2010, 2). Likewise, conspiratorial appeals to scientific uncertainty and misapplications of the "precautionary principle" seriously undermined vaccination efforts during the COVID-19 pandemic (Grimes 2022, 320–321), serving as a stark reminder of the dangers of improper communication of scientific processes (Tannert et al. 2007, 894). These approaches can be understood as leveraging uncertainty as a "strategic ploy" and a "resource" to discredit science, including "through the transmission of information that has been willfully distorted for public consumption" (Birkenholtz and Simon 2022, 155–157). Even if not coordinated in such a manner, pressures can exist on scientists to produce findings with a high degree of certainty, whether generated by funding sources, scientific community norms, or career ambitions (Birkenholtz and Simon 2022, 157; Bocking 2019, 129).

Another consistent source of difficulty can emerge as "ontological uncertainty," caused by "stochastic features of a situation, which will usually involve complex technical, biological and/or social systems" (Tannert et al. 2007, 893; see also Senanayake and King 2021, 130) and "may arise due to characteristics of both the method of study and the object of study" (Birkenholtz and Simon 2022, 155). Adrianne C. Kroepsch and Katherine R. Clifford (2022) have further theorized this aspect of uncertainty through the concept of "inscrutable spaces," emphasizing how the “biophysical factors interact with epistemic and political economic influences to produce gaps in environmental knowledge production that are persistent and consequential” (171). Of particular relevance to this study is their specific highlighting of the role of the “vastness and heterogeneity of a space, plus the dynamism of important circulations of things within a space” in complicating efforts to “actually gather meaningful information across big spaces” (Kroepsch and Clifford 2022, 174). Given expectations by states, industry, and the public for clear answers to complex questions, scientists may overstate the degree to which a study or project can meaningfully resolve such ontological uncertainty.

This issue can be compounded by differences in understandings of uncertainty based on audience and forum. At a general level, an editorial in *Nature Climate Change* (2019) highlighted a “subtle, but important” difference between the scientific meaning of uncertainty, which “conveys the degree to which something is known,” compared to the layperson understanding of it that “conveys rather the sense of not knowing” (797). Similarly, Charles Weiss (2003) compared the “binary concept of scientific truth” frequently expected by the public—with an assertion either proven or unproven, providing “unambiguous truth, free of uncertainty”—with the far more “nuanced and pragmatic” approach that scientists often employ in their daily work that involves degrees or gradients of certainty (35). Major scientific publications intended for public consumption have increasingly included attempts to better reflect this more nuanced approach to the question of certainty.

For instance, the Intergovernmental Panel on Climate Change (IPCC) introduced a seven- (Weiss 2003, 39) and later nine-level scale (Lewis and Gallant 2013) to account for degrees of certainty, such as “about as likely as not” (33 to 66 percent probability) and “very likely” (greater than 90 percent probability). Drawing on legal standards of proof, Weiss (2003) proposed an 11-

point scale that ranged from “beyond all doubt” to “impossible,” neither of which are represented in the IPCC approach (41–42). Practices like margins of error are also designed to help account for the potential range and likelihood of uncertainty (Birkenholtz and Simon 2022, 156). However, scientists can also lapse into a type of “epistemic hubris” in their public communications of findings, which can “often omit or oversimplify analyses of uncertainty that are present in insider communications” and “portray scientific claims with more certitude than is justified” (Covitt and Anderson 2022, 1161).

Scientific uncertainties and their associated difficulties are particularly notable within oil spill science. Marine and aquatic oil spill experiments are challenging to execute, requiring the large-scale dumping of a widely reviled pollutant into water bodies with unclear results. Go-to approaches of improving predictive capacities are confounded by the immense complexity and infrequency of full-scale experimental spills, with the contested and costly quality of these field studies limiting the ability for researchers to repeat and modify research to achieve greater degrees of confidence and certainty. As a result, findings have often been highly local and specific. This meant that experimental representativeness is frequently *asserted*, a process in which “experimental evidence becomes convincing” (Galison 1987, 18).

Such limits would not necessarily be of concern if the scientific questions and goals were of a hyper-local quality that integrated feminist critiques of science about the inherent “partial perspective” possible in any given endeavour of knowledge production (Haraway 1988, 583). However, like with many scientific inquiries tied to large-scale industry, the goal of this work has been to generate findings that can be extrapolated and applied to spills in many diverse contexts through an assertion of universalism (Liboiron 2021, 51–52). Using the approach of aforementioned scales, the level of scientific certainty about spill outcomes can often appear several degrees higher than seemingly warranted given the available evidence and complexity of the scientific problem. For example, in a publicly oriented lecture delivered in the style of a "TED Talk," leading Canadian spill researcher Kenneth Lee asserted that "over time, in the long term, most of the oil that's been spilled in the ocean is actually bio-degraded" (Lee 2020, 5:00). This framing could be interpreted as an extremely high level of certainty—such as "beyond a reasonable doubt" or "virtually certain" (Weiss 2003, 41)—about an extremely wide variety and scale of situations in which such certainty can not be reliably claimed.

Following Donna Haraway (1991), this study of experimental spills works to theorize the history in a way that "neither worships nor rejects natural science, which refuses to make nature and its knowledge into a fetish" (9–10). Specifically, it argues that contemporary claims of confidence and even certainty about spill response does not meaningfully engage with the active production of the "future eco-perfect" inherent in the legacy of experimental spill work that underpins much of what is known. Like with other oil industry innovations—such as carbon capture and storage (Smit et al. 2014) and end-pit lake tailings management (Grant 2012)—positive results from small-scale testing are projected into the future as a technology fix to current socioecological issues, which critically function to delay and rebuff larger structural transformations that would reduce the production of oil and resulting spill risk. Through this work, spill scientists have helped to produce expertise and legitimacy for the oil industry, and in turn *helped produce the potential conditions for spills to occur.*

The dissertation will proceed in the following manner. The first chapter will provide an overview of the socioecological problem of marine and aquatic oil spills and the history of their emergence as a crisis for experts to resolve through scientific research in Canada. The following five chapters of the dissertation are case studies examining experimental spills from different vantage points, divided into two subsections that demonstrate the materialization of the "future eco-perfect" in scientific practice: 1) the production of idyllic conditions in the form of a) siting; b) timing; and c) oiling; and 2) the management of undesirable aspects in the form of a) new natures/residues and b) scientific uncertainty. Collectively, this modification of Collard and Dempsey's (2022) theoretical approach using STS and related literatures will seek to demonstrate how "science in the making" (Latour 1987, 4) is shaped by a complex assortment of priorities, decisions, and contingencies that should inform how we grapple with this research in the present. This analysis does not speculate on the individual subjective motivations or priorities of scientists themselves but rather lets the scientific work speak for itself. It takes experimental planning, processes, and outcomes seriously as a *subject in itself* that has considerable contemporary relevance. Further, it seeks to understand the politics of science beyond the most obvious "external" factors such as funding and commercial interests, examining the intricacies and complexities of scientific work in the making.

Chapter 1: Oil/Spill/Experiment

> Wednesday, January 4, 1989
> Dear Sister:
> I can't sleep so I will write to you.
> The beaches are a mess: major oil spill. (Gervais 1989, 1)

This brief refrain opens the journal entries of Nicole Gervais recounting the arrival of spilled oil onto the beaches of western Vancouver Island in early 1989. Twelve days earlier, just before Christmas 1988, a barge transporting almost 11 million litres of bunker oil collided with its tug near Grays Harbor, Washington, after the towline snapped during rough weather (Keltner 2020). Government officials initially thought that the resulting *Nestucca* spill was localized and insignificant. As a result, "both Canadian and American officials were surprised at the large quantities of oil that showed up on Canadian beaches on January 3rd and 4th" (Canadian Coast Guard Western Region 1989, iii). Currents carried an estimated 875,000 litres of oil northward by currents, hitting hundreds of kilometres of shorelines in the days and weeks to come.

> Miraculously, or rather because of the direction of the wind in yesterday's storm, the area in front of my house is yet untouched... But my favourite beach, Schooner Cove, reeks of oil. At low tide, the wet sand has an unnatural "mirror-like" glow to it. Every few feet there are 2" to 3" blobs of oil that looks like molasses. Higher up on the beach, dead birds lie wrapped in bunker oil, surrounded by big blobs of oil and some blobs are a few feet wide and 10 inches thick---awful stuff. (Gervais 1989, 1)

Gervais—who had been living in Esowista, next to the island's iconic Long Beach, since 1987 (Renwick 2021; Plummer 2022)—meticulously and emotively chronicled the impacts of the spill and her dedicated volunteer efforts to help clean the shoreline. Six months after the spill, she submitted these recollections under the title of "How I Lived Through the Oil Spill: A Journal," with a sketch of a bald eagle's head on the cover, to David Anderson, a former Liberal politician and long-time critic of the oil industry who was then serving as the B.C. premier's special advisor on oil transportation and oil spills. Along with the journal, Gervais (1989) included a hand-written note to Anderson explaining its intention: "Included in this journal are feelings as well as events. It is also a critique of the government's response. If you read this, you might get the feeling that you have lived the oil spill with us westcoasters, and so will become more convincing when asking the government for a more appropriate response." Anderson (1989a) replied in a letter shortly after, thanking Gervais for both the submission and her participation at a recent public hearing in Tofino, noting that "your journal and your contribution to the meeting are both very helpful to me."

> The tide has brought many big blobs in front of my house. It is still below the logs. It still can be picked easily. A dead harbour seal is rolling in the small waves on the shore-his body tainted with oil. (Gervais 1989, 5)

Gervais' journal entries remain remarkable for several reasons. Most clearly, and as noted in her introductory remarks to Anderson, is the emphasis on the emotional toll of living through a major oil spill. Unlike the highly technical and dispassionate reporting of spill analysis by state departments and private consultants, Gervais' journaling centred her experience of sadness, rage, and despair. She wrote of silently pleading to "three beautiful sandpipers" to stay in the area rather than flying to the ravaged Schooner Cove (Gervais 1989, 1), and of being so angry that she needed to "sit still and meditate" in order to "clear myself of this anger and fill up on new energy to face tomorrow" (Gervais 1989, 3). She detailed the physical effects of shoveling oil into plastic bags for many hours at a time (Gervais 1989, 2): the feeling of oil burning exposed skin (Gervais 1989, 6); the "cold and the wet get[ting] into my bones" (Gervais 1989, 8); reports of headaches, nausea, and weakness from volunteers exposed to the fumes of evaporating oil (Gervais 1989, 9). There were even moments of occasional, albeit fleeting, optimism: fifteen volunteers enjoying tea outside her house after spending a long day picking oil from the beach—

"they filled me with renewed energy and strength" (Gervais 1989, 6)—and a vet saving a sick seagull who had been found by her daughter (Gervais 1989, 5–7).

> We met a park warden. He said he had a chance to look at the West Coast Trail yesterday. He said, "A lot of big blobs are already buried underneath the sand. We need the army." (Gervais 1989, 8)

There is a second, related reason that Gervais' journal still offers vital insights. Through a reading of her careful observations based on extensive volunteer labour, we can see that the objectives and definitions of "cleaning" an oil spill vary enormously between local residents and state or private responders, a reality heightened by the complex and dynamic materialities of oil and non-human natures like shoreline sediment and organisms. From the first days of the spill, Gervais noted that much of the oil was leaching into the sand, especially in the hot sun, meaning that "the oil can't all be picked up" (Gervais 1989, 1). Another day, three hours of work by a dozen volunteers recovered oil from about 100 feet of beach, yet "it wasn't properly cleaned, just the most obvious stuff" (Gervais 1989, 2). A federal minister who arrived in the area a few days after the spill "landed in a helicopter and said, 'Where is the stuff?'" Along with showing the minister "the blobs, mixed with the worm casings and the seaweed," a volunteer explained that much of the oil was "already buried underneath the sand and rendered invisible, especially from the helicopter." About this, Gervais noted that: "The minister looked uncomfortable. He had been shielded from the truth all day, flying over the coast in a helicopter" (Gervais 1989, 4–5).

> Around 4 pm., I talked on CBC again. I let the anger show in my voice. I told how the government is putting its head under the sand instead of facing the mess we are in. (Gervais 1989, 9)

This tension only became increasingly stark. A week into the response, Gervais wrote that the Coast Guard's on-scene commander, Colin Hendry, claimed on national news that "the damage is contained to a few miles of shoreline, otherwise we have clean beaches" (Gervais 1989, 5).

Similarly, a private contractor told her and other volunteers about a still-oiled beach that "this beach is clean" (Gervais 1989, 8). To such claims, Gervais wondered: "If the beaches are clean, how is it that I picked over 100 bags of contaminated material today, with 6 volunteers?" (Gervais 1989, 5). Several days later, she explained to *CBC* that state and private responders "are just picking in the very worst hit areas, relying on the ocean to clean the rest" (Gervais 1989, 8). Although new oil continued to wash ashore during low tide—"the first breath I get is similar to the smell one gets at the gas station"—Gervais noted that by the time that the Coast Guard would show up, "the tide is high and they don't see the mess" (Gervais 1989, 9).

> The sea has washed away the blackened sand. There is still oil, but not more than on any other beach. One has to know what to look for to identify it. Some kelp and eelgrass looked normal to Bob, but I knew otherwise. I asked him to touch. His fingers got black. (Gervais 1989, 10)

Even the oil that responders had recovered from the beaches was being improperly stored at a nearby airport, with Gervais observing: "Open bags lie on the pavement. No precautions are taken to prevent leakage" (Gervais 1989, 8). Gervais and the First Nation filed complaints due to the close proximity of their drinking water well to the storage site; however, critics described the stopgap solution as ineffective: "The stream that gathers run-off is very polluted. The leaves on the bottom are black and mud is oily" (Gervais 1989, 10). Despite this, a toxic waste management employee told Gervais that they "didn't find it too bad, with only minimal oil on the surface," to which she responded, "I know what I have seen and some people were there to see it with me" (Gervais 1989, 10). The next day, Gervais wrote that the sand on the beaches had frozen, rendering everything "greyish and indistinguishable," so that "nobody can pick anymore" (Gervais 1989, 11). She also called off her regular checking-in on the nearby Schooner Cove due to frequent sitings of a cougar in the area (Gervais 1989, 11). The "clean up" of the region was over.

> February 7: “Life is getting back to normal, though as one walks on the beach, it is hard to avoid seeing all the dead starfish, mussels and crabs. But after dinner, as I share raspberry tea and chocolate with my children, I forget for a few moments the pain and sadness I carry inside. L'oubli…” (Gervais 1989, 11)

The journal submitted by Gervais to Anderson in 1989 was the perspective of a single observer about the impacts of the *Nestucca* spill on a particular segment of Vancouver Island. Yet it reveals fundamental conflicts that often manifest between impacted community members and spill response experts about the objectives and processes of spill response itself. The ubiquity of such conflicts is evident from the Coast Guard’s own reporting about the spill, noting that despite its best public relations efforts, “the media preferred interviews with individuals belonging to special interest groups who invariably presented a view of the situation that was much worse than the actual circumstance” (CCGWR 1989, 48). This concern eventually led the agency to begin regularly distributing “fact sheets” to local officials and the media, but such efforts “were not enough to get out the government’s side of the story” (CCGWR 1989, 75).

Government officials had also taken such measures at the *Arrow* disaster almost two decades earlier. In response to an alleged “great deal of misinformation” (Hart 1971, 138) and a “hostile local environment,” it was deemed necessary by state officials to create a dedicated “community relations unit” to provide daily updates and present locals with “knowledge of the facts and evidence of positive action,” soon finding that a “novel method of imparting information to the community was through its children” and resulting in high school students being bused into the daily briefings almost every day for six weeks (MOT 1970, 13). Mediating the public perception and image of what was happening with the oil on the shorelines, in the ocean, and within the wreck was critical to the management of escalating backlash: a role that experimental spill work and related scientific knowledge production can also meaningfully contribute to by generating reliable information to describe processes that cannot be monitored.

Ahead of the five case studies that theorize historical oil spill experiments as a materialization of the "future eco-perfect," this chapter provides an overview of three closely related concepts: 1) oil as a materiality and commodity; 2) spills as a problem to be responded to; and 3) experimental oil spills as a complex tool to understand both to a greater degree. This three-pronged overview will work to provide a basic understanding of the major factors in play when it comes to oil spills and response, with much closer examination of scientific practices offered in the following case studies.

Oil

We often discuss "oil" as a singular, coherent, and universal materiality. At a fairly high level of abstraction, oil can indeed be seen as a uniquely energy-dense and versatile fuel and raw material (Labban 2008, 6; Pirani 2018, 4), with its inherent or produced liquidity facilitating its cheap and efficient transportation (Huber 2013, 18). In one of the more renowned pieces of recent critical oil scholarship, Timothy Mitchell (2011) argued that key differences between the production of oil and coal can help explain the loss of worker power previously exerted in the coal industry, writing that "unlike coal, therefore, oil was not concentrated into vital channels on which other processes depended, and oil regions did not become industrial centres" (31–32). Other scholars have assessed the extremely convoluted pricing dynamics of oil in the context of both artificial and natural monopoly conditions (Labban 2008, 42) and financialization through oil futures contracts (Labban 2010). More recently, Adam Hanieh (2024) has similarly worked to counter the common framing of oil that "ascribes a causal power to oil itself, which, at the end of the day, is simply a sticky black goo" (3).

These interventions have helped to denaturalize the ubiquity of oil in society, centring the prime movers of profit, competition, and financial markets (Shaikh 2016; Heinrich 2012).

Through these processes, the oil industry has massively expanded the production and use of the commodity of oil. At the same time, it remains important to understand oil at a far more granular and particular level, a reality that becomes especially evident during oil spills. At this level of analysis, it is possible to understand how oil itself is constituted as extraordinarily complex and diverse materialities that take on near-countless different compositions and forms depending on origin, stage of production, and environmental context. Canadian oil spill scientist Merv Fingas (2015) has explained this clearly: "Crude oil contains many compounds of different sizes and different classes. In fact, there are so many that as time goes by more and more compounds are identified in the oil. Currently, analysts have preliminarily identified up to 17,500 compounds in an oil. In the future, this number will no doubt rise significantly" (53). Other scientists have described oil as an "ever-changing mixture of compounds" with shared chemical signatures, again highlighting the extremely dynamic character of the materiality (Passow and Overton 2021, 110).

Ahead of the case studies that examine experimental oil spills in close detail, it is necessary to briefly describe the complex natures of oil. As indicated by their name, hydrocarbons are almost entirely made up of carbon and hydrogen, along with small quantities of nitrogen, sulphur, and oxygen (NSO) compounds and trace metals like nickel and vanadium (Fingas 2015, 53; Wiens 2013, 10). These arrangements of carbon and hydrogen exist in an incredible number of forms and variations. A popular although limited classification system uses the acronym SARA to represent *saturates*, *aromatics*, *resins*, and *asphaltenes* (Kharrat et al. 2007; Shiskova et al. 2024). Saturates, named due to the carbon atoms being maximally "saturated" by hydrogen atom—and also sometimes referred to as alkanes or aliphatics—are typically the most common class of compound found in light crudes and refined products like gasoline and diesel. *Straight-chain* or "normal" alkanes (often described as n-alkanes) start with the most basic compounds of methane, ethane, and propane, all of which are gases in their natural state; methane constitutes the bulk of what is conventionally known as "natural gas." Alkanes that are larger than four-carbons are liquid in their natural state. Lower-weight alkanes ranging from five- to eight-carbons are targeted for gasoline production, while medium-weight compounds are used for diesel and kerosene (jet fuel) production. The oil industry describes alkanes larger than eighteen-carbons—which are solid in their natural state—as waxes, with these fractions often refined into heavy fuel oils including marine fuels.

However, there are many more saturates than straight-chain alkanes. In particular, isomers—or different arrangements of same chemical formula—result in an enormous number of *branched-chain* alkanes, such that "the number of possible branched compounds rises to over one million by the time carbon number 22 is reached" (Fingas 2015, 55). Although much remains unknown, "it is suspected that the branched alkanes account for about two to five times" the proportion of straight-chain alkanes in oil. Further, there are *cycloalkanes*, sometimes called naphthenes, with the carbons joined in a ring formation in several different structures. Diesel, in particular, tends to have higher proportions of cycloalkanes. Yet another complication is the presence of alkenes (or olefins) and alkynes, which have at least one double or triple carbon bond, respectively. Due to being unsaturated, with some of the hydrogen atoms displaced by the additional bonding, these are not classed at saturates and are not included in the SARA system. Refineries produce these compounds—which constitute the foundations of the global petrochemical industry, with ethylene and propylene the two most basic alkenes that are the building blocks of plastics production—as part of their broader processing of oil and gas.

The next major class of hydrocarbon compounds is *aromatics*. These are defined in their most basic form of benzene, which has a ring of six carbon atoms, including three double carbon bonds. Along with benzene, the other most common aromatic compounds are toluene, ethylbenzene, and xylenes, collectively known as BTEX; these are called monocyclic aromatics, due to having a single ring. Gasoline is intentionally refined to contain high levels of BTEX, which helps provide the “explosive force driving the internal combustion engine” (Huber 2013, 134). However, due to their volatility, BTEX pose acute and severe toxic risk when spilled, quickly evaporating, dissolving, and integrating into organisms (Wiens 2013, 11). Compounds that have two or more of these benzene rings are described as polycyclic aromatic hydrocarbons, or PAHs, ranging from the simplest two-ring compound of naphthalene up to five- and even six-ring compounds. PAHs are of particular concern due to their toxicity and long-term persistence of higher-ring compounds, which spill scientists often use as a “fingerprint” to identify and track oil over time (Fingas 2015, 58; Wiens 2013, 11). Heavier crudes and refined fuels tend to have much higher proportions of PAHs. “Heterocyclic” compounds are additional variations of aromatics in which nitrogen, sulphur, or oxygen supplants a carbon group, which increases their solubility and “their bioavailability and thus poses a risk to living organisms” (Passow and Overton 2021, 111).

The third and fourth classes of hydrocarbon compounds are known as resins and asphaltenes, which are differentiated by their solubility in lighter hydrocarbons. These compounds frequently contain high concentrations of metals and heterocyclics. However, unlike saturates and aromatics, far less is known about these compounds (Fingas 2015, 69), and rather than chemical constituents they are “defined operationally by the method of separation” (Speight 2004, 473). Resins and asphaltenes are “generally considered together as they are what is left when the saturated and aromatic hydrocarbons are removed from the oil" (Wiens 2013, 12). Importantly, this non-volatile fraction of oil is "not water soluble and is largely responsible for the density and viscosity of crude oil" (Wiens 2013, 12). They are also "practically resistant to microbial degradation" (Passow and Overton 2021, 111). Heavy oils and fuels have particularly high proportions of resins and asphaltenes, requiring producers to dilute bitumen from the Alberta oilsands for transportation; refiners also require complex and specialized systems such as coking units to process these fractions.

The behaviour, effects, and fate of spilled oil is shaped by the proportion of saturates, aromatics, resins, and asphaltenes in the oil. For instance, massive differences in the density and gravity of these fractions determine the ability for oil to float in water—with oils that have more resins and asphaltenes more likely to sink in certain conditions—while the volatility and flash point of oil products that facilitate its evaporation and burning are far greater in oil products high in aromatics and saturates. Meanwhile, the probability of stable water-in-oil emulsions forming, which can in turn complicate response efforts, is strongly influenced by the viscosity of the oil, which increases with the proportion of resins and asphaltenes (Wiens 2013, 12). The higher-weight alkanes, larger PAHs, and fractions of asphaltenes and resins are "less bioavailable and only degraded slowly even in the presence of nutrients and oxygen," with their "extreme water insolubility … limiting their mixing ability with the oxidants, and accessibility to light and microbes" (Overton et al. 2022, 8). However, this does not mean that lighter oils are innocuous: on the contrary, volatile and soluble compounds can cause extreme acute toxicity resulting in widespread socioecological harms.

Hydrocarbon materialities are only further complicated by the circulative reality that economically, politically, and technologically recoverable oil reserves (Labban 2008, 3) are highly geographically concentrated and "often remote from large markets" (Mitchell 2011, 32), necessitating extensive and complex networks of tankers, pipelines, trains, and trucks to ship to sites of profitable consumption. In combination with the "coercive laws" of capitalist competition (Heinrich 2012, 89) that impel cost-cutting and regular crises of overproduction (Labban 2008, 4), the inherent complexity of these infrastructures leads to an "inevitable litany of spills" (Huber 2013, 133; Kheraj 2020). These spills, whether from an accidental train derailment or from a blowout hundreds or even thousands of feet below the ocean surface, spread oil throughout ecosystems including oceans, lakes, rivers, and forests, and configurations like First Nations reserves, farmland and urban or industrial areas. These aspects are also deeply sociopolitical and geopolitical in character. As only one of many possible examples, the rise of the oil supertanker in the late 1960s was propelled by the closure of the Suez Canal following the Six-Day War of 1967 in order to profitably ship oil around the Cape of Good Hope, with the "limits of the advances of scaling up" quickly demonstrated with the *Torrey Canyon* oil spill that same year (Khalili 2020, 244–245; Campling and Colás 2021, 245, 252). This spatiotemporal dynamic has meant that spills can and do happen anywhere that oil is produced, transported, and consumed—practically every part of the globe—while the incredibly complex materiality of oil itself produces an incalculable variety of spill scenarios and outcomes. These material realities render scientific study and response preparation an extraordinarily challenging task.

Spill

The oil spill is the quintessential ecological crisis of the last half-century. Countless other environmental issues have had monumental impacts: the DDT of *Silent Spring*, nuclear fallout of Chernobyl, and deforestation of the Amazon. But it is the large-scale release of oil from tankers, offshore rigs, pipelines, trains, and refineries that has most consistently and powerfully shaped public consciousness, activism, and policy of environmental issues since 1970. One could effectively tell much of the environmental history of the US using the oil spill as analytic, tracing a lineage through the Santa Barbara blowout of 1969, *Exxon Valdez* grounding of 1989, and the *Deepwater Horizon* disaster of 2010. Closely articulated with struggles for Indigenous nationhood and rapid decarbonization, the dire threat of oil spills to ecosystems, non-human animals, local economies, and human health has been one of the foundational concerns motivating decades of resistance to fossil fuel extraction and infrastructures. In the mid-1970s, Vince Steen, an Inuk from Tuktoyaktuk and future politician, warned the now-legendary Mackenzie Valley Pipeline Inquiry: "with one oil spill of any size big enough to hurt those animals, we're finished. The Eskimo population and culture is finished, because you [will] have to live as a white man and you [will] have nothing left" (Berger 1977, 67). Enormous anti-colonial struggles against the Dakota Access Pipeline and Trans Mountain Expansion have been similarly oriented around the significant risk of spills introduced or worsened by such projects.

It is the *visibility* and *immediate impact* of the oil spill that makes it such an urgent and contestable crisis. Unlike many other socioecological disasters—most notably the greenhouse gases rapidly propelling climate catastrophe—the consequences of a spill tend to manifest within hours and days of the incident: clear waters are fouled; thousands of birds and fish wash up dead; local communities are evacuated. It can also significantly disrupt other sectors including fisheries, tourism, and communities that rely on water intake from nearby sources. A large oil spill is typically impossible to ignore, depriving industry and state of the oft-preferred mechanism of deferring radical action well into the distant future. Further, due to the incredible ubiquity of oil production and consumption, spills can and do happen anywhere: lakes, farmland, cities, oceans. Along with the hyper-visibility of the crisis and the urgent timeliness of a response, this tremendous geographic reach—related to oil's specifically liquid and energy-dense properties—implicates almost all aspects of industrial society in a way that few other environmental threats do. Depending on location, weather conditions, and spill specifics, an assortment of response tactics—containment booms and skimmers, in-situ burning and dispersants, manual labourers and heavy machinery—must be quickly deployed under the guidance of an on-scene commander, response organization, and contingency plan to try mitigating the most perceptible harms of the incident. Every minute counts. Poorly managed spills can result in widespread public criticism and major costs to industry: years of clean-up and monitoring, hits to share values and reputations, protracted insurance and liability battles, stricter regulations and project reviews, fines and criminal charges, suspensions and cancellations of drilling activities, and even regional moratoriums or bans; as a particularly extreme example, BP faced concerns of possible bankruptcy and eventually had to pay out $65 billion in compensation for the devastating *Deepwater Horizon* spill of 2010 (Bousso 2018).

The oil industry itself has long been aware of such possibilities. In a 1972 letter, the chair of the Arctic Petroleum Operators' Association's (APOA) oil spill committee warned that "should a spill of any significance occur, the industry would be the subject of severe criticism from the public sector and the governmental agencies involved and could seriously jeopardize future operations in the Arctic" (Wright 1972, 2). Similarly, in early 1978, the manager of the federal Arctic Marine Oilspill Program (AMOP) stressed that "the ability of Industry to combat an oil spill would be a major concern expressed at public hearings dealing with exploration drilling in new offshore areas" (Telford 1978, 2). Yet another industry meeting in early 1982 that discussed a recent critical report about an extremely delayed spill response in the Arctic concluded that "at all costs industry should never been seen to be doing nothing in terms of response and the Oil Industry must be prepared if we do not want to incur the same sort of criticism" (APOA/EPOA OSC 1982, 1). States can also suffer significant crises of legitimacy, especially for those anchoring their accumulation strategies and hegemonic visions on fossil fuel development (Jessop 2016). In this sense, it is useful to think about oil spill science as a form of what Deborah Cowen (2014) has termed "supply chain security" in logistics, or efforts to "govern events and forces that have the potential to disrupt trade flows" which "mobilizes preemption techniques to mitigate vulnerability … and preparedness measures to build resilience and recover circulation in the wake of disruption" (78–79).

However, there are profoundly differing views on the objectives of spill response, particularly between the public and spill scientists and responders. When speaking with colleagues, spill experts are often extremely candid about their own stark differences from public perceptions and expectations of spill response. For example, in 1981, a staff member of Environment Canada's Environmental Emergency Branch wrote about a panel discussion he observed at an oil spill conference in Atlanta, Georgia, that: "In summary, it is clear that the 'experts' from government and the oil industry can agree on how clean is clean; the public unfortunately has a different perception of the answer to this question than the experts have" (Kingham 1981, 1). David Dickins (2022) similarly explained that while conventional techniques like booms and skimmers can be deployed fairly effectively for small spills in contained settings like harbours, they are useless in most situations of large marine spills (42:40–43:00). Offering a response to Dickins' comments, ExxonMobil spill researcher Tim J. Nedwed added: "Everyone wants mechanical recovery. Everyone wants the oil to go back into a container. But the impossibility of doing that is really the heart to understanding that you've got to open up the aperture" (Dickins 2022, 1:21:55–1:22:10). While Transport Canada has indicated that between

10 to 15 percent of a marine spill can be recovered in open water (Nikiforuk 2016), actual spill responses often result in far less than that: only 2 to 5 percent of the oil spilled at *Deepwater Horizon* was physically skimmed from the water surface (French-McCay et al. 2021, 7).

Rather than seek to physically collect spilled oil, the main objective of most spill response is instead to *leverage and accelerate natural processes*, or what Jason W. Moore (2015) has described as "putting nature to work" (1). Along with response measures like dispersants and burning, a major focus of spill response involving "natural attenuation," or "remediation of a contaminated site by natural processes alone, without human intervention" (Lee et al. 2015, 24). For example, the Royal Commission study into the *Arrow* spill of 1970 concluded that "eventual clean up would be conducted by the forces of Nature" (Hart 1971, 157). In 1981, Jim Kingham of Environment Canada's Environmental Emergency Branch referred to this understanding in explicit terms when he wrote: "the biosphere can absorb a certain loading of oil whether from natural sources or man-made spills. This assimilative capacity of the marine environment needs to be recognized" (Kingham 1981, 1).

There are many more instances of spill scientists indirectly appealing to this notion. A year after Kingham's description, Environment Canada's manager of the Baffin Island Oil Spill (BIOS) project told media that the spill experiment had proven that "nature will tend to protect itself" as "wind and waves will tend to spread the oil so far and wide there will not be devastation" and "sunlight will destroy oil, bacteria will eat it, cold will congeal it, and ice and snow will absorb it" (Keating, 1982). Following widespread criticism of Coast Guard response to the 1989 *Nestucca* spill that, like the *Arrow* response, left much of the oil stranded on the shorelines left for "natural cleaning" (Canadian Coast Guard Western Region 1989), a UBC oceanographer explained "there's a consensus among scientists that the ocean does a pretty good job of cleansing itself of an oil spill's effects," while a retired federal scientist added that "natural wave action is the best way to handle spills on exposed coastlines" (Mertl 1989). Three decades later, Kenneth Lee (2020), a leading oil spill researcher with Fisheries and Oceans Canada, framed it in similar terms that "the question is, when a spill occurs, what is nature doing on its own?" (28:00–28:10) and that the role of oil spill response is "to help nature along" (7:05–7:15).

Copious quantities of spilled oil can indeed be removed from the water surface and shoreline through an array of natural processes. Within mere minutes and hours of a spill, "many petroleum hydrocarbon compounds fractionate rapidly into the atmosphere and water column," especially via processes of evaporation and dissolution (Gros et al. 2014, 9400). In addition to these processes of physical transfer, some fractions of oil also undergo chemical transformation into new compounds via microbial and photochemical oxidation (Ward and Overton 2020; Overton et al 2022). In an ideal scenario, such processes can efficiently redistribute and dilute the most toxic compounds to sub-lethal levels and convert some of the lighter fractions of oil into less harmful or even neutral outputs such as carbon dioxide and water. During the *Deepwater Horizon* blowout, microbes biodegraded an estimated 60 percent of the oil in the deep "intrusion layer" within only weeks of the spill (Passow and Overton 2021, 113).

The primary goal of such responses is to efficiently remove oil from the water surface and shoreline, which can cause highly visible mass die-offs of birds and marine mammals, along with significant damages to fisheries, recreational areas, and coastal communities (Potter et al. 2012, 62). The interventions of in-situ burning and chemical dispersants are designed to accelerate this mass transfer of oil into the atmosphere and water column, respectively. For instance, Lee has described the use of dispersants as "primarily an offshore spill response technology to keep the oil slick from coming to shore and near-shore waters, where biodiversity is higher and where environmental impacts from oil may be much greater" (Clear Seas 2020). Similarly, while in-situ burning produces massive quantities of particulate matter and gases like sulphur dioxide and nitrous oxides, the potential short-term impacts are deemed to be justified given the limited alternatives. In particular, the widely used "Net Environmental Benefit Analysis" (NEBA) provides a means of "weighing the advantages and disadvantages of different oil spill responses and comparing them with the advantages and disadvantages of natural cleanup" (Lunel and Baker 1999, 619; Baker 1995; Owens et al. 1999).

The major problem, however, is that nature's ability to process spilled oil is rarely as agreeable or seamless as often claimed. While some oil is degraded and transformed, significant portions of a spill can remain in the environment in various forms. For instance, simple evaporation of oil can transport a "gigantic quantity of VOCs into the marine atmosphere" and contribute to production of ground-level ozone in coastal regions (Song et al. 2011, 1312), while the creation of water-in-oil emulsions (also known as "chocolate mousse"), marine snow, oil-mineral aggregates (OMAs), bacteria-oil aggregations (BOAs), and "rather recalcitrant" oxygenated compounds (Aeppli 2022, 6) that "represent the major component of tar balls" (Kimes et al. 2014, 6) can lead to long-term persistence and continued toxicity of oil in ecosystems. Over time, the removal of lighter and volatile fractions of oil often leaves the heavier and insoluble fractions to sink to the seabed or congeal on shorelines, where they can become trapped and effectively preserved for decades. Although much-heralded processes like biodegradation can certainly produce successful results in some sites, it can be heavily curtailed due to lack of nutrients and oxygen.

All of these factors combine to mean that a combination of spill responders and natural processes can shift oil spills from a particularly visible iteration of "nature" without ever actually being "cleaned up" in any real sense. These realities led to a study of the long-term effects of a major spill in a port in Northeast China concluding that "the quality of seawater may improve after an on-site cleanup, but it does not mean that pollution has disappeared or that the ocean has returned to its original state" (Guo et al. 2022, 11). Effects from spills can also take a long time to manifest. Recent studies of long-term spill impacts on shoreline systems have documented "unprecedented sublethal impacts" on mangrove forests in Brazil (Lassalle et al. 2023) and massively escalated erosion rates and "cascading and lingering effect on the dependent marsh food web" in coastal wetlands of Louisiana (McClenachan and Turner 2023, 7). Many of the biological impacts of the *Deepwater Horizon* blowout—such as chronic lung disease and reduced reproduction in dolphins—are expected to last decades or even centuries (Passow and Overton 2021, 129). Further, apparent fixes can later re-erupt into crisis, such as long-sunken ships starting to belch large volumes of oil and restarting response processes decades after a spill (Jones 2018; *CBC News* 2020; Chan 2024). Such outcomes are vastly different than the image of spill response often claimed by politicians and oil companies. As researchers concluded a review article about the *Deepwater Horizon* disaster, the state of post-spill recovery is a "*matter of viewpoint and scale*" (Passow and Overton 2021, 129).

Experiment

Between 1970 and 2000, at least 40 experimental oil spills were conducted in Canada. These spills ranged enormously in volume, research objective, and location, occurring extensively on all three coasts, the St. Lawrence River, and smaller lakes and rivers. Throughout this time, federal departments had major and often primary involvement in this work, with the largest spill experiments involving international collaboration—such as the Newfoundland Offshore Burn Experiment and BIOS project—led by Environment Canada scientists. Many industry research associations and state-industry partnerships were also established during this time to advance experimental spill work and associated research. While funding and prioritization has ebbed and flowed over the years, the greatest level of continuity in this work has come from federal departments and services, particularly Environment Canada's Environment Protection Service. We can theorize this consistent involvement by the state as means of attempting to reproduce one of the conditions of production necessary for capitalist accumulation: namely socioecological well-being, which includes neutralizing or otherwise containing struggles that could impair accumulation (O'Connor 1998, 176; Rudy 2019; Fraser 2022).

This research work overwhelmingly corresponded with anticipated oil production and transportation in a given region, with "frontier" exploration in the Arctic and East Coast greatly accelerating with the establishment of Petro-Canada in 1975 and the National Energy Program in 1980, in response to the global "oil price revolution" of the 1970s (Laxer 1983, 2; Garavini 2019). The research was also significantly shaped by rising environmental consciousness and Indigenous resistance to many large-scale resource extraction projects, such as proposed hydroelectric development that led to the James Bay and Northern Quebec Agreement of 1975. Along with the *Arrow* disaster, public concern about large spills had also been greatly heightened in the wake of the 1967 *Torrey Canyon* tanker grounding in the UK, 1969 *Santa Barbara* blowout in offshore California, and notorious *Manhattan* voyage through the Northwest Passage in 1969, which tested the possibility of transporting Alaska oil to the East Coast of the US using an icebreaking tanker (Grant 2010, 351; Coen 2012). This dynamic was exemplified during the now-famous Mackenzie Valley Pipeline Inquiry of the mid-1970s; based on widespread opposition by Inuit and Dene people to the proposed pipeline, inquiry commissioner Thomas

Berger (1977) called for a temporary moratorium on pipeline development and highlighted the need for spill research:

> The greatest concern in the Beaufort Sea is the threat of oil spills …. I urge the Government of Canada to ensure that improvements in technology for prevention of spills and development of effective technology for containment and clean-up of spills precede further [in] advance of industry in the Beaufort Sea. I further urge that advances in knowledge of the environmental consequences of oil spills should likewise keep ahead of offshore development. (xv–xvi)

Some of the first experimental spill work was conducted through the "environmental-social program" of the federal Task Force on Northern Oil Development, which "quickly outgrew its original mandate to become a tireless advocate of Mackenzie Valley oil and gas pipelines" (Bregha, 1979, 20). Scientists conduced three separate spill studies in Mackenzie Delta rivers and lakes to assess the biological impacts of oil in aquatic environments, in clear anticipation of the possibility if companies built pipelines through the Mackenize Valley (Snow et al. 1975; Snow and Rosenberg 1975a; Snow and Rosenberg 1975b; Snow and Scott 1975). Two Environment Canada scientists involved in this work explained this linkage clearly:

> Now that one of the frontiers of oil exploration activity is the Arctic, the problem is likely to become acute, since this environment adds new dimensions. The rigorous climate increases the longevity of deleterious effects, decelerates natural biodegradation processes, and hinders remedial measures by imposing severe constraints on men and machinery. (Snow and Scott 1975, 527)

Another round of experimental spill work was triggered when the federal government issued an "approval-in-principle" for exploratory drilling by Dome Petroleum in the Beaufort Sea in mid-1973 (Dome et al. 1982, 2.15). The state explicitly conditioned this approval on addressing concerns that "an oil-well blowout is still possible, and its obvious threat to the fragile arctic environment" (Ages 1975, 3). The estimated $2.5 million in oil industry expenditures on Arctic research prior to that point was acknowledged but deemed insufficient due to having focused on "safe operation (i.e. on preventing a blow-out) rather than on clean-up" (Ages 1975, 4). As a result, the federal state did not allow offshore drilling to begin in the Beaufort until mid-1976, and a "careful assessment of the environment in the Beaufort Sea" had to be completed via an "environmental assessment, in essence an accelerated program" called the Beaufort Sea Project (Ages 1975, 3).

Between 1974 and 1976, the Beaufort Sea Project involved more than 100 scientists and produced 46 technical reports through "joint direction" by APOA and the federal environment department (Nikiforuk n.d., 5; Dome Petroleum et al. 1982, 2.15). Most notably, scientists conducted the massive 56,000 litre Balaena Bay spill experiment—still one of the largest spill experiments in Canadian history—in 1974 and 1975 as part of the program. Although industry contributed $4.1 million of the $5.3 million in new spending necessary for the Beaufort Sea Project, "the total government contribution, including personnel, equipment and facilities amounted to approximately 7.5 million dollars" (Ages 1975, 4). The federal state was also "responsible for coordinating the program and maintaining cost control, as well as having final authority over work specifications and awarding of contracts" (Dome Petroleum et al. 1982, 2.15). Along with the importance of the research itself, the Beaufort Sea Project was heralded as significant due to how "the petroleum industry became directly involved in the environmental studies, and could assist government scientists with its experience" (Ages 1975, 4).

While offshore drilling was rapidly increasing in prominence, concerns remained around the possibility of large *Arrow*-like spills from tankers and barges in more southern regions, particularly in or near the harbours and coastlines of major cities. In such settings, containment booms and mechanical skimmers were frequently framed as the most effective and "ideal" oil spill response (Solsberg et al. 1976, 1), given that they directly remove oil from water rather than displace it into other forms and fractions of the environment. This possibility led to the federal

Environmental Protection Service's Centre of Spill Technology drawing up a set of testing procedures and criteria for skimmers in mid-1973 (Solsberg et al. 1976, 75). At least 11 separate rounds of experimental spills were conducted throughout the 1970s on the West Coast, East Coast, and the St. Lawrence River, with each of these rounds often involving dozens of small spills in water to evaluate the performance of skimmers. However, as spill scientists increasingly found skimmers to be challenging and even ineffective to operate in open-water offshore conditions, large-scale experimental spill work progressively pivoted towards use of other response measures such as chemical dispersants and in-situ burning.

The creation of Petro-Canada and the National Energy Program (NEP) further accelerated this pivot, particularly given the often-extreme locations that federal state incentives sought to propel investments in. Along with attempting to shore up oil supply for domestic energy security, a major motivation by the federal Trudeau-led government was to assert greater control and revenue-generating capacities over the oil industry, especially from the provinces and US oil companies. The Alberta government, in particular, was consistently obstructing any and all efforts to rebalance the national landscape of oil supply, pricing, and trade (*New York Times* 1973; Borders 1973; Lalonde 1990, 54). As a result, the federal state worked to further promote oil exploration and production in the territories and offshore regions that it had authority over, guaranteeing far greater control over its use and revenues.

Economist Robert McRae (1982) described the NEP as explicitly "in favor of encouraging development of Canada Lands as opposed to provincial lands" and anticipated that it would lead to a "premature displacement of production from a low-cost area to a high-cost area" (McRae 1982, 178). Although not explicitly stated, the frontier focus of the NEP was to "shift activity to areas under federal jurisdiction," with its architects believing that "oil was too important a commodity to remain under provincial control" (Pratt 1985, 182). Generally, there was hope among economic nationalists in federal cabinet that such interventions could serve as an "adjunct to an industrial policy that gave domestic industry the advantage of lower energy costs," becoming an "element in a broader strategy for the achievement of a more self-reliant, productive, technologically sovereign Canadian economy" (Laxer 1983, 83).

While the vicious backlash against the NEP (Gutstein 2018, 17; English 2009, 488–491; Laxer 1983, 81–84) ensured that such a dream never came anywhere close to fruition, the federal policies and incentives for frontier exploration worked extremely effectively. Between 1976 and 1985, Petro-Canada accounted for an estimated 40 percent of total industry spending on exploration in the "Labrador, Baffin and Arctic Islands regions" (*New York Times* 1985). These frontier-focused efforts resulted in significant finds. In 1979, an industry consortium that involved Petro-Canada with a 25 percent stake—only slightly less than consortium leader Mobil's 28 percent participation (Metz 1979)—discovered the gigantic Hibernia oil field offshore from Newfoundland, which had "revealed to the government and companies that major commercial oil discoveries could be made in the frontiers" (Pratt 1985, 181). Petro-Canada partnerships also discovered the Venture gas field near Sable Island (Zehr 1979)—which industry eventually commercialized as part of the Sable Offshore Energy Project—and the Hekja gas discovery in Davis Strait (*Globe and Mail* 1980a).

Larry Pratt (1982) argued that Petro-Canada's "essential purpose was to promote exploration for oil and gas resources in Canada at a rate and in high-risk areas which could not be expected of the private sector" and that the acquisition of companies with conventional assets like Pacific Petroleums and Petrofina was "to obtain a stream of earnings which could help finance its costly, high-risk investments" (52–54). Pratt (1982) continued that frontier activities, frequently disparaged by the industry as the product of “managerial inefficiency,” should instead be understood as the outcome of Petro-Canada’s specific mandate, “which is not to maximize profits but to accelerate the development of higher-cost energy sources” in the frontiers (54). In other cases, Petro-Canada was not involved in drilling activities but the private ventures were generously supported through state subsidies via the NEP; for instance, the discovery of the huge Amauligak oil field in the Beaufort in 1984 was drilled by a partnership led by Gulf Canada but a “large portion” of the $140 million well cost was “paid by the Canadian government” (*Wall Street Journal* 1984). In total, under the NEP’s fiscal policies that especially incentivized frontier drilling, a total of $6.8 billion was distributed between 1981 and 1987, largely for exploration work in the Beaufort Sea, Grand Banks, and Scotian Shelf and Slope (EMRC 1987, 10–11).

All of this exploration work led to significantly higher spill risk. Several major federally coordinated spill research initiatives were started in the late 1970s to help address this issue, including the Arctic Marine Oilspill Program (AMOP)—which organized some experimental spill work, such as the Griper Bay multi-ice spill of 1978 (Comfort and Purves 1982)—and the Eastern Arctic Marine Environmental Studies (EAMES) program (Hume et al. 1983; Mackay 1984; Sutterlin and Snow 1982, iii). Government and industry also formed the Canadian Offshore Aerial Applications Task Force (COAATF) in 1976 to evaluate dispersant application from airplanes and helicopters (COAATF 1986, 1), leading several major trials in Alberta, Newfoundland, and Nova Scotia throughout the 1980s. In 1978, the Environmental Studies Revolving Funds (ESRF) were created by the federal government using levies from the frontier oil and gas industry, providing a “forum for industry and government to develop a common knowledge base and to jointly design a focused study program which addresses the needs of both groups and avoids a repetition of effort and expense” (CIRNAC 2017), much of which focused on or related to oil spill science. The ESRF supported several major spill experiments, including a large dispersant test offshore of Tuktoyaktuk (Swiss and Vanderkooy 1988) and an oil-in-ice study offshore of Nova Scotia (Buist and Dickins 1987).

In 1980, industry formed the Canadian Offshore Oilspill Research Association (COOSRA) as the amalgamation of the oil spill research and development committees of two industry groups that were themselves organized along regional lines: the Arctic Petroleum Operators' Association (APOA) and Eastcoast Petroleum Operators' Association (EPOA) (Jones 1981; Hume et al. 1983, 315; Gainer 1982, 1). Although APOA and EPOA had both organized and funded extensive research work—totalling more than 200 projects and $50 million in spending between the early 1970s and 1982—expanding offshore oil and gas exploration meant that "industry and government concern for the environmental impact of a potential oil spill increased" (COOSRA 1985, 1). Privately, industry feared that it had become "evident that development of offshore oil and gas would not be permitted until certain questions could be answered more satisfactorily," particularly relating to cold-water and Arctic conditions, and that "there were some implications that development and perhaps even exploration permits would be denied to those who did not acquiesce to join in supporting" federally organized spill research projects (Jones n.d., 1).

Industry viewed the forming of COOSRA as an answer to this issue, along with resolving inefficiencies and helping to overcome "the problems of confidentiality and duplicated research effort that could hamper spill research" (Hume et al. 1983, 315). By the mid-1980s, COOSRA (1985) had 17 "operator members," had spent about $5 million in spill research, and was involved in a total of 26 research projects (Goodman 1980, 1; COOSRA 1985, 2–3). Along with organizing industry support of BIOS (Hume et al. 1983, 315; Blackall and Sergy 1983, 455), COOSRA participated in several other experimental spill studies including a return to Balaena Bay—the site of a large-scale controlled spill in the mid-1970s—to evaluate longer-term effects, under-ice spill studies in McKinley Bay, and the Beaufort Sea dispersant trials (COOSRA 1985; COAATF 1986).

This kind of industry involvement proved increasingly important in the early 1980s, as oil company personnel flagged an "erosion of [the federal state's] scientific capability and hence credibility in northern research and management" and described the main contributors as "static funding and escalating costs, compounded by geographic and logistic problems of working in the offshore areas" (Lewis 1980, 2). Independently, Dome Petroleum had worked to advance spill response research, including the aerial igniter test near Yellowknife (D. F. Dickins Engineering 1979) and taking over the leadership role of the major McKinley Bay oil-in-ice experiment after the federal AMOP had its budget cut nearly in half in the early 1980s (Dickins et al. 1981; APOA OSC 1978, 1). Notably, a Dome representative had told other industry personnel that the company was "disappointed" in lack of industry support for continued spill research (Jones 1980, 10), and Dome opted to keep the results of the first McKinley Bay experimental spill results confidential "because most members of the industry have shown little interest in financing the project" (*Globe and Mail* 1980b).

By early 1983, the chair of the APOA/EPOA spill committee had called a meeting "on short notice" in order to "discuss the possible demise of the Federal Department of Environments' oil spill Research and Development programs" (APOA/EPOA OSC 1983, 1). A growing issue flagged in the meeting was that new priorities had been developed within the Environmental Protection Service—with greater emphasis being placed on acid rain and toxic chemicals—and that "significant budget cuts have already occurred and the first areas affected is likely to be contract services," an especially worrisome proposal given that "the AMOP program is run almost exclusively on contact services" (APOA/EPOA OSC 1983, 1–2). Specifically, oil industry specialists anticipated that such budget cuts would "directly affect the AMOP Conference and BIOS and other government/industry joint programs such as the offshore dispersant trials" (APOA/EPOA OSC 1983, 2). Spill experts feared that funding cuts would further jeopardize research activities in 1983 and 1984, with the loss of "one focal point" leading to existing work becoming "fragmented" (APOA/EPOA OSC 1983, 2).

The global oil price collapse of the mid-1980s—a combination of the "Volcker shock," slowing oil consumption, and rising oil production from non-OPEC producers (Hanieh 2024, 193; NEB 1984, 9), only worsened by Canada's domestic pricing deregulation—devastated the oil industry and predictably had major effects on spill research funding and capacities. As feared, spill research continued to decelerate in the coming years as oil prices and industry activity collapsed, especially in the country's high-risk frontiers. In 1985, a meeting of oil spill committee executives reported that spill planners cancelled a dispersant workshop in Ottawa "due to a lack of enthusiasm from officials in government" (APOA–OOD/CPA OSC 1985, 3). It was concluded that future efforts for such "information transfer" should be reallocated to "regional level officials," with plans for similar seminar taking place in Whitehorse the following year, especially given that an earlier workshop in Yellowknife was attributed as having "paved the way" for approvals for dispersant use at a recent spill (APOA–OOD/CPA OSC 1985, 3).

Similarly, study planners cancelled a research project in 1986 designed to evaluate the performance of skimmers in viscous oil due to a combination of costs, the industry downtown, the "lack of impetus for Hibernia," and the loss of committee members (CPA-FD OSC 1986, 2). Previous committee meeting's attendance had been "so small, no minutes were kept" (CPA-FD

OSC 1986, 1). In October 1986, the supervisor of Dome’s oil spill program told the manager of the Canadian Petroleum Association’s frontier division—which had absorbed both the EPOA and APOA—that the oil spill committee did not plan to undertake any “major new activities” in 1987, a “reflection of the general downturn in offshore activity for both the East Coast and the Beaufort Sea and the concomitant reduction in concern related to oil spill response” (Swiss 1986, 1). However, industry personnel assured that “when offshore activity increases again, many of the concerns related to spill response will return and the Committee’s activities in this area would increase as well” (Swiss 1986, 1).

This prediction of returned spill concern and research was fulfilled with the ramping up of activities around the giant Hibernia offshore oil project, with an operating consortium formed in 1988, and a production license issued and soon followed by the finalization of the fiscal regime in 1990 (Hibernia Management and Development Company 2025). Further, a joint venture started oil production at the small Cohasset-Panuke project in Nova Scotia’s offshore in 1992, adding to the revived impetus for spill research. However, in contrast to the oil industry’s increased share of scientific research in the 1980s, federal state departments returned to a leadership role in the 1990s. Much of this related to the state’s own investment in Hibernia. In 1993, with the project facing imminent collapse due to Gulf Canada leaving the project, the federal government agreed to take an 8.5 percent share for $290 million to keep it alive—in addition to the $1 billion awarded in 1990—with cabinet explaining that “Ottawa's participation is warranted because Hibernia will help open a new frontier of offshore oil drilling on the East Coast and develop Canadian expertise, as well as help ‘stabilize’ Newfoundland's struggling economy” (Marotte 1993). Long-standing concerns about Hibernia’s spill risk propelled new spill experiments and studies (Yaffe 1985; *Canadian Press* 1986), with the 1987 Newfoundland

Oil Spill Experiment (NOSE) explicitly "intended to test equipment that would be used should an accident occur in the Hibernia offshore oil field southeast of the Newfoundland coast" (*Globe and Mail* 1987).

Then, in 1993, Environment Canada developed and led the massive NOBE that involved more than two dozen sponsors from industry and state agencies, and represented the largest spill experiment in Canadian history. This leadership role by Environment Canada in international research collaborations, largely forged through BIOS, continued in the years that followed, most notably in the In-situ Treatment of Oiled Sediment Shorelines (ITOSS) experimental spill work in Svalbard, Norway, in 1997, which involved state departments and agencies from the US, UK, Norway, and Sweden. While university scientists have also played a significant role in recent years, the federal state has continued to play a principal role in coordinating and funding such work, including through the Multi-Partner Research Initiative (MPRI) of the Oceans Protection Plan.

This opening chapter has provided an overview of oil as a highly complex materiality, spills as socioecological crisis that is regarded in very different ways by the public and experts, and the historical use of experimental spills to advance scientific knowledge about the issue, particularly in anticipation of offshore exploration and production in the so-called "frontier" regions. The next five case studies will examine this experimental work at a far more granular level. As outlined in the introduction, and building on the conceptual and historical work developed in this chapter, each will demonstrate how the design and execution of this experimental work materialized conditions best described as a "future eco-perfect" scenario that frequently understated the sheer complexity and unpredictability of actual spill response. To understand the often radical disconnect between scientific understandings of spills and the material realities of spill response, it is necessary to closely investigate the actual scientific practices that contributed to this certainty in the first place.

Chapter 2: Siting

Nobody wants an oil spill in their backyard, even when its purpose is for scientific research. This was made abundantly clear in the late 1970s and early 1980s, as a group of oil companies and state agencies attempted to find a suitable location for the Baffin Island Oil Spill (BIOS) project, which planned to intentionally spill almost 50,000 litres of oil through several discharges to evaluate its impacts and the effectiveness of various response technologies in Arctic conditions (Sergy 1986, 24). Federal state narratives of the search later framed this question as a process of identifying coastal areas of Labrador, Lancaster Sound, and the Beaufort Sea as "all potentially appropriate" experimental spill sites; "air and ground surveys and community consultations" led spill scientists to the focus on northern Baffin Island (Sergy 1986, 6). However, while Baffin was given the imprimatur of scientific authority, meeting minutes from the planning process in early 1980 reveal that Labrador had already been rejected as a spill site due to resistance by Inuit, not merely technical limitations or concerns.

Several members of the BIOS management committee preferred the Labrador coast site, with the Petro-Canada representative arguing that "industry support would be much easier to obtain if such a move was made," while another committee member argued that "insufficient effort had been expended in trying to select and obtain approvals for a Labrador site" (BIOSPMC 1980, 9–10). In response, Peter Blackall of the Environmental Protection Service recounted that he had asked residents of the small Labrador Inuit communities of Rigolet and Makkovik if they would be willing to "give up a small piece" of their fishing grounds for the scientific work (BIOSPMC 1980, 10); in the late 1950s, many Inuit from more northern communities had been forcibly relocated to these more southern towns for state and commercial benefits (Bernauer and Peyton 2021, 349; Wat 2024). Community members reportedly "firmly indicated that their livelihood depended on fishing" and "were not prepared to give up any portion of their fishing area" (BIOSPMC 1980, 10–11). Representatives from the Labrador Inuit Association and Labrador Resources Advisory Council then outlined their fishing territory, spanning the "whole coast from Nain to Makkovik," at which point planners surveyed the "short stretch of shoreline" remaining for consideration and found it to be inadequate for the experiment (BIOSPMC 1980, 11–12).

At this point, spill planners notified the potentially impacted communities that they had not found an alternative site in Labrador, and requested a reconsideration of the blanket restrictions on the region. However, Blackall said that "the limited response indicated that no other areas were acceptable" (BIOSPMC 1980, 12). To the planning committee, Blackall added that "pressure by the oil companies and/or the Newfoundland government and/or the federal government might force the people to accept an alternate site, but he cautioned that the experiment would likely be in constant jeopardy from vandalism as a result of such pressure" (BIOSPMC 1980, 12). As a result, he recommended to the committee that the Cape Hatt site on Northern Baffin Island—which the nearby communities of Pond Inlet and Arctic Bay supported (Sergy 1986, 5)—be seen as "the best choice for the experiment" (BIOSPMC 1980, 12). Following this discussion, the committee unanimously voted to use the site at Baffin Island for the experiment (BIOSPMC 1980, 13). The question of siting the experiment in Labrador was revisited at a meeting between federal state and industry personnel hosted several weeks later, but it was again rebuffed, in part because foreign state funding had been allocated for the Cape Hatt site "as it is considered analogous to areas of concern to prospective funders" (Jones 1980, 1–2).

This conflict was a particularly acute instance of the complex and political process of siting experimental spills, with Inuit opposition relocating a test from taking place in a region that could directly impact their livelihoods. Similar tensions emerged in the years that followed: in a 1983 industry spill committee meeting, it was announced the Tuktoyaktuk council had "decided that they do not want any more oil spill experiments conducted" in the area, requiring a planned offshore dispersant trial to be relocated (Robson 1983, 2), although small-scale testing was to eventually return to the area (Dickinson et al. 1985). Spill planners conducted considerable public outreach ahead of an experimental shoreline spill on the St. Lawrence River in 1998, with local communities described as "very sensitive to the quality of their environment and tend[ing] to resist any project that could affect that quality" (Grenon et al. 2001, 1467). Researchers embarked on a year-and-a-half long process to "sell the project to the local authorities and citizens," in order to minimize "any confrontations that could jeopardize the experiment" (Grenon et al. 2001, 1467–68). This lengthy process of site selection, contingency planning, and public forums proved successful, with the experiment and sampling proceeding without public backlash or obstruction (Grenon et al. 2001, 1467–69).

Such dynamics have also been present in many other experimental spills, in far less overt but equally revealing forms. Siting has been a central consideration and challenge in planning and executing controlled experimental oil spills, regardless of whether it has triggered public concern and outcry. Competing and even contradictory goals have shaped spill siting in many ways, frequently requiring compromises and improvisations. As with all aspects of experimental spills, state regulatory and permitting processes had significant impacts on siting. At the same time, scientists and researchers played leading roles in these decision-making processes, working to shape many of the particulars that fit within broader state requirements. However, these factors have consistently involved the production of "future eco-perfect" conditions for the spills to take place, materially shaping the processes and outcomes of the experiment. Specifically, three major priorities have underpinned spill siting decisions: distance from perceived impacts; proximity to necessary infrastructure and other scientific requirements; and presence of natural and artificial containment.

Examining the specific priorities and decisions in siting experimental spill work reveals the extreme lengths that spill scientists have undertaken to produce conditions that minimize potential impacts, facilitate intervention, and maximize scientific findings. In contrast to the notion of scientists merely observing and representing reality through controlled experiments, these siting processes demonstrate the complexities of fieldwork in which "replication is not so easily effected, the environment is less readily controlled, and impromptu ingenuity is in correspondingly greater demand" (Livingstone 2003, 45). This work involved determinations about siting that were not only intrinsically social in character, but which produced entirely improbable conditions for a spill to occur in and spill responders to address. As a result, this scientific work did not merely "bear the imprint of its location," as David N. Livingstone (2003) framed it, but was mutually co-constituted through siting decisions in a manner that has led to a distorted sense of real-world spill response capacities (13).

Distance

As exemplified by the failed negotiations to site an experimental spill off the Labrador coast, a major concern of communities and state personnel was related to the risk that a planned oil release posed to human and non-human health. For instance, in the initial planning of oil-in-ice experiments in the Beaufort region in the mid-1970s, scientists recognized that a loss of control of the spilled oil in the biologically productive Mackenzie Bay area could result in "very large kills" of birds and marine mammals (NORCOR 1975, 6). Such an outcome would clearly be calamitous to the public reputation of scientists, state departments, and the prospects of the oil and gas industry more generally. The most common means of reducing such risks was by siting the experimental spill at sizable distances from locations where it could have significant and perceptible impacts, especially on human health and activities. This represented the first way that a "future eco-perfect" spill materialized, existing in sharp contrast to many real-world spills that directly impact vital socioecologies.

These efforts were most straightforward in the siting of spill experiments in the East Coast offshore during the 1980s and 1990s. The spills—designed to evaluate the effectiveness of various spill responses technologies such as dispersants, in-situ burning, and spill-treating agents to aid physical recovery—were consistently sited at least 40 kilometres from shore (Gill and Ross 1982, 258; COAATF 1986, 3; Tennyson and Whittaker 1989, 101; Seakem Oceanography 1990, 2). The largest spill experiment of the era, the Newfoundland Offshore Burn Experiment (NOBE) of 1993, took place about 42 kilometres east of St. John's, Newfoundland, requiring three hours of travel by boat to reach (Environment Canada et al. 1993, 5-1; Fingas and Lambert 2018, 286). Along with creating a 30 square kilometre spatial grid for the test that "reflects the maximum possible over-the-ground drift of emissions from the experimental burn," the area was "deliberately chosen to minimize interference with fishing and recreational activity" (Environment Canada et al. 1993, 5-1). The "remote location" of the spill reportedly ensured the elimination of "essentially all risk of any oil from the project reaching the shoreline" (Environment Canada et al. 1993, 5-23). This intricate planning was deemed particularly necessary because if a smoke plume was "advected into a populated area, the impacts would probably be unacceptable due to the high particle concentrations" (Ferek et al. 1997, 46).

These distances were often mandated to receive federal authorization for ocean dumping, with a 1986 oil-in-ice experimental spill permitted with the requirement that "the distance offshore of this area shall be more than 25 nautical miles," or almost 50 kilometres (S. L. Ross Environmental Research and D. F. Dickins Associates 1987, 97). That particular experiment ended up siting its spill at a far greater distance, in ice about 140 kilometres east of Chedabucto Bay, Nova Scotia, as it was in "an environmentally acceptable area: the water is deep, no fishing takes place in the pack ice, and any oil remaining after the spills would drift out to sea rather than ashore" (S. L. Ross Environmental Research and D. F. Dickins Associates 1987, 7). Regardless of specific treatment or goal, the experimental design of these spills ensured minimal discernible impacts by siting research activities in locations far from shore, producing near-idyllic conditions for scientists to spill oil.

These decisions were simple when involving open-water spills that were far offshore, merely requiring establishment of a minimum distance from land. This process became increasingly more complicated in nearshore and shoreline areas due to the possibility of long-term persistence of stranded oil and the overall visibility of operations, especially when the scale and risks of spill experiments increased. Two of the largest experimental spills—the Balaena Bay oil-in-ice experiments of 1974–75 and the BIOS of 1980–83—exemplify this complex work to locate a suitable site sufficiently distant from impacts. As part of the Beaufort Sea Project of the mid-1970s, the federal state contracted engineering firm NORCOR (1975) to conduct a study that would "generate fundamental data on the interaction of crude oil with Arctic sea ice" (3) and the effectiveness of response technologies. Given that the area of greatest concern for future spill risk was the shallower waters of the Beaufort Sea beyond the Mackenzie Delta due to oil exploration plans, spill planners acknowledged that "ideally, the tests should have been undertaken in the Mackenzie Bay area" (NORCOR 1975, 6).

Yet, ironically, the lack of data about the "probable performance of the oil" compromised the ability to "ensure that control could be maintained at all times," a concerning prospect given the area's enormous wildlife population (NORCOR 1975, 6). Spill scientists also acknowledged that they would confine testing to fast ice, rather than moving multi-year pack ice—where they deemed ice conditions "very dynamic" (NORCOR 1975, 145)—again due to the inability to predict and control outcomes. As a result of these many limitations, a wide expanse of the Beaufort—from Herschel Island on the west to Sachs Harbour on the east—was assessed for possible locations, with scientists eventually narrowing in on Cape Parry in the Amundsen Gulf due to its "numerous small sheltered bays" and outside of most migratory flightpaths compared to the delta area (NORCOR 1975, 6).

It was also concluded that "with the exception of several trappers and the occasional social visit," Cape Parry was not regularly visited by residents of Paulatuk, about 100 kilometres to the southeast (NORCOR 1975, 6–8). The experiment that became the Balaena Bay test required immense work to ensure that it was controllable and socially permissible, producing near-idyllic siting conditions to proceed. Similarly, while spill planners relocated the BIOS project to Baffin Island due to cooperation from the communities of Pond Inlet and Arctic Bay, the site still had to be "acceptable to local residents concerned about the possible adverse environmental impacts" (Sergy 1986, 5). As a result, the location of Cape Hatt, some 65 kilometers away from Pond Inlet, was selected in collaboration with the two communities (Sergy 1986, 5). While close to shore, planners saw these locations as sufficiently distant from human communities to minimize the risks of impacts.

Determinations of ecological value were inherently subjective and relative to other sites, involving the marginalization of supposedly unimportant ecosystems and assumptions about the ability for oil to be tolerated and processed. Much of this rested on speculation and lack of scientific knowledge. For example, while the Balaena Bay site was selected for its isolation and lack of biological productivity, studies indicated that the location was “relatively rich in both plant and animal life,” with primary productivity rates during the summer “quite high” (NORCOR 1975, 141). Similar contradictions were present in the BIOS siting process. Despite the Cape Hatt area deemed “relatively unproductive” and supposedly representative of the claim that “the majority of arctic coasts are neither critical habitat to these species nor utilized extensively by man,” it was also found—like most of the Arctic—to have a highly productive subtidal zone, such that potential bioaccumulation in the food chain would take on “more importance in regions where they are harvested for commercial sales or local consumption by man” (Sergy 1985, 574–75; Sergy and Blackall 1987, 3–4).

Additionally, one of the major attributes of the site highlighted by its planners was that it supposedly did “not support large populations of birds or marine mammals” (Sergy and Blackall 1987, 3; Sergy 1986, 5). While observers did not report any birds or marine mammals entering the spill site during the experiments, “plankton, fish, sea birds and mammals were not included in the study because of their transient nature and mobility” (Sergy 1986, 8). Siting and distance took on another set of meanings in this instance, with the uncooperative mobility of some organisms and mammals taking them beyond the artificial boundaries of the research design. Scientists could not transcend distance; as another report explained, “our experimental approach was not suitable for the direct measurement of effects on these higher organisms” (Sergy and Blackall 1987, 4). The achieving of near-perfect conditions also required an undervaluing of socioecologies.

Meanwhile, the Grand Banks area where the NOBE took place was renowned for its high biological productivity and diversity (Environment Canada et al. 1993, 5-3), yet experimental planning predicted that the small scale of the spill and expectation that the site would be avoided due to noise and the presence of oil meant that it was "highly unlikely that there will be any impact on the fish stocks" (Environment Canada et al. 1993, 5-19) and that it is "not expected to cause any significant impacts to seabirds" (Environment Canada et al. 1993, 5-21). Scientists acknowledged, however, that the spill could cause "localized mortality" of phytoplankton and zooplankton, but that "such mortality will be negligible" (Environment Canada et al. 1993 5-20).

Similar conclusions were drawn in experimental spills between Halifax and Sable Island in 1987, a location that Environment Canada concluded would be "unlikely to suffer environmental damage as a result [of] the activities planned" (Seakem Oceanography 1990, 2), and the 1998 shoreline study on the St. Lawrence that predicted the chosen wetland would experience "no significant impacts" due to the "small area of the experimental site compared to the total area of the marsh" (Grenon et al. 2001, 1469). However, the sheer expanse of water bodies and mobility of aquatic organisms makes tracking the acute and chronic effects of spills exceedingly difficult, often involving complex calculations to estimate death tolls (Wilhelm et al. 2006; Bik et al. 2012; Schlenker et al. 2022).

Sublethal and long-term impacts are even harder to evaluate; as Rob Nixon (2011) reflected in the wake of BP's sealing of the *Deepwater Horizon* blowout and ending of dedicated media coverage, "the incalculable, incremental damage spread through biomagnification of the toxins was only beginning" (276). While the design of experimental spills ensured that there were not large-scale die-offs of larger organisms, it was effectively impossible to confirm speculation about less visible organisms given the extremely complex behaviour and movement of spilled oil. Nixon's "slow violence" plays out incrementally as sublethal and long-term effects such as growth defects and reproductive impairments that can take years or even decades to manifest.

There were also several experiments that combined these locational attributes—a distance from visibility and the downplaying of effects—in the form of siting spills in places that were already "seen as forsaken" (Bennett 2016, 265; see also Klein 2007, 406–422; Liboiron 2021, 57). For example, as part of a research program into the impacts of oil in Mackenzie Delta snow, scientists conducted a small experimental spill in 1972 at the Beare Road Landfill Site in Scarborough (Mackay et al. 1974, 107–109), which served as a Metro Toronto dump between the late 1960s and early 1980s (Noonan 2015). Likewise, 1979 testing of air-deployable igniters on a small pool of crude oil took place on the ice surface of a lake on the property of the now-notorious Giant Mine, near Yellowknife (Sandlos and Keeling 2016), a site that was decided upon through discussions with several federal departments and branches due to its "extremely limited outflow, and already polluted nature" (D. F. Dickins Engineering 1979, 5).

Skimmer testing in 1978 and 1980 took place in a settling pond, where industry leaves wastewater to separate over time, at a refinery owned by Golden Eagle (and later Ultramar) in Holyrood, Newfoundland (Gill and Ryan 1979, 498; Technical Services Branch 1984, 7). One of the benefits of this siting was that once scientists had completed the test, they could dump emulsions of water and oil back into the pond for further trials, allowing researchers to evaluate the skimmer's effectiveness "against oil of increasing water content and viscosity" (Gill and Ryan 1979, 498). This continuing pollution of the site was possible as scientists and regulators *already saw it* as permanently degraded, an act that "preserves already degraded environments while erasing any memory of a cleaner or healthier environment" (Barandiaran 2020, 62; see also Whyte 2018, 139–140).

In other cases, field studies were conducted in sites that were still seeing as having some utility but had undergone massive land-use changes in the past. Most notably, spill scientists organized large-scale dispersant spraying from firebombers in early 1979 over an "abandoned airstrip" (Dennis and Steelman 1980, 1) in the Sumas Prairie, near Abbotsford (*Abbotsford News* 1979b), which had once been a lake that was drained for agricultural production in the 1920s (Cameron 1997; Gomez 2021; McSheffrey 2021). As Jonathan Peyton (2017) demonstrates with the case of the abandoned Dease Lake Extension in Northern British Columbia, discarded infrastructures can have "effects that continue to percolate long after its demise" (87).

We can detect a similar impetus in the extensive oil spill experiments led by Dome Petroleum that took place between 1979 and 1982 in McKinley Bay, on the north side of the Tuktoyaktuk Peninsula. After overwintering its drillships at Herschel Island and near Cape Parry for several years, Dome had selected McKinley Bay as its storage location for 1979–1980, requiring extensive dredging work that had been opposed by the Canadian Wildlife Service and other federal agencies due to the impacts on wildlife (Karasiuk and Boothroyd 1982, 1–5). While not explicitly acknowledged in the experimental spill planning, another important factor was that McKinley Bay was *already* the site of significant oil pollution, with a "large fuel spill" occurring in the winter of 1979 due to a supply vessel hitting a fuel barge, and at least 14 more spills happening in 1980 due to the company's activities (Karasiuk and Boothroyd 1982, 27–28). We cannot separate the claim that McKinley Bay featured a suitable "remoteness from environmentally sensitive areas (Dickins et al. 1981, 183–184) for large oil-in-ice and in-situ burning spill experiments in 1979 and 1980 from this existing production of ecological degradation.

Previous locales of spill experiments were even at times cited as at least in part justifying another large-scale discharge, producing a minor spill/site/spill feedback loop of a kind. In a 1992 planning document for the NOBE, David Dickins noted that spill scientists had previously used the site for the Newfoundland Oil Spill Experiment (NOSE) of 1987, with “ocean dumping of crude oil … approved in the test area for that exercise” (D. F. Dickins Associates 1992, 2). Scientists signalled to prior degradation for the sake of scientific research, for the sake of future oil discharges. Although not explicitly stated in reports, spill scientists also conducted two shoreline spill experiments in a coastal salt marsh at a beach in Petpeswick Inlet near Halifax in the late 1980s and 2000, with both studies reporting identical geographical coordinates for the experiment (Lane et al. 1987, 8; Garcia-Blanco et al. 2007, 2). Scientists also repeated similar small-scale shoreline studies in a nearby cove in 1984, 1985, and 1986 (Lee and Levy 1987; Lee and Levy 1989).

Along with siting experimental spills far from shore or in areas remote from human usage, a major aspect of this work was the determination of certain places as socioecologically unimportant, including through use of sites already produced as forsaken and abandoned. Such a “future eco-perfect” materialization existed in sharp contrast to the realities of real-world spill situations, which often have catastrophic impacts on socioecologies that are by no means considered expendable or forsaken. Such decisions produced scientific outcomes that understated the threat of spilled oil to human and non-human organisms alike.

Proximity

An equally important yet effectively contradictory motive for selecting experimental spill sites was ensuring proximity to necessary infrastructure for the purposes of maximizing scientific research and meeting permitted requirements concerning response capacities. As with the goal of ensuring adequate distance from perceived impacts of the spill, especially affecting humans and "higher organisms," this objective produced testing within artificially ideal conditions that elided the reality that spills often take place in conditions that are not spatially proximate to the infrastructure and supplies required to deploy effective responses.

Experimental spills are typically enormous and complex operations requiring the careful coordination of scientific equipment, boats and airplanes, personnel, and, of course, plenty of oil. We can most clearly observe this reality in situations of logistical breakdown. This could result from minor procurement issues, such as dispersant trials in Halifax Harbour in 1975 unable to complete its full testing program due to "supply problems" (Gill 1977, 394). A small-scale spill experiment that took place in Mackenzie Bay a decade later was also plagued by a combination of communication issues, permitting delays, and insufficient supplies that led to "unnecessary delay," "unpredictable changes in schedule," and inability to "complete the experiment as planned" (Dickinson et al. 1985, 24).

As was the case in many Arctic operations in general, the presence of ice could contribute to major complications in scientific plans. During the set-up for the Balaena Bay testing of 1974–75, the barge carrying all of the supplies for the scientific work arrived about six weeks later than anticipated due to "exceptionally heavy ice," and was unable to reach the inner cove of the bay where scientists had planned the testing to occur (NORCOR 1975, 11). These adverse conditions necessitated a massive logistical undertaking that moved 13,000 kilograms of "essential goods" by helicopter to the test site and another 120,000 kilograms of supplies by snowmobile over the course of the winter (NORCOR 1975, 11). Issues were also encountered due to the distance from the field site and laboratories at the University of Toronto, where chemical analysis of oil, ice, and snow samples was to take place, with some "damaged in transit" and the melting of samples leaving "considerable air space … which likely introduced some error" (NORCOR 1975, 24–26). Even well executed field studies could still create complications: a shoreline study conducted in the late 1980s near Halifax noted that a simultaneous microcosm study in a Dalhousie University greenhouse "allowed more frequent and more detailed observations than were possible in the field" (Lane et al. 1987, 4).

While clearly never guaranteed, one means by which researchers worked to reduce such possibilities was through the process of siting experimental spills, necessarily shaping the outcomes of research by ensuring as much as possible was in place and controllable before a spill took place. It is useful to understand these efforts within broader critical scholarship about the so-called "logistics revolution" (Chua 2017, 169). We can also see this orientation towards "continuous flow" through hyper-precise timing and communication (Bernes 2013) in the organization of experimental spills themselves, with extensive planning working to minimize costs and maximize scientific knowledge production. Experts render both logistical and experimental spill spaces as free of conflict, interruption, or resistance as possible.

The importance of nearby infrastructure was especially important for skimmer testing, with most experimental spills happening close to shore and involving federal state facilities. During the late 1970s, trials took place next to the Department of National Defence naval base in Esquimalt Harbour, Victoria, with several of the boats and their operators provided by the base (Solsberg et al. 1977, iii). Coast Guard bases also served as common testing site, including Quebec City and Sorel bases located on the St. Lawrence River, with the Coast Guard playing a "major role in making available materials and space for the evaluation program" (Solsberg et al. 1977, 1; Tidmarsh and Solsberg 1977, iii, 1). Another small-scale experimental spill in 2008 in the St. Lawrence Estuary conducted the discharge, response application, and sampling from a Coast Guard ice-breaker (Lee et al. 2011, 3). Other skimmer tests required even more direct support from the shoreline. For example, to deploy the "Little Giant" into a refinery settling pond, scientists first positioned the skimmer on the pond's shore and then "pivoted into the oil" (Technical Services Branch 1984, 7, 11), requiring a shore-based "hard surface from which to work" (Technical Services Branch 1984, 48). Further, the skimmer had a preheater unit installed beneath its collection apparatus to facilitate collection of more viscous oil, in that case using high-pressure steam provided by the refinery to heat the oil (Technical Services Branch 1984, 12–13).

While highly specific in its design—using only dispersants, not oil—spill scientists demonstrated the importance of suitable infrastructure by the 1980 testing of aerially applied dispersants at the Defence Research Establishment in Suffield, Alberta (COAATF 1981). Recognizing the importance of using large aircraft to apply sizable volumes of dispersants, the Canadian Offshore Aerial Applications Task Force (COAATF) selected the military research site as it "permitted low level flying on almost any heading," with only minor elevation changes and an instrumented tower nearby to assist with evaluations (COAATF 1981, 5). Suffield also benefited from its proximity to other airports, with the dispersants delivered to Medicine Hat, only a half-hour drive away (COAATF 1981, 8). Unlike other testing circumstances, the fact that Suffield's conditions were deemed "ideal with respect to unrestricted flying" (COAATF 1981, 16) had as much to do with the regulatory framework of military research operations as the physical environment itself; while not discussed in the research publications, the Suffield site had also long served as a key testing area for chemical weapons including nerve gas (Smith 2017), meaning that it again had a pre-existing legacy of ecological degradation.

In cases of open-water spills in the East Coast offshore, the most important piece of infrastructure was an existing nearby harbour or airport that would allow for ease of dispatching vessels and planes in a highly planned fashion. Planning and permitting for a 1981 dispersant trial near St. John's required that the location be close enough to shore to allow for the sampling boats to reach the site, with shoreline infrastructure including a port, airport, and accommodation (Gill and Ross 1982, 258). These intersecting requirements led to a site about 50 kilometres north of St. John's being selected and approved, requiring a four-hour trip to and from the site (Gill and Ross 1982, 258–260). Similarly, the 1983 dispersant testing off the coast of Nova Scotia required an intricately positioned combination of a Coast Guard icebreaker, a discharge vessel, smaller sampling boats, and helicopters and a fixed-wing plane for monitoring, with the marine vessels loaded and dispatched from the Halifax harbour for the three-hour voyage (COAATF 1986, 6–8, 19).

The NOBE of 1993 involved about 200 people and a huge number of vehicles including two Coast Guard ships, 16 small vessels for monitoring and sampling, two remote helicopters, four remote sampling boats, two observer vessels, a blimp, two spotter helicopters, and three fixed-wing aircraft (Amoco 1993, 1). Given "all operating and monitoring units in position and ready" was a required condition of the permit for the experiment to proceed (Christopher and Vanderkooy 1991, 1), this predictably required considerable coordination in advance, with the "procession" led from the St. John's Harbour by one of the Coast Guard vessels and closely followed by two smaller boats towing a boom (Environment Canada et al. 1993, 1-3). These efforts were as much logistical feats as scientific studies.

However, researchers could not easily find such infrastructural and logistical advantages in more remote areas of the country. Like with other aspects of siting spills, spill planners had to meticulously scout and inspect these regions for suitability to conduct testing. A major logistical factor motivating the siting of the Balaena Bay trials was that the turbidity of the Mackenzie River delta impeded the "sufficiently clear" conditions necessary for divers and instruments to observe underwater impacts of the oil spill (NORCOR 1975, 6); a small-scale 1984 dispersant testing in Mackenzie Bay demonstrated the importance of this consideration in siting, with researchers observing during one of the spills that "the diesel fuel was virtually invisible against the brownish Mackenzie River discharge" (Dickinson, Mackay, and McWatt 1985, 21). As a result, one of the basic necessities in scouting was to find a suitable location with sufficiently clear waters that would allow for scientific activities like underwater observation (NORCOR 1975, 6). While not infrastructure in a strict sense, visibility was an adjacent requirement of scientific work that shaped similar siting decisions.

Along with the aforementioned advantages that Cape Parry was found to offer due to its alleged distance from major ecological impacts, the site further benefited from the presence of the Distant Early Warning (DEW) Line radar station and Atmospheric Environmental Service's meteorological station that included an airstrip, barge service, communications infrastructure, and more than a decade of ice measurements (NORCOR 1975, 6–8). Although planners found that sites especially close to the DEW line facility would have "simplified logistics" even further, factors involving containment outweighed these relative benefits, requiring a compromise in siting (NORCOR 1975, 8). Spill scientists also conscripted nearby ecologies to facilitate the scientific work, with a "small lake serv[ing] as a landing strip during the winter" (NORCOR 1975, 11). As Andrew Stuhl (2016) has theorized through his formulation of "unfreezing the

Arctic," new rounds of scientific research typically have had deep ties to previous frontier developments, with DEW Line stations serving as "the most grandiose instantiation of Arctic science twinned with geopolitics" (Farish 2006, 184).

We can also observe this regeneration of previous sites of commercial and state activity for research purposes in Dome-led experimental spills conducted in the Beaufort Sea in 1979/1980 and 1986. The first testing program sited just outside McKinley Bay used the "borrow pit" of an artificial "sacrificial beach" island constructed from dredged sand for exploratory drilling and later abandoned by Esso, leaving a deep crater in the ice that allowed the researchers to freeze in a barge to serve as a working platform for the experiment (Dickins et al. 1981, 184). It was determined that testing sites near the overwintering location at McKinley Bay were "ideal" due to the proximity of a "comfortable base camp with communications facilities and an ice air strip for logistics support" (Dickins et al. 1981, 184).

We can again detect the importance of these factors in Dome's second ice-focused spill, with McKinley Bay identified as the most suitable context due to the logistical and equipment support, sufficiently deep water for diving, and landfast ice with large features that could complicate findings (Buist and Dickins 1983, 3). Likewise, the large-scale dispersant trial in the Beaufort Sea took place near Esso's Arnak artificial island, which was also a "sacrificial beach" construction. In this case, spill scientists stored the dispersants used in the experiment and loaded them onto helicopters from the island itself (Swiss and Vanderkooy 1988, 8). Along with the utility of the pre-existing artificial island, the site benefited from being "well outside the influence of the Mackenzie River plume in an open ocean environment," which scientists had previously identified as impeding experiments due to the turbidity (Swiss and Vanderkooy 1988, 4). Given that the Beaufort dispersant trial primarily relied on aerial remote sensing to evaluate dispersant effectiveness—rather than subsurface water sampling, which had faced many challenges in prior experiments and impeded testing during more intense sea states—the nearby airport at Tuktoyaktuk also greatly aided the work (Swiss and Vanderkooy 1988, 15). In each of these cases, prior iterations of extraction provided the physical requirements that enabled more efficient siting and logistical planning for experimental spills.

Further instances of this took place within the Arctic Islands. A 1978 study into the behaviour and burn potential of spilled oil in multi-year ice happened in Griper Bay of Melville Island, which had long served as the informal headquarters of oil and gas exploration in the region (Wilt 2020, 1–2). A year later, this area was again used for preliminary ice detonation testing—investigated as a means of containing an under-ice oil blowout—with full-scale testing later taking place at Panarctic's Whitefish drilling location on the ice west of Lougheed Island (Corcoran 1979, 1). Planners specifically chose the latter site as there was already a camp and airstrip established to facilitate drilling activities (Corcoran 1979, 1).

The main exception to this tendency of siting spills near existing infrastructure and logistical supports was the BIOS project of 1980–83, which constructed a research environment and "supply chain security" from the ground up. A key factor enabling this, in contrast to smaller exercises that required greater proximity to existing infrastructures, was BIOS' comparatively enormous budget of some $7 million and support from many companies and states; at the start of the project, the oil industry was set to cover 40 percent of costs, while the federal state contributed 30 percent, the US another 25 percent, and 5 percent from Norway (Sergy 1985, 571; Sheppard 1980). Although extremely remote relative to other experimental spills, its sizable operations—including accommodations for up to 60 people—were intentionally sited next to a freshwater lake and close to "an area suitable for an airstrip" (Sergy 1986, 6).

As described by Gary Sergy (1986), the "installation and supply of a remote camp required the movement of massive quantities of material," with seven loads of equipment and supplies carried by Hercules aircraft transported across sea ice and "hundreds of drums of fuel and tons of equipment" brought by a Coast Guard icebreaker and sea lift vessels (9). During the course of the experimental work, helicopters and airplanes also conducted regular transportation and support work (Sergy 1986, 9). Spill planners also materialized this rationale with the selection of bays for the BIOS spills, with an explicit aim of being geographically close enough to for logistical ease (Dickins et al. 1987, 100). Even when distant from potential impacts, it was vital for scientists to render experimental spill sites close to required infrastructure, transportation, and supplies.

Many of these experimental spills involved extremely unlikely infrastructural and logistical support for real-world application, producing overstated capacities for real-world response. This tension was sometimes explicitly noted in response to favourable testing outcomes, as in the successful trialing of an improved "Oil Mop" skimmer in Sorel, Quebec, in 1977, with researchers noting that the skimmer could be deployed with "relative ease" with the provision that there is "good road access," which does not exist in vast stretches of the country (Tidmarsh and Solsberg 1977, 26). Further, scientists deemed that the significant power requirements of the immersion heaters needed for the Oil Mop preheater to help recover more viscous oils was unlikely to exist on many spill response vessels, meaning that "the unit will have limited applicability to spill emergencies, particularly at more remote locations" (Tidmarsh and Solsberg 1977, 26). While the testing was effective, it was concluded that the revised unit has "severe application constraints" given that "large generators are difficult to obtain and even more difficult to transport" in remote conditions (Tidmarsh and Solsberg 1977, 27, 30).

Although an extreme example, the constraints identified about the Oil Mop skimmer were more generally applicable to many other experimental spills. The siting of this scientific work necessitated close proximity to infrastructure that would enable the execution and monitoring of the spill, involving extensive scouting and planning ahead of time. In most instances, this process relied on the leveraging of existing infrastructures: military and Coast Guard bases, refineries, abandoned drilling sites. However, as in the case of BIOS, this could also involve the creation of entirely new infrastructures to facilitate the spill work which, as we will see, would go on to produce other contaminated (or attenuated) scientific spaces for oil. Collectively, this aspect of siting experimental spills produced conditions for maximal control and scientific benefit: understandable from a regulatory and research perceptive, but improbable in many real-world disasters, which often occur in remote sites with limited access and resources. This scientific work thus materialized "future eco-perfect' in spill response, projecting an array of logistical requirements in the future that simply may not exist whatsoever.

Containment

The third major factor that shaped decisions about siting experimental spills concerned the ability for scientists to effectively contain and concentrate the oil using a combination of natural and artificial barriers. There were several major reasons for the prioritization of this goal. Firstly, planning effective containment was extremely important for gaining permitting approvals; one of the conditions for the Dome-led experiment spill in 1982 included highly specific spill guidelines to ensure that "all oil released in this manner will be contained within the experimental plots" (Buist and Dickins 1983, Appendix F). Containment was also important for the success of the scientific testing itself, with the BIOS nearshore test area outlined with booms to prevent "cross-contamination" between different testing sites (Sergy and Blackall 1987, 4).

The most important contribution of containment, however, was its role in concentrating oil into sufficient thicknesses to be able to burn, apply spill-treating agents to, or physically recover. Almost all skimmers were found to reach their greatest effectiveness in "relatively thick" oil slick, requiring a high volume of oil to be collected within booms (Fingas et al. 1979, 74). Maintaining a minimum thickness of oil was also extremely important for burning experiments, as oil that spread and thinned becomes incapable of sustaining a burn (D. F. Dickins Associates 1992, 2; NORCOR 1975, 2). Meanwhile, studies have found that dispersants are less effective in thinner slicks—with the dispersant at risk of migrating through the oil without mixing into it (Smedley 1981, 254)—and benefit from greater homogeneity in oil thickness (COAATF 1986, 111). While distinct in dynamics, various spill responses tend to benefit from some form of containment that produces a baseline thickness for treatment.

There were two general categories of containment used in experimental oil spills. One was "natural" containment, which involved the scouting and production of geographies that would limit spread of oil. The second was "artificial" containment, largely through the use of various designs and arrangements of booms. In combination, experimental spills that sited and planned containment well in advance of the test circumvented one of the most challenging aspects of spill response, a condition that was by no means guaranteed in real-world incidents. Firstly, the siting of several major experimental spills included finding locations that offered the possibility of natural containment. Sometimes, this natural containment was merely a function of the site's exposure to waves, tides, and currents.

In the case of skimmer trials, spill sites were frequently calibrated to the specific type of skimmer that was being used, with stationary skimmers tested in 1976 in the St. Lawrence River "away from the direct influence of the current" (Solsberg et al. 1977, 3). Another round of skimmer testing in Quebec City a year later similarly selected one side of Louise Basin in the city's port area as it was "not subjected to currents or significant waves" (Abdelnour et al. 1978, 46). Small harbours and bays meant that experimental spills were far easier to control and recover. For instance, researchers conducted a spill for the purposes of dispersant testing at McNab's Cove, just south of the Dartmouth Coast Guard base, in the mid-1970s as it offered "protection from a southerly sea swell while remaining clear of harbour traffic" (Gill 1977, 392). Another factor considered in siting small nearshore spills was insulating the experiment from disruption by boat wakes, particularly due to "limitations of the containment boom" (Solsberg et al. 1976, 66). Researchers sited early skimmer testing in Bedford Basin, within the Halifax Harbour, where "minimal interference from shipping would be encountered," and in the Port Moody Arm of Burrard Inlet as it was "relatively remote from commercial shipping and recreational boating" (Solsberg et al. 1976, 72).

Larger spill experiments required greater scales of natural containment. Along with the factors of distance from perceived impacts and proximity to infrastructure already discussed, another dimension that shaped the siting of the Balaena Bay spills was "on the basis of its unique shape" (NORCOR 1975, 8). Specifically, the entrance to the "small sheltered cove" (NORCOR 1975, 134) was less than 100 metres wide, meaning that it would be possible to easily place booms across it "in the event of loss of control of the oil" and that "contamination would be confined to the bay" (NORCOR 1975, 8). Due to this finding, researchers conducted extensive measurements and shoreline surveys of the site, after which they selected the specific cove and established a permanent camp (NORCOR 1975, 3).

Similarly, the siting of BIOS meshed with available natural containment. Following extensive surveying of the area, planners sited the nearshore dispersant testing in three similar bays in Ragged Channel: one for them to conduct an untreated oil spill in, and second for them to release an oil slick pre-mixed with dispersant, and other bays to serve as an unpolluted reference site (Sergy 1986, 10). These bays allowed for balance of achieving oil concentrations "similar to those encountered after actual spills" while also ensuring experimental control over the discharge (Dickins et al. 1987, 100). The individual spills were also sited and scheduled in close accordance with their specific characteristics, with the untreated oil spilled in what was referred to as "Bay 11" as it offered more protection and ability to contain a surface slick with boom, while the dispersant-mixed oil was spilled from a subsea discharge into "Bay 9," which featured more predictable underwater currents (Dickins et al. 1987, 103; Owens and Robson 1987, 235). Meanwhile, scientists conducted a distinct shoreline spill study at the entrance of and inside the nearby "Z Lagoon," which was a "well protected embayment" to the eastern side of Cape Hatt (Sergy 1986, 6). Planners specifically chose this "isolated lagoon" as it offered a "series of segregated bays that could be used for discrete experiments with control and countermeasure plots" (Owens et al. 1987a, 244). In this case, a main objective of the study was to assess the degradation of stranded oil over time, especially at various distances from tides. For instance, the plots spilled in 1981 (at Crude Oil Point) and 1982 (at Bay 106) for the purposes of countermeasure testing took place in "relatively sheltered" and a "very sheltered" site, respectively, with the latter including a backshore site in addition to the standard intertidal site (Sergy 1986, 20; Owens et al. 1987a, 244).

At other experimental spills, planners more actively constructed natural containment, especially in the case of burning experiments on ice. The most straightforward means of building on-ice containment and improving burning potential was by clearing snow away from a small area on the ice surface, which was additionally important due to the difficulty of igniting mixtures of oil and snow (Energetex Engineering 1981b, 6). This process was used at the 1973 spill experiment near Rimouski to create a 15- by 18-foot area (Coupal 1976, 1); while helping to initially prevent spreading of the oil, it was found during some burns that the testing area expanded significantly, doubling in size in one case, due to the immense heat (Coupal 1976, 13). Similarly, at “Crater Lake” on Giant Mine property, where aerial in-situ burning tests were conducted in 1979, a site was created in the centre of the frozen lake by clearing snow from it to simulate a “realistic melt pool” that might be found on sea ice, but did not occur on freshwater lakes (D. F. Dickins Engineering 1979, 5).

Scientists sometimes used additional reinforcement to shore up natural containment efforts. The initial snow dike created at Crater Lake failed due to rapid melting that left “bare ice,” but was followed with a more successful version constructed on the day on the testing day that had been “reinforced” with logs (D. F. Dickins Engineering 1979, 5–7). This combination “survived the first burn,” with “only minor shoring up necessary” (D. F. Dickins Engineering 1979, 11); it was also found that all of the oil remained within the contained pool, with none of it observed to have been blown over the dyke and onto the surrounding ice by the helicopter’s downwash, a frequent frustration in such testing (D. F. Dickins Engineering 1979, 17). Similarly, at Balaena Bay, an ad-hoc snow dyke was constructed around the perimeter of the testing site to prevent the spread of pooled oil in the spring, with empty oil barrels arranged to create a wind break that was then covered in snow over time; this creative approach was employed after cutting snow blocks was found to be “ineffective” (NORCOR 1975, 18). However, in a similar experience as near Rimouski, scientists found that this perimeter had been “breached on several occasions” during the burns (NORCOR 1975, 18).

Clearly, harnessing natural containment could only go so far, necessitating the use of artificial barriers. Such systems varied widely in design. In 1972, researchers used a large mesocosm-like plastic enclosure system dubbed the “Contained Ecosystem Pollution Experiment” (CEPEX) for small-scale dispersant testing in Saanich Inlet (Green et al. 1982, 5), while they attached a series of wooden booms underneath six-foot ice for a 1974 spill in Resolute Bay (Dotto 1974c). Others spill research attempted to provide some degree of containment while working to avoid corresponding constraints, especially involving dispersants. Scientists found the enclosure system used in Saanich Inlet impeded dispersant mixing and action, requiring “open ocean experiments in which the artificial constraints of an enclosure are removed” (Green et al. 1982, 3). As a result, the subsequent spill experiment in a “semi-protected coastal area” near Royal Roads—formerly a naval training facility and military college, now a public university—was conducted in an “open ocean situation” that had “no restrictions on movement of the dispersed oil in the water,” save for the booming surrounding the spill that contained the oil until it could be treated, helping to reduce the exposure of local beaches to the oil (Green et al. 1982, 1, 3). During small shoreline spills in the mid-1980s, researchers buried synthetic nylon mesh bags in the sand to help “prevent tidal-driven loss of treated sediments,” as the focus of the study was on biodegradation potential if researchers added nutrients to the plot (Lee and Levy 1989, 480).

Spill scientists leveraged standard booming measures for many other experiments. As required by Environment Canada’s testing guidelines for skimmer trials, scientists carefully boomed the various spill sites created for the task to prevent the escape of oil (Solsberg et al. 1976, 69). For stationary skimmers, oil had to be “spilled into a contained area which should approximate natural conditions,” using booms that the Department of Environment had approved

(Solsberg et al. 1976, 76). Booms were also frequently augmented with sorbent arrangements to absorb any escaped oil, such as bags containing shredded polyurethane (Solsberg et al. 1976, 70). These arrangements often extended to shoreline studies as well. At the Svalbard trials in the late 1990s, researchers surrounded the shores with multiple layers of booms to contain any oil transferred to the water, with "at most only a thin sheen of oil … observed to have escaped from the booms" (Sergy et al. 1998, 81–82). Likewise, the shoreline study on the banks of the St. Lawrence in 1998 involved a raft of contingency measures including containment booms around each oiled plot and spill responders on site with skimmers and sorbents at the ready (Grenon et al. 2001, 1469).

Due to design requirements, some skimmer testing required even more intensive containment efforts. For instance, the testing in 1980 of the cumbersome Morris MI–80 skimmer—which integrated two skimming systems into a vessel—necessitated the significant expansion of a boomed area that scientists had already established for other skimmers, as it needed much more room to be able to maneuver (Technical Services Branch 1984, 9). Several other skimmer designs also required that booms were physically attached to the skimming unit itself prior to a spill commencing, helping to create an "oil spillway" that would maximize containment and intake (Solsberg et al. 1977, 5, 76–80). However, the attachment of such booming systems was by no means straightforward. In an especially convoluted case, attempts to attach two booms to a skimmer to create a V-shaped intake were riddled with problems including the initial lifting of partially inflated boom sections into the water resulting in their "twisting or dislocating" and some "abrasive damage" (Beak Consultants et al. 1978, 2–3). It took personnel two hours of work to straighten the booms and finish preparations for full inflation with the report concluding that "during this period three men worked constantly in positions which would have been precarious had the booms been laid out in a rougher sea" (Beak Consultants et al. 1978, 3). Further challenges were experienced attempting to connect the booms to the skimmer, as the booms "bounced around" on the mild waves, rendering attachment "difficult and would be further hampered in any kind of sea" (Beak Consultants et al. 1978, 3).

Another common strategy to contain and concentrate oil for testing purposes, especially involving oil-in-ice, was to freeze underwater containment skirts into the ice prior to the spill. An early example of this occurred in 1972 near Shirleys Bay, close to Ottawa, with four large ponds constructed that were each "doubly lined with polyethylene sheets with the ends buried under the earth" prior to ice formation (Scott and Chatterjee 1975, 3). An experimental spill in 1973, this time taking place in two lakes in the Mackenzie Delta, divided areas into experimental and control plots using polyethylene sheeting that scientists weighed down and buried into the sediment, along raising it above the water surface using wooden posts (Snow and Scott 1975, 527–28).

At Balaena Bay, the prospect of a "free flowing spill was environmentally unacceptable," so planners built large containment areas for each discharge using black fabric skirts (NORCOR 1975, 12–15). These skirts of various lengths—determined based on the particulars of the spill—required considerable work to assemble, with a two-person crew able to produce three per day by augmenting the membrane with a "flotation collar" and "cable ballast" to guarantee containment effectiveness (NORCOR 1975, 15). Once created, personnel then cut a circular hole in the ice with a chainsaw and inserted the skirt through it (NORCOR 1975, 15). While a two-person team could complete this stage of the installation process at a rate of three skirts per six-hour shift, that rate declined to one per day as the ice almost doubled in thickness (NORCOR 1975, 15). This containment system appeared to function well in the experiments, although researchers observed that "some finely dispersed oil was found to have entered the water column since the diver found his gear to be contaminated by a film of crude oil" (Adams 1975, 10). Scientists also found over the course of the winter that "small quantities of oil migrated up the joint between the ice and the skirt" due to the ice not fully freezing with the skirt, with the presence of the containment having "enhanced local melting" (NORCOR 1975, 126).

Along with helping to prevent broader contamination of the area, the careful discharging of oil into preset containment areas meant that the "precise position of each pool was known in advance," with regular sampling and analysis helping to refine the exact timing of the burns (NORCOR 1975, 144). Such an advantage would clearly not be available to real-world responders, with the location of under- and in-ice spills by far one of the most challenging aspects of mounting such a response. Like with the Balaena Bay experimental spill, personnel also froze skirts into the ice ahead of the 1982 experimental spill in McKinley Bay (Buist and Dickins 1983, 3–5). The scientific report from the project specifically referenced the prior use of "similar" containment measures at Balaena Bay and detailed a near-identical process of assembly and insertion into chain sawed slots, with the low temperatures meaning that the "skirts were rapidly frozen into the growing ice" (Buist and Dickins 1983, 3–5). Divers equipped with video cameras inspected the placement and integrity of the skirts prior to the commencement of testing (Buist and Dickins 1983, 8). In combination with the carefully selected volume and discharge of oil under-ice (Buist and Dickins 1983, 5–8), this containment system helped to produce the homogeneity of thickness vital to the success of the experiment. Once again, this level of pre-planned containment is impossible in the case of real-world spills.

Experimental spills conducted in open water required a different approach. Despite conventional booms being difficult to deploy in the best of circumstances, let alone in conditions of high winds and waves, many of these experiments fundamentally relied on the use of pre-set booms to contain and concentrate the spilled oil for response. This approach was often a requirement for governments to permit an experiment. Concerning this aspect, environmental chemist Donald Mackay heralded the 1984 small-scale dispersant experiment in the Beaufort, which he was involved in planning. as demonstrating the merits of a "boomed channel experimental spill" as it ensured that "the surface oil is contained at all times thus concerns of contamination of the area are allayed" and, in turn, "may make for easier regulatory approval" (Dickinson et al. 1985, Appendix F). Scientists calibrated all parts of the small-scale experiment to these booming requirements. The sorbent booms, used to absorb oil to weigh the dispersed oil and evaluate effectiveness, were "oriented with the wind" ahead of the spill to ensure maximum containment (Dickinson et al. 1985, 4). The volume of oil discharged was also adjusted in accordance with booming requirements, with the first test in the series finding that spilling 20 litres of oil meant that "the resulting area was far too large to avoid contact with the boomed channel sides, and subsequent spills used only 4 litres of oil" (Dickinson et al. 1985, 10), with the subsequent test explicitly designed to confirm that the boom set-up was "large enough to contain [a] thin oil slick" (Dickinson et al. 1985, Appendix C). The researchers found that the booms were effective but that larger sea swells caused them to "roll excessively," with significant challenges also encountered with weighing the sorbent booms as a metric of dispersant effectiveness (Dickinson et al. 1985, 23).

Booming was most important during the NOBE of 1993, which used newly developed fireproof booms. The technological advancement of fireproof booms was one of the major research objectives of spill science during the early 1980s, and had been described as shaping up to be the "success story" of the industry-organized Canadian Offshore Oil Spill Research

Association (APOA/EPOA OSC 1982, 4). Although expensive to develop and test, such a boom was desired as a facilitator of in-situ burning and as a help in avoiding costly and labour-intensive skimming activities. By the early 1990s, when planners had scheduled NOBE to take place, improvements in fireproof booms would reportedly provide the "potential, under suitable wind and sea conditions" to ensure minimum thickness requirements for burning and prevent the outward spread of the oil and fire (Environment Canada et al. 1993, 1-1).

Specifically, spill experts viewed the 3M Fire Boom as especially "durable, readily deployable, and proven in actual use" (D. F. Dickins Associates 1992, 2–3). Along with a Helitorch, which the forestry industry had long used to ignite controlled burns, the Canadian Coast Guard bought a 3M Fire Boom ahead of the NOBE and equipped it with instrumentation to monitor temperatures during the burn (D. F. Dickins Associates 1992, 6; Fingas and Lambert 2018, 290). A secondary sorbent-loaded containment boom trailed this fireproof boom to contain any oil that escaped (Environment Canada et al. 1993, 1-3; Fingas and Lambert 2018, 290), with it deemed capable of "effectively containing oil in wave heights twice as severe as those that limit the use of the fire boom" (Environment Canada et al. 1993, 7-8). Planners also intricately designed the spill itself to ensure maximum containment and concentration of oil. For one, the oil thickness could "easily be controlled" with the boom tow speed: slowing down the towing allowed the oil to spread within the boom, while speeding up pushed it back into the boom to concentrate it (D. F. Dickins Associates 1992, 15). The volume of oil spilled, too, was considered to be the "lower limit of a typical boom capacity" (Fingas and Lambert 2018, 290).

Scientists reported that maximum temperatures within the boom ranged from 1,000°C (Fingas and Lambert 2018, 303) to 2,000°C during the burns (Christopher and Vanderkooy 1993, 2). Although some "signs of fatigue" were observed in the stainless-steel core of the fireproof boom after the first burn, it was declared “still fit for another burn” (Fingas and Lambert 2018, 292). However, partway through the second spill, spill scientists stopped the discharge as “one of the boom flotation sections parted from the boom” (Christopher and Vanderkooy 1993, 2). Scientists later found that the stainless-steel mesh in the boom failed due to “heat exposure and constant movement caused by wave action” (Christopher and Vanderkooy 1993, 2–3), in part attributed to part of the boom being “not properly constructed” (Fingas and Lambert 2018, 299). One of the major concerns resulting from the NOBE was the “survivability limitations” of fireproof booms (NIST 1994, 12), especially in the context of high wind speeds (Christopher and Vanderkooy 1993, 3).

Much of the escaped oil ended up burned outside of the boom, with the process concluding about a half-hour after the discharge ceased (Christopher and Vanderkooy 1993, 2–3). Even in situations of technical failure, the prior containment of the experiment ensured that the oil remained sufficiently close and thick to apply response measures to. While successfully producing “disciplinary space” that introduced lab-like limits to fieldwork, spill planners entirely produced conditions that responders would be unlikely to replicate during actual spills. These measures could have major impacts on outcomes: a small-scale shoreline study in 1984 found that biodegradation was considerably less productive compared to a previous study that had used “‘closed systems’ in which nutrient losses were prevented, since water movement and exchange in their enclosures were greatly reduced in comparison with the natural environment” (Lee and Levy 1987, 414). Whether involving the carefully scouted natural containment of bays and coves, constructed and reinforced snow dikes, or the installation of mesocosms, under-ice containment skirts, or closely calibrated boom arrangements, all of these spill experiments materialized near-idyllic containment that limited spread, promoted thickness, and maximized the effectiveness of response measures.

These containment measures were developed in close interaction with the tensions of siting experimental spills—including at a minimum distance from visible effects while remaining in close proximity to scientific and logistical requirements—to produce research contexts that radically understated many of the most complicated dynamics of actual spill response, including close proximity to important socioecological sites, massive logistical and organizational hurdles, and lack of ability to install required containment systems before the oil spreads and thins beyond the ability to effectively respond to it. As a result, these siting decisions produced necessary conditions for useful scientific inquiry, while at the same time materializing an entirely unlikely set of circumstances for real-world application. These processes concretely demonstrate how fieldwork is not merely a process of observing a pre-existing reality but actively materializing conditions necessary for scientific work to successfully take place. "The field" does not exist as an abstraction that scientists can enter and exit at will; rather, scientists actively produce the field in conjunction with community demands, regulatory requirements, and scientific priorities.

Collectively, we can understand this contingent work of siting as one aspect of producing "future eco-perfect" spill studies, in which scientists extrapolate the positive findings from highly controlled experiments to the possibilities of actual spill situations. In doing so, siting decisions made during experimental spills asserted a highly particular form of geographical knowledge and control in spill situations, which we can detect in present-day confidence about the ability for responders to efficiently confront spills. The next chapter continues this argument by adding the dimension of *timing* to the spill experiment.

Chapter 3: Timing

Along with Indigenous resistance to pipeline construction on unceded lands (Hemens 2024), the locking-in of massive greenhouse emissions growth (Lee 2024), and greatly increased risk to local orca populations (Ecojustice 2024), a major factor driving widespread opposition to the Trans Mountain Expansion Project (TMX) has been the potential for a catastrophic spill in Vancouver's Burrard Inlet due to the ten-fold rise in tanker traffic (*CBC News* 2024). Western Canada Marine Response Corporation (WCMRC), an industry-funded spill response organization, has tried to allay these concerns by highlighting its response to the 2007 spill of about 100,000 litres of diluted bitumen (dilbit) from the pipeline into the inlet as proof that it is possible to clean up a dilbit spill on Canada's West Coast (Moreau 2015; WCMRC 2018). The WCMRC (2018) boasted that "the Inlet Drive incident is the largest spill WCMRC has cleaned up on Canada's West Coast—it was a diluted bitumen spill, and 95 per cent of the product was recovered," and that "if diluted bitumen spills again, we are prepared." Left unsaid in this account, however, is that the spill response occurred in *almost ideal conditions*.

In addition to the oil's immediate proximity to the shoreline, having spilled through stormwater drains rather than from a vessel, there were a series of "favourable environmental factors at the time of the spill" (Stantec 2012, 3). These factors included "sunny weather" that "slowed the movement of oil in storm drains" and "facilitated evaporation of oil," the spill itself occurring during an incoming tide that "helped keep the oil near shore while booms were placed" and "helped limit the movement of oil in the inlet," and seasonal timing outside of important migration and breeding periods for both birds and salmon (Stantec 2012, 3). Belcarra mayor Ralph Drew highlighted these variables during 2013 debates over the TMX:

> Drew said that response time has been disputed, but added it was in the middle of the day in summer in ideal conditions. He said responders must assume the next accident – whatever it is – will come at the most difficult possible time. "It could

> happen in dark and stormy weather on a winter weekend, maybe Christmas Eve, with everyone on vacation and nobody responding to the callout." (Nagel 2013)

Such conflict about the contingent timing of spill response is also present in much broader studies of spill behaviour, effects, and fate. Time and temporality is at the centre of oil spills in a very general sense. Oil begins to transfer to new sites and transform into new compounds within minutes, hours, and days of a spill (Ward and Overton 2020; Overton et al 2022). As the lightest volatile fractions of oil are lost, primarily through evaporation, the remaining oil becomes more viscous and difficult to ignite, disperse, or physically recover. Given the countless complexities of spill response—inclement weather, mechanical issues, remote geographies, logistical limits—this factor can rapidly undermine response effectiveness, especially when involving heavier oils such as dilbit that start with a lower share of lighter fractions.

Another notable temporal aspect of oil spills involves ice and snow, which often provides a unique stalling function to oil transfer and transformation. In a webinar on the interactions of oil in ice, David Dickins (2022) explained that "the net benefit that we have with a spill in ice is that we have an increased window for response, especially with burning and dispersants" (12:30). For Dickins, "Time is really the most precious commodity in an oil spill response. Ice buys you time in a big way. In many cases, it may allow you weeks or even months to plan a response in the spring. That's an opportunity you never have with a spill in open water" (Dickins 2022, 12:30). As a result of ice's contribution in shielding the shoreline from oil, concentrating it into leads and channels, and becoming co-constituted with the oil itself to preserve it for a later response, the oil industry of the 1980s coined the phrase "ice is nice" to refer to Arctic activities (Clark et al. 1997, 123).

Delays can occur in less helpful ways, however, such as the long-term persistence of stranded oil on shorelines, especially in frigid conditions. Due to their extreme longevity and high oil concentrations, “asphalt pavement” formation has been observed at several *Arrow* sites and the enormous *Metula* spill site in Chile (Owens et al. 1987b, 118–119). Long-term monitoring of bioremediation effects has also played a significant role at the *Exxon Valdez* spill site (Owens et al. 2024, 3). Although some studies have indicated that long-term residual deposits such as the *Arrow* and *Metula* sites are “very rare and relatively minor” (Owens et al. 2024, 12), and that “natural attenuation would be the preferred option” in many instances (Owens et al. 2024, 3), other analysis has suggested that oil continues to pose a threat to local ecosystems even decades after being spilled. Recent returns to the BIOS site led to findings that “roughly forty years of natural attenuation processes alone are insufficient to remediate the priority PAHs within the crude oil” (Hunnie et al. 2023, 11). Scientists have speculated that if trapped in fine-grained sediment within low-energy ecosystems, oil can remain “in excess of 150 years” (Lee and Levy 1989, 479). Experts are still actively debating understandings of spilled oil’s complex temporalities.

Spilled oil can also often stick around in sites for much longer than initially expected or even known. An early instance of this dynamic was accidentally discovered during the Arctic IV expedition of 1974, when a diving engineering located 11 large depressions on the seafloor of Resolute Bay that contained an “extremely high concentration of oil” speculated to be the result of a 1972 spill in the area, along with the presence of herbicide that was one of the two major compounds in Agent Orange, notoriously used “for defoliation of Vietnam jungles in the early years of the war” (Dotto 1974a). Researchers found that oxygen levels in the “death holes” were extremely low and that conditions had killed all nearby marine, representing a “microcatastrophe” that had been “killing marine organisms for two years and most likely will continue, perhaps for many more years” (Dotto 1974a). It was also determined that the holes were likely created by grounding icebergs, with the oil interacting with and concentrating the herbicide in them, where low water circulation preserved them "for indefinite periods" (Dotto 1974a). This discovery exemplified the specific ecological threats of pollution to the Arctic: the herbicide did not originate in the area but likely arrived from southern currents or winds, combining with spilled oil while the ice cover limited currents and prevented the flushing of the holes. As a result, the diving engineer warned that "the polluted depressions discovered on the bottom of Resolute Bay, although relatively small, are indicative of problems that large-scale pollution could have on the Arctic" (Dotto 1974a).

This chapter argues that the *practices* of experimental spills were profoundly temporal in character, producing a "future eco-perfect" in the realm of time itself, and that we must specifically assess this dimension to understand their processes and limitations of knowledge production. As with the process of siting experimental spills—which overwhelmingly located discharges in places that minimized impacts, facilitated scientific research, and maximized the effectiveness of response measures—these temporal aspects sought to produce near-complete control over spill conditions and results in order to fulfill regulatory requirements and scientific goals. Spill planners explicitly prioritized this for the 1981 St. John's dispersant trial, with a key dimension of the experimental design being that the "number of field trial parameters should be minimized in order to keep the test manageable in the face of changing control" (Gill and Ross 1982, 255). While valuable from the perspective of scientific knowledge production, such laboratory-like control was in sharp contrast to many actual spill events, which often occur in highly unfavourable circumstances of heavy waves, wind, ice, and other adverse conditions, all of which impede spill response. These decisions materialized a "future eco-perfect" scenario in which scientists extrapolated findings from highly planned and controlled studies to real-world conditions.

Continuing arguments about field studies and scientific knowledge itself, we must understand time and temporality as actively *produced*. Noel Castree (2009) argues:

> capitalism – today, as much as yesterday or tomorrow – is *constituted* spatially and temporally. It is not a system whose operation occurs *in* space and *through* time, as if these were empty matrices waiting to be filled with the diverse products of human activity. Instead, space and time are, in specific and quite profound ways, core components of capitalism. (27; emphasis in original)

Much has been written about the production of space and place, particularly within geography. However, the dynamic and contingent quality of time often remains less intuitive. After all, modern technologies such as the clock, calendar, computer, and smartphone now perfectly define and regulate the passage of time, without the constant and often highly visible changes that can happen through material geographies due to extreme weather events, vast engineering projects, or war. Yet while time does indeed now have a largely coherent character at a global scale—with some exceptions, such as differences over daylight saving time—it, too, is materialized, especially in relation to the rise of the capitalist mode of production.

In a particularly renowned historical analysis, E.P. Thompson (1967) demonstrated that task-oriented time-keeping in peasant societies was replaced with increasingly formalized measurements such as watches and timesheets in order to increase labour discipline (57) and internalized “time-thrift” in workers (93); Elmar Altvater (2021) described this is a transition from activity as a measure of time to time being a measure of activity (102). Critically, this era created new divisions and experiences of time, especially between “work” and “life,” in which “those who are employed experience a distinction between their employer's time and their ‘own’ time” (Thompson 1967, 60–61).

Likewise, David Harvey has worked to historicize spatiotemporalities within capitalist development. In contrast to the "absolute space" of Newton and Descartes—a "'thing in itself' with an existence independent of matter"—and even the "relative space" of Einstein, in which there are "multiple geometries from which to choose and that the spatial frame depends crucially upon what it is that is being relativized and by whom," the "relational space" of Leibniz "holds there is no such thing as space or time outside of the processes that define them" (Harvey 2006, 271–273). This process-focused concept of "relational space" demonstrates that "it is impossible to disentangle space from time" (Harvey 2006, 273) and that it is necessary that the "triumvirate of space-time-process be considered as a unity at the ontological level" (Harvey 2007, xix). While noting that absolute, relative, and relational spatiotemporalities are constantly in flux and tension through human practice itself (Harvey 2006, 275), he also observes that "relational space-time is the primary domain of Marx's value theory" (Harvey 2007, xix), in particular generated through the highly specific mandate of socially necessary labour-time (Heinrich 2012, 51). Related spatiotemporal forces within capitalism include credit and interest rates (Harvey 2007, 410; Castree 2009, 44–45), fixed capital (Harvey 2007, 237), and ground-rent (Harvey 2007, 371).

It is from this theoretical basis and Marx's concept of "annihilation of space by time" that Harvey (1990) developed his landmark theorization of "time-space compression," in which "the time horizons of both private and public decision-making have shrunk, while satellite communication and declining transport costs have made it increasingly possible to spread those decisions immediately over an ever wider and variegated space" (147). Recently, such analysis has underpinned much of the aforementioned critical scholarship on logistics, with Martín Arboleda (2020) writing that the "logistics revolution—in the interest of speed—has deliberately and decisively blurred the boundaries between making and moving—production and distribution" (115) and Michael Simpson (2018) calling for assessment of "pluri-temporal strategies of circulation" that involve an intentional slowing down of circulation for the purposes of profit (111). All of these theoretical approaches make clear that time and temporalities are not merely filled (as in "absolute space-time") or linearly related (as in "relative space-time") but actively produced through human practices and processes. Working within this tradition, Ashley Carse and David Kneas (2019) have also emphasized the protracted quality of temporal production in large infrastructure projects that are abandoned or fall into disuse, writing that "unbuilt and unfinished infrastructures can become the axes of social worlds and sites where *temporalities are knotted and reworked in unpredictable ways*" (10; emphasis added). The processes and effects of time are not only highly dynamic but often unexpected.

The incessant need to defer or displace various capitalist crises requires constant geographic and temporal expansion of accumulation, regardless of the often-significant obstacles and challenges that arise. While oil spills are not themselves the direct product of accumulation—instead, the accidental byproduct of accumulation strategies, often posing severe threats to it—they occur and are anticipated in spatiotemporalities largely shaped by profit-seeking and corresponding state projects. This case study demonstrates the specifically temporal work of experimental oil spills. Specifically, it argues that, like with siting, the timing of this experimental work was highly controlled and calibrated in accordance with scientific and political requirements. Through this work, scientists *produced* extremely particular spill temporalities to facilitate various observations and interventions. However, this work functioned to significantly overstate the ability for real-world spills to be responded to, materializing a near-ideal level of timing and control that could rarely if ever be replicated outside of experimental conditions. This serves as another iteration of the "future eco-perfect" in scientific work, with tight control over timing and related factors extrapolated to actual spill response.

Planning

Timing was a central consideration of the initial planning and permitting process of spill experiments. In conjunction with siting decisions, planners often timed spills as a means of reducing potential impacts on seasonal human and nonhuman activities. For instance, a "number of concerns regarding commercial fishing and waterfowl sanctuaries" expressed about a proposed dispersant testing off the coast of St. John's in the early 1980s appeared to have been rectified through the selection of a fall date for the experimental spills (Gill and Ross 1982, 258). Likewise, planners explicitly chose the month of August for the NOBE of 1993 as it helped to "avoid conflicts with the commercial and recreational fishing session" (D. F. Dickins Associates 1992, 6) and to "minimize ecological damage and interference with the fishery" (Environment Canada et al. 1993, 1-2). These general measures worked to greatly limit potential fallout from the research by carefully calibrating its timing with other activities in the region.

However, broad seasonal and monthly planning could only go so far. Extensive planning also involved anticipating shifting environmental conditions, particularly involving waves, winds, and visibility. As with the logistics dimension of siting, the rationale for this was demonstrated most clearly through various testing failures. At Balaena Bay, even *seeing* what happened under the ice was extremely challenging: while researchers extensively documented the movement and behaviour of the oil under the ice with underwater video and still cameras, they experienced issues with capturing necessary details as "during the depth of winter, lighting proved very difficult" (NORCOR 1975, 30). During the full-scale aerial dispersant testing in Suffield, a "slight rain" on the second day of trials prevented the use of some sampling equipment (COAATF 1981, 17). Meanwhile, part of the small-scale dispersant trial in the Beaufort was conducted late in the day in low-light conditions, meaning that it was difficult to accurately assess the slick's movement and fate; as a result, one of the recommendations for future studies was that they be conducted at times "with excellent natural light" (Dickinson et al. 1985, 21). And while by no means calamitous to the experiments, higher-than-expected tides at the BIOS and Svalbard shoreline studies led to significant redistribution of spilled oil into the water and other shorelines (Owens et al. 1987a, 249–252; Owens et al. 2003, 262).

Many steps were regularly taken to reduce the possibility of wasted scientific efforts, especially when involving the costly and controversial spilling of large volumes of oil. For instance, one of the other major factors shaping the timing of the NOBE was due to the "high probability of favourable weather" (D. F. Dickins Associates 1992, 6). Specifically, scientists estimated that the wave height would be suitable for in-situ burning off the coast of Newfoundland for about 44 percent of the time in August, while wind speed and direction would be suitable for about 49 percent of the time (Environment Canada et al. 1993, 5-13). Planners developed a 10-day window—from August 5 to 15, 1993—for the experiment to take place during, with the "wide weather window" providing options to "maximize the chance of favourable weather and sea state conditions" (Environment Canada et al. 1993, 1-2).

A similar motivation shaped the timing of the St. John's dispersant experiment, as it would "involve colder water while avoiding the winter storms and spring fog" (Gill and Ross 1982, 258). In that case, such planning turned out to be successful, with the weather conditions for the testing on the chosen day described as "favourable," including winds at a speed between 10 and 20 knots and waves "seldom exceeding 1 metre" (Gill and Ross 1982, 258). The timing of oil discharges was also carefully determined to maximize scientific findings and response effectiveness. Scientists specifically timed oil discharges at BIOS so they would occur in "conditions that would carry it to the designated areas" (Sergy 1986, 12). Among other calculations, scientists released the oil during the six-hour rising tide period, "when oil would normally be expected to move inshore," which also proved successful (Sergy 1986, 12; Sergy 1985, 571; Boehm et al. 1987, 134).

Along with facilitating intended scientific studies—in the case of BIOS, the behaviour of dispersed versus untreated oil in nearshore environments, with the latter expected to become stranded on the shore—this timing also provided an additional layer of natural containment to the experiment, preventing large and uncontrollable losses of oil. Timing of spills was also a major factor in the Svalbard shoreline experiments. Rather than spilling the oil into the water and letting it wash ashore—like in the Bay 11 trial of BIOS — the Svalbard study applied the oil "directly to the beach face" (Guénette et al. 2003, 254). In addition to reducing excess oil in the water, this application method improved the ability to produce more reliable scientific findings, rather than the "unacceptable variance" in the oil loading that comes from more random stranding (Guénette et al. 2003, 254). In order to achieve this goal, scientists timed the spills to facilitate the oil's integration with the sediment and exposure to tides (Sergy et al. 1998, 82). At the same time, it was recognized that this method produced a "worst-case scenario" for shoreline contamination, given that a real-life spill would be more uneven in its results (Guénette et al. 2003, 254). The timing of the experiment actively shaped the scientific outcomes.

Planners also developed highly detailed contingency plans to determine whether a spill experiment should proceed on any given day or time. The Halifax dispersant trial of 1983 limited operations based on visibility, wave state, and the likelihood of precipitation (COAATF 1986, 3–4). For the 1986 Beaufort dispersant experiment, a nine-part criteria was created to determine acceptable conditions for the experiment to commence, with "no-go" factors including "unacceptable flying conditions," low visibility at sea, rain or snow, ice cover, and wildlife presence (Swiss and Vanderkooy 1988, 4–5). Given the importance of wave energy in mixing dispersant with the oil for effective application, another condition was that waves had to be at least 0.5 metres in height, which differed from most other response approaches (Swiss and Vanderkooy 1988, 4). To achieve permit requirements (Christopher and Vanderkooy 1993, 1), the NOBE also developed a similar "go/no-go" decision-making process using a set of criteria relating to environmental conditions (Environment Canada et al. 1993, 7-1). Specifically, the "critical parameters" identified to conduct the "tests safely and without loss of oil" were wave height, wind direction and speed, visibility, cloud ceiling, and surface currents (Environment Canada et al. 1993, 5-13).

Many different factors shaped this list of requirements: visibility and daylight operations were considered especially necessary given that helicopters were required to direct the oil spill experiments and conduct aerial surveillance for wildlife (Environment Canada et al. 1993, 7-1–7-3), while the possibility of oil being naturally dispersed into the water column was intentionally curtailed by opting to conduct the experiment during "low wave energy" (Environment Canada et al. 1993, 5-23). Planners also outlined a series of conditions that would "alter the course of the experiment" including "sudden weather changes, failure of the oil to ignite, loss of oil from the boom due to excessive tow speeds, and incomplete combustion of the oil" (D. F. Dickins Associates 1992, 25). The spill experiment could be "terminated immediately" if it was found that the "burn is not effective or environmental conditions suddenly change to become unsuitable for burning" (D. F. Dickins Associates 1992, 25).

Many studies had integrated such an approach, having commenced, continued, and called off spill experiments on the basis of shifting environmental variables. At an exceedingly small scale, this dynamic decision-making could be seen in the Saanich Inlet dispersant testing in mesocosms, which was concluded when the "beginning of fall storms made removal of the bags mandatory" (Green et al. 1982, 6). Due to such considerations, data collection and environmental monitoring was often a key part of experimental design. The St. John's dispersant testing used ship-based instrumentation to satisfy the "necessity of carefully monitoring sea state, water temperature, currents and wind data" (Gill and Ross 1982, 258). Similarly, planners dedicated a meteorologist to NOBE to ensure the accuracy of weather forecasting (Christopher and Vanderkooy 1993, 3), with long-range forecasts provided by the Atmospheric Environment Service (D. F. Dickins Associates 1992, 14).

However, this contingency planning and monitoring often come into contradiction with the aforementioned aim of achieving realism and representation of research. A main motivation of the 1986 Beaufort Sea dispersant testing was to better reflect Arctic operating conditions, such as low temperatures and a more remote location, which "could be expected to be more strenuous … than those encountered in more southern latitudes" (Swiss and Vanderkooy 1988, 2). Yet scientists aborted the first attempt to conduct the Beaufort dispersant experiment when they identified an "operational problem" with the helicopter's spray bucket that rendered the apparatus "inoperable," and they called off efforts to use the second bucket when fog rolled into the area (Swiss and Vanderkooy 1988, 18). By this point, helicopters had discharged 5,000 litres of the available 15,000 litres of oil during the attempt in the form of two spills, meaning that "it was not possible to complete the remainder of the trial as originally planned" (Swiss and

Vanderkooy 1988, 9, 18). It took another three days until conditions were suitable to proceed in a modified form that accounted for the lower volume of oil (Swiss and Vanderkooy 1988, 4).

A similar process occurred during the NOBE project. August 7 was the first day in the August 5 to 15 window when the weather conditions were deemed suitable (Christopher and Vanderkooy 1993, 1). The "armada" left the St. John's harbour at 3 a.m., arriving at the test site five hours later (Christopher and Vanderkooy 1993, 1–2). Observers reported visibility as "poor" upon arrival, but personnel successfully deployed the booms and sampling vessels (Christopher and Vanderkooy 1993, 2). By noon, "all units were in place," and system checks were completed by 3 p.m. (Christopher and Vanderkooy 1993, 2). However, visibility continued to deteriorate, so scientists suspended the experiment for the day, with all equipment collected and returned to port (Christopher and Vanderkooy 1993, 2). By that point, pilots had already aborted air sampling flights (Ferek et al. 1997, 12). Researchers still regarded the cancelled experiment as a successful "dress rehearsal" and a "complete system check," with no issues, "only numerous seasick reports" noted (Christopher and Vanderkooy 1993, 2). It took another five days, on August 12, until "ideal weather conditions" were achieved and the enormous spill experiment conducted (Christopher and Vanderkooy 1993, 2).

For other experimental spills, scientists prioritized cold temperatures due to their need to test the applicability of response technologies in Arctic conditions. However, these prioritized conditions also ranged considerably. A few tests did take place in extremely cold temperatures. Scientists conducted small-scale burning tests in ice trenches near McKinley Bay in -32°C temperatures, with the experiment leading to the conclusion that responders could indeed successfully burn oil in frigid temperatures, although high snow content limited burning (Energetex Engineering 1981b, 57). Researchers also undertook an oil-in-snow spill in a forest near Norman Wells in -20°C, with the oil cooled to the same temperature prior to the spill (Mackay et al. 1974, 125). Another spill experiment in Dorset, Ontario—a location chosen due to having closer climatic conditions to Norman Wells than previously used (Mackay et al. 1974, 112–113)—took place in sub-zero temperatures, with researchers concluding that oil that had spilled into snow would remain "stable" within such conditions until spring, when "the melt water would cause considerable spreading of the oil" (Mackay et al. 1974, 125). And the seemingly positive findings of the generally frigid BIOS nearshore experiment, with the "surprisingly high" loss of 70 percent of stranded oil from the untreated spill over the following two years, was followed with the warning that oil "input" would carry on for far longer than in warmer climates, "providing a continued source of potentially toxic hydrocarbons to the benthic communities at the time of greatest growth" (Humphrey et al. 1987, 160).

Yet many other spills explicitly intended for cold-water testing occurred in far warmer conditions. For example, dispersant field trials were conducted in the Halifax Harbour during August 1975 and March 1976, specifically seeking to understand the impacts of varying water temperature; however, wintertime testing conditions were 4°C (Gill 1977, 391–393). While generally successful, researchers noted that the objective of testing the performance of dispersants in colder conditions was hampered by the use of a light Venezuelan crude that "cannot be assumed to be indicative of the success one might experience with cold, weathered crude oil," leading to the recommendation of "further cold weather work" (Gill 1977, 394). Similarly, while reported as "relatively cold" (Goodman and MacNeill 1984, 144), the water temperature at the St. John's cold-water dispersant testing ranged between 6.5 and 8°C, still well above freezing in saltwater conditions (Gill and Ross 1982, 261).

Similar constraints occurred in skimmer testing during the late 1970s and early 1980s. The aforementioned "Oil Mop," which was specifically designed to recover viscous oils and augmented with a "hot water bath" to aid its processing, was tested in Sorel, Quebec, within air and water temperatures that were well above freezing. Yet researchers deemed that the conditions were low enough to demonstrate whether the addition of the preheater would offer a "workable answer" to the identified problem (Tidmarsh and Solsberg 1977, 10). Despite successful testing, the report advised that the unit be "tested under 'worst case' environmental conditions over an extended trial period" (Tidmarsh and Solsberg 1977, 5). It was also cautioned that a potentially "explosive atmosphere" could be produced if the preheating tank was used with an insulated cover and volatile fractions of the oil concentrated; such a cover was not used in the Sorel testing, due in part to the mild temperatures (Tidmarsh and Solsberg 1977, 24).

As a result of such outcomes, experimental spills for skimmer testing frequently ended with recommendations of future trials in colder conditions. For example, the "DIP 1001" skimmer experienced several problems during testing in Quebec City, notably including the "freezing of air exhaust mufflers," leading researchers to conclude that such issues would necessitate more testing for operations "at temperatures lower than those encountered during the course of the Quebec test program" (Solsberg et al. 1977, 19). And although a system designed to collect, separate, and store or discharge the oil and water found considerable success during another round of skimmer testing in Quebec City, researchers warned that increased viscosity with "cold, thick oils" would "limit pumping rates" (Abdelnour et al. 1978, 53).

There were several other factors that shaped the temporalities of experimental spills. One related to safety. Federal skimmer testing guidelines required that researchers ensure an array of factors prior to testing for reasons including worker safety, environmental protection, and quality of research results. For instance, while guidelines advised that testing take place in a variety of sea conditions for the purposes of adequately assessing the capabilities of the technologies, they also required that researchers exercise "due consideration for personnel and equipment safety" (Solsberg et al. 1976, 75).

As a result of these requirements, skimmer testing was frequently conducted in low-intensity weather, with worse conditions leading to extremely poor or non-existent oil recovery. Although weir skimmers are reported as "economical" and "can have large capacities" (Fingas 2011, 321), many designs suffer from high rates of water intake due to their "tendency to rock back and forth in choppy water, alternately sucking in air above the slick and water below," often necessitating significant separation capacities prior to storage and disposal (Fingas 2011, 320; Schulze 1998, 94). Meanwhile, the "suction" or "vacuum skimmer," which sucks the oil using a floating skimmer head into a boat or truck for storage (Schulze 1998, 85), is regarded as "simple to operate" and "can be used nearly everywhere" but can also become easily clogged with debris (Schulze 1998, 85) and have the same problem of rocking in waves, often resulting in "massive water intake" (Fingas 2011, 322).

Along with the presence of effective booming, spill planners consistently timed skimmer testing to occur within these narrow environmental parameters. For example, while an "inverted oleophilic endless belt" skimmer performed well in experimental spill tests in mid-1975—recovering about three-quarters of the 1,500 litres of oil spilled over 11 test runs, producing a 90 percent oil recovery factor (Solsberg et al. 1976, 9, 50)—it was explicitly recommended that the skimmer was tested "in other than a calm wind and wave situation" (Solsberg et al. 1976, 9). There was also extreme variation in testing results based on differences in wave conditions. During testing at Quebec City in 1976, the oil recovery factor for two skimmer models plummeted from up to 85 percent in calm conditions to 0 percent in small waves, with similarly stark differentials present with its oil content factor (Solsberg et al. 1977, 8, 11–13). As a result, researchers deemed that one of the skimmers was only effective in "virtually calm conditions" (Solsberg et al. 1977, 8).

In occasional cases, however, higher-intensity weather actively benefited the experimental spill situation. During the same round of testing at Quebec City in 1976, another skimmer experienced a slight improvement in oil recovery in wave action, especially in thick oil, which was the result of its "upward-sloping weir" design (Solsberg et al. 1977, 9–11, 60). Two years later, during efforts to test a skimmer within "normal offshore sea conditions," researchers placed specialized buoys to report wave heights to identify higher-intensity testing conditions (Gill and Ryan 1979, 498). However, the timing of this experiment ended up resulting in weather conditions that were "unusually moderate with a negligible swell," the opposite of what researchers desired for the purpose of the testing (Gill and Ryan 1979, 498). Scientists regarded this reality as "disappointing" as there was a desire for "more rigorous conditions in order to better assess the handling characteristics of the skimmer head" (Gill and Ryan 1979, 499). Even in these "ideal" conditions, however, the skimmer exhibited poor oil recovery and high water intake, a finding that did not prevent it from being promptly shipped to Tuktoyaktuk, "where it became a component of the Canadian Coast Guard contingency plan for offshore petroleum exploration in that theatre" (Gill and Ryan 1979, 497–499).

The 1987 spilling of 10 oil slicks between Sable Island and Nova Scotia to evaluate the effects of two spill-treat agents was also found to greatly benefit from more intense sea states. Application of Elastol resulted in an intended increase in the viscosity and elasticity of oil—with the highest concentration of it leading to the sample becoming "almost semi-solid" or "superelastic"—and the better performance of Elastol in the field than the laboratory explicitly attributed to the high mixing provided by wave energy in "natural oceanic conditions" (Seakem Oceanography 1990, 20). Yet "rough weather" then delayed and then eventually cancelled the remainder of the test program (Seakem Oceanography 1990, 7–11). Likewise, the Newfoundland Oil Spill Experiment that happened only a few weeks later ended by deciding to apply an estimated seven pounds of Elastol as "weather was deteriorating and night was falling" (Tennyson and Whittaker 1989, 102). Even in circumstances when researchers desired higher intensity weather for experimental purposes, the scientific outcomes were still regularly shaped and steered by the conditions themselves.

Like with siting, experimental spill planners worked in collaboration with regulators to minimize the effects and maximize response effectiveness through the timing of the experiment itself. Most notably, many experimental spills were subject to a strict set of requirements relating to timing that had to be met for it to proceed, with several major spill experiments called off right before the discharges due to lack of appropriate conditions. Once again, such a priority was understandable from the perspective of generating usable scientific data and preventing the loss of control of the oil. Yet the problem of its extrapolation to spill situations when responders cannot guarantee such controlled timing and conditions can result in the significant overstating of levels of response that may actually be feasible.

Winds

Scientists had already identified winds as a recurrent theme in the timing of experimental spills, especially the planning and monitoring of environmental factors to ensure suitable conditions. However, there were many more specific aspects of the wind that require closer examination. In particular, researchers found that wind had sizable effects on in-situ burning and aerial dispersant application, directly shaping the timing and outcomes of experimental spills and associated scientific work. Winds were frequently monitored and closely accounted for with a degree of precision that is unlikely in real-world spill situations. But most notably, the failure and disruption of experimental spills in high-wind circumstances consistently demonstrated the importance of low-wind conditions, reiterating the improbability of translating positive results into many real-world situations.

Initially, researchers thought that wind may in fact assist with in-situ burning potential. Specifically, given the extreme challenge of responding to oil spills in ice-dense environments, there was scientific interest in the possibility of using "wind herding" to collect oil into greater thicknesses for easier ignition and increased combustion efficiency (Energetex Engineering 1981b, 3–4). In addition to ice edges and fireproof containment booms helping to corral the oil in necessary thicknesses, researchers suggested that "winds could prove to be the most economical … for the purposes of herding and confining large oil slicks" (Energetex Engineering 1981b, 4–5). Further, the use of wind herding "delivers relatively more air to the flame during in situ combustion, thereby allowing for reduced smoke emissions and more complete oil combustion" (Energetex Engineering 1981b, 5).

Scientists identified timing and weather conditions as key variables in the potential success of such an operation (Energetex Engineering 1981b, 5–6). However, they quickly discovered during testing that even low wind speed had a major detrimental effect on flame spread (Energetex Engineering 1981a, 19). At trench burning tests in McKinley Bay, they also found that increased wind velocity reduced the spread of flames in the trenches and impede combustion efficiencies, confirming prior testing in Waterloo that reported the "flame did not propagate against the wind very well" (Energetex Engineering 1981b, 57). These effects were also a major problem at NOBE and directly resulted in the early termination of the second burn. Unlike the first spill of NOBE, when wind speed was minimal, the second spill experienced higher wind speed that proved "sufficient to hold the edge of the burn down at the apex of the boom" (Christopher and Vanderkooy 1993, 3). This process ended up charring the boom more than expected, with wind speed and direction later flagged as one of the major limitations of the experiment (Christopher and Vanderkooy 1993, 3). Additionally, the observed strain on the boom tows used at NOBE was attributed to currents and winds (Fingas and Lambert 2018, 302). A recent retrospective about NOBE reported that the wave height during the experiment averaged 0.6 metres during the first burn and 0.8 metres during the second, while the wind velocity never exceeded 11 km/h, suggesting that outcomes could have been even worse in windier conditions (Fingas and Lambert 2018, 287).

Although a dispersant experiment, the 1978 experimental spill at Royal Roads— where wind speeds reached a high of 20 knots—clearly demonstrated this possibility (Green et al. 1982, 77). Researchers discovered that the boom failed to contain the oil, particularly under more intense conditions, and that "some oil escaped under the mildest conditions experienced" (Green et al. 1982, 85). And the 1987 Newfoundland Oil Spill Experiment (NOSE) that tested the performance of booms and skimmers largely failed when "the wind came up, the waves got choppy and much of the oil got away," leading the Environment Canada project supervisor to conclude that "we know now that the booms that are in St. John's, used under these kinds of conditions, don't work very well" (*Globe and Mail* 1987).

These outcomes highlighted the extreme effects that winds in particular can have on the control of spilled oil and possible responses. Issues of aerial igniter deployment that researchers repeatedly identified through burn experiments only compounded these concerns. One of the greatest challenges facing the prospect of large-scale in-situ burning was the ignition of the oil. This question was of particular focus given that an under-ice blowout could result "thousands of individual pools spread over hundreds of kilometers" (D. F. Dickins Engineering 1979, 1), representing an extreme spatiotemporal crisis once the ice began to melt. The potentially catastrophic temporalities of spill response necessitated an anticipatory co-production of technologies and contingency plans.

Such a possibility demanded the development of an igniter technology that responders could deploy safely from the air, both in terms of safety and efficiency. Various recommendations were developed to anticipate such an outcome, such as that helicopters deploying igniters should be supported from a ground crew "in the early stages of the melt process," and replaced with an aerial support operation once ice had "deteriorated to a point where they were no longer safe" (Dickins et al. 1981, 188). However, scientists again quickly found that wind speed and direction heavily influenced the effectiveness of ignition and burning. Engineers had already dedicated considerable work to improving igniter designs. One of the prototypes tested at Crater Lake in the late 1970s consisted of a "small slab of solid propellant" that was surrounded by "standard Bar B-Q briquettes" of gelled kerosene, and housed within a bent metal sheet (D. F. Dickins Engineering 1979, 3–4), while a Defence Research Establishment Valcartier (DREV)-designed igniter trialed at McKinley Bay was a "canister-type" device that used a "high temperature-resistant phenolic dome which serves to direct the heat and hot gases onto the slick surface" (Energetex Engineering 1981a, 2). As intended, testing led to the identification of problems and recommendations for future designs. For instance, engineers improved the igniters used during the 1980 trials in the following years by "incorporating aluminum foil wrapping for the gelled kerosene fuel" and developing a flameless “glow energy type ignition system” due to the impracticality of using matches during large-scale deployments (Energetex Engineering 1982, i–1).

Yet general issues of igniter accuracy—with units frequently missing the oil pool (D. F. Dickins Engineering 1979, 18), bouncing off the ice (Dickins et al. 1981, 188), or rolling away (Energetex Engineering 1981a, 8)—were worsened in the presence of wind. As discussed, burn testing had found that even low wind speed had a major effect on flame spread, with an identified “inability of flame propagation upwind for wind velocity greater than 10 km/hr” (Energetex Engineering 1981a, 8). This led to an attempt to aim igniters specifically for the upwind portion of the melt pools, which researchers regarded as a contributing factor to inaccuracy issues (Energetex Engineering 1981a, 8). Such conclusions echoed a prior report about igniter design, which noted that winds and helicopter downwash could significantly influence the accuracy of igniter deployment (Energetex Engineering 1980, 32). In some igniter experiments, wind velocity generated by the helicopter blade downwash was specifically measured to account for its contribution to accuracy (D. F. Dickins Engineering 1979, 7–8), with downwash also found to have “unavoidably herded [oil] over to one side of the pool” (D. F. Dickins Engineering 1979, 11).

Several ad-hoc solutions were devised for the purposes of effective study. Extremely careful helicopter piloting was employed to counteract these factors at least partially. At McKinley Bay testing, researchers noted that “ideally, the test should be conducted with a highest possible helicopter speed for which high deployment accuracy is possible” (Energetex Engineering 1981a, 10). But as a result of the “small pool size, irregular geometry and their closeness,” the testing was instead conducted at an extremely low helicopter speed of between 2 and 5 km/h, with it stopping to hover about each pool to allow for accurate deployment

(Energetex Engineering 1981a, 10–14). Researchers found this approach provided greater accuracy of the igniter (Energetex Engineering 1981a, i–ii). Further, due to the findings that helicopter downwash had "negative affects on the flame propagation and therefore will hinder the pool ignition," the helicopter was advised to move from the area "as soon as possible after the device is released" (Energetex Engineering 1981a, 19). This process of improving the accuracy of igniters was the product of extremely delicate timing of helicopter presence that could be much more difficult to execute in higher-intensity conditions.

Another major aspect of the impact of wind on burning experiments was the varying redistribution of its byproducts. The most visible output was the "dense black smoke plume" from the burn, which was mostly made up of elemental carbon (or soot)—the product of incomplete combustion (Fingas 2018, 4)—along with other gases including carbon monoxide, nitrous oxides, and sulphur dioxide (Ferek et al. 1997, 3). Many factors have been found to shape this combustion efficiency, including differences in oil thickness, fire diameter, carbon dioxide concentration, and the presence of natural gas (Ferek et al. 1997, 24–34; Ross et al. 1996, 257). Of particular concern to researchers has been the presence of polycyclic aromatic hydrocarbons (PAHs), which are persistent, toxic, and carcinogenic compounds (Georghiou and Sheppard 1982, 2–3, 6). In large-scale burns, winds and waves can easily spread PAHs (Georghiou and Sheppard 1982, 3).

While there are varying findings on the production of PAHs through burning (Georghiou and Sheppard 1982, 8–9, 19; Ferek et al. 1997, 3; Fingas 2018, 33), an obvious priority in experimental spills has been to limit the potential spread of PAHs through the smoke plume itself. As a direct result of these concerns, permitting for most burning experiments explicitly required that they only take place if there are winds that blow the smoke away from the coast

(Environment Canada et al. 1993, 5-23). Such planning contributed to vastly improved control over smoke behaviour. For instance, the Rimouski burning test in 1973 found that smoke from the burning remained "very dense directly over the test site" due to low wind levels (Coupal 1976, 3). During the NOBE burn, the smoke plume rose to high altitudes and spread "over a wide path" northward and eastward (Ferek et al. 1997, 13–14, 22; McGrattan et al. 1995, 12), the smoke never threatened to blow towards the shoreline due to the design of the experiment itself. Similar motivations were present for limiting the spread of burn residue, which is the highly concentrated and viscous aftermath of burns that cannot sustain further combustion. Prior to the Balaena Bay testing of the mid-1970s, a burn in high winds had resulted in residue becoming widely distributed across the snow and ice, accelerating its melting in the following week (NORCOR 1975, 129). However, during the burning of an estimated 33,000 litres of spilled oil during the Balaena Bay trials, there was "no evidence of fallout" farther from the site, which scientists specifically attributed to the lack of wind during the burn (NORCOR 1975, 126–129).

Wind was also a major concern in aerial dispersant testing, requiring extensive planning, monitoring, and calibration to account for. Whereas the burning experiments had dealt with the effects of wind in multiple directions—the downward drop of the igniter, the upward expansiveness of the smoke plume—the impacts on dispersant application related to the spraying of the chemicals onto the sea surface. This dynamic was particularly acute during the Suffield dispersant testing in 1980. One of the main focuses of this effort was to assess whether a more "uniform distribution" of dispersant was feasible by orienting the aircraft "into the wind instead of having to align it with a runway," helping reduce "lateral dispersant drift" (COAATF 1981, 3). In particular, smaller droplet size led to a "greater tendency to drift" in higher winds, which pilots had to correct by shifting the flight path to account for shifting wind directions (COAATF 1981, 18).

To achieve the goal of better spraying accuracy, researchers marketed out each flight line in advance using survey stakes based on the "best-guess estimate of the wind vector" and the pilot aligned the airplane accordingly (COAATF 1981, 6). However, it took an estimated 20 minutes between each test run to reset the sampling instruments, making this objective challenging to maintain (COAATF 1981, 6). Researchers used meteorological instruments to assess the wind speed and direction in real-time once the airplane started to apply dispersant, allowing for post-testing analysis of the impacts of wind on the coverage (COAATF 1981, 13). Although planners deemed the Suffield testing location "ideal with respect to unrestricted flying" (COAATF 1981, 16), differences in wind speed and direction meant that they could not successfully compare tests that they had grouped based on similar dosing, dispersant, or application specifics (COAATF 1981, 16).

For instance, on the day when Corexit 9527 was being tested, the ability to compare the second and third flights with the eighth and ninth was confounded by the wind direction shifting that "necessitated an alteration in the flight path axis" (COAATF 1981, 16). While the use of many raindrop nozzles, rather than three large pipes, appeared to provide greater dispersant coverage, the substantial reduction in wind speed prevented accurate comparison and impeded more definitive conclusions (COAATF 1981, 17). Similarly, the test flights conducted in conditions of even lower wind speed enabled a "remarkably confined spray pattern," but scientists could not easily compare them to prior results due to the differing conditions (COAATF 1981, 17–18). Researchers concluded that "stable atmospheric conditions" had a greater impact on "achieving uniform ground coverage" than differences in the design of nozzles that distributed the dispersant (COAATF 1981, iii). Researchers also found that the most successful test runs were those that took place in flight conditions of crosswinds of five knots or less, or with the airplane parallel with the wind direction (COAATF 1981, 19).

Like with the burning experiments throughout the same period, the dispersant testing at Suffield reiterated the centrality of wind to effective spill response. However, it was a *failure* of testing that clearly demonstrated the need to better anticipate such effects in future experimental work. Planners designed such consideration into later dispersant trials. During the Halifax dispersant testing of 1983, which opted to use a Bell 212 helicopter and a spray bucket rather than testing aerial application from a large airplane, a “floating dyed smoke market” was deployed at the top of each spill to help account for the impact of wind-caused oil spreading (COAATF 1986, i, 10).

Likewise, the 1986 Beaufort Sea dispersant testing included “onshore winds” and “unacceptable flying conditions” as key factors in the go/no-go decision-making process (Swiss and Vanderkooy 1988, 4). Notably, wind direction and speed were the first two conditions listed under a description of the weather and sea state of the experiment, and dispersant application from the helicopter oriented to “make parallel passes upwind over the slick” (COAATF 1986, 13). Further, the subsequent report detailed that “by using a coloured smoke flare, which was deployed at the upwind edge of the slicks, the spray helicopter was able to align itself accurately both in relation to the prevailing wind and the edge of the previous swath” (COAATF 1986, 13). Such tremendous precision in limiting and managing the effects of wind on experimental spills produced conditions that would be unattainable in real-world emergencies.

Response Time

Along with the general planning of spill experiments to occur in specific weather conditions and the major factor of wind, the third interlinked aspect of experimental temporalities involved extremely precise *response times* to spills. This aspect included the length of time that scientists allowed oil to remain untreated in the environment prior to intervention, and ensuring a near-perfect timing balance when assessing oil-in-ice spills. While some degree of "realism" was sought in such work, these approaches materialized an improbable temporal aspect to real-world spill response, which is often marred with considerable time delays, uncontrollable oil spread, lack of monitoring capacities, and siting complications outlined in the previous case study.

Many experimental spills integrated a planned time lag to better represent real-world response conditions. Scientists recognized that application of response measures would rarely, if ever, be instant, and this approach worked to produce more realistic findings. However, such a time window ranged sizably, and often maintained extremely rapid intervention. Aerial application of dispersants often occurred about 15 to 20 minutes after an experimental spill was discharged, providing the oil time to spread on the water surface (Gill and Ross 1982, 255; Goodman and MacNeill 1984, 146; Swiss and Vanderkooy 1988, 12). At the Crater Lake igniter testing in 1979, researchers left the oil for a half-hour "in order to absorb some solar radiation, and affect both oil and water temperature" (D. F. Dickins Engineering 1979, 7). And during the testing of two spill-treating agents between Sable Island and Halifax in 1987, researchers treated the control slick with Brand M after the five-hour mark, resulting in rapid reduction within only 10 to 15 seconds in water-in-oil emulsion and overall viscosity (Seakem Oceanography 1990, 15, 22–23).

Time delays were often more pronounced during shoreline studies. During the BIOS shoreline studies, scientists left plots to weather for 24 hours before they started to apply clean-up techniques (Sergy 1986, 20). At the Svalbard trials of the late 1990s, which used about one-third of the oil volume as BIOS, various treatments commenced after a week, to allow for tidal action and the oil to stabilize (Sergy et al. 1998, 73), with this week-long delay of treatment "very representative of a feasible response time for a remote location" (Sergy et al. 1998, 87). During small-scale shoreline spills in Nova Scotia during the mid-1980s, nutrients were not added to the experimental plots for two weeks after the oil, as previous studies had indicated that such efforts to stimulate biodegradation would not be effective until some of the lighter fractions of the oil had evaporated or been washed away (Lee and Levy 1989, 480). In a few cases, spill experiments that sought to understand the longer-term behaviour of oil intentionally stretched studies far longer. At the 1972 spill of oil at the Scarborough landfill, researchers left the spilled oil for a period of three months to assess its behaviour over periods "roughly corresponding to the season of winter, spring and summer" (Mackay et al. 1974, 109). However, the intention of such studies was not to test response technologies; in the spring, much of the oil was carried into a creek near the site, expanding 15 times in size and leaving behind a "dark tar-like scum" (Mackay et al. 1974, 109–112).

Another means by which researchers attempted to materialize a time delay was through the artificial weathering of the spilled oil prior to its discharge, which changed the physical composition of the spilled oil. At BIOS, personnel artificially weathered the oil by bubbling air through the oil for several days, reducing its volume by 8 percent (Boehm et al. 1987, 134; Dickins et al. 1987, 101). Prior to NOBE, the oil had been weathered to reduce it by 10 to 15 percent in volume to simulate the slick having been on the water for between 4 and 12 hours

(Environment Canada et al. 1993, 7-4; Fingas and Lambert 2018, 287). The Halifax and Beaufort dispersant trials weathered oils to reduce 13 to 17 percent, and 15 to 20 percent, of volume, respectively (COAATF 1986, i, 4; Swiss and Vanderkooy 1988, 9). And at the St. Lawrence shoreline spill in the late 1990s, researchers weathered the oil prior to discharge by “mixing for 130 hours with a submerged air line,” resulting in a removal of about 14 percent the oil’s light fractions (Lee et al. 2001, 324). In several experimental spills, water-in-oil emulsions were also intentionally produced prior to discharges, a development which takes hours or days to occur in real-world conditions. Dome’s 1982 experimental spill at McKinley Bay used an “extremely well mixed and stable emulsion” of 60 percent water and 40 percent crude that personnel had produced using a centrifugal pump (Buist and Dickins 1983, 2, 8). Likewise, during the BIOS shoreline spills, researchers created emulsions by mixing equal portions of seawater with oil to simulate the creation of “chocolate mousses” (Humphrey et al. 1992, 7; Sergy 1986, 20).

Each of these measures, in varying ways, worked to modify the temporality of the experiment to advance particular scientific goals. However, in each of these cases, researchers maintained considerable and improbable levels of control over the oil that in many ways compensated for this move towards greater realism, including through the limiting of spreading and the ensuring of viable conditions for response methods to be applied. The frequently rapid application of various treatments to weathered or emulsified oil meant that burning or dispersants could still achieve a high level of success within experimental limits. Scientists additionally co-produced modified temporalities with other key aspects of spill planning that materialized facets of “future eco-perfect” conditions. Another major facet of this production and management of time in experimental spills specifically involved ice. Like with other test settings, the regulatory approval process itself had a direct role in shaping oil-in-ice experiments: during the second round of experimental spills at McKinley Bay, the first spill was scheduled to occur in February 1982 to evaluate differences in emulsion behaviour under different thicknesses of ice, yet “delays in receipt of a necessary permit” meant that only the later March testing was conducted (Buist and Dickins 1983, 3). However, this temporal aspect was also determined by the scientific imperatives and the desire to maintain maximum control over the spilled oil.

This process was by far the most evident at the large-scale Balaena Bay experiment of the mid-1970s, which specifically sought to better understand oil-in-ice behaviour. For starters, planners had scheduled the tests to evaluate the behaviour of oil across the range of “dominant stages in the ice growth and depletion cycles,” requiring spills to happen incrementally over a longer period of time (NORCOR 1975, 12). Like at the later McKinley Bay spill, there were timing-related impediments due to permitting: although the testing was originally planned to begin before or during freeze-up, “delays in obtaining the necessary approvals to discharge oil” meant that the start date had to be pushed back and the small “open water test … simulated” by removing a small section of ice (NORCOR 1975, 12). Another major factor was the technical requirements of the thermistor chains—the technologies that were used to measure the temperatures of the ice, water, and air (NORCOR 1975, 22)—as their spacing “set close limits (± 2 cm) on the ideal ice thickness and hence the day for the test” (NORCOR 1975, 13). The temperature and thickness of the ice thus informed the particular day that researchers conducted each discharge, in order to meet scientific and technical requirements (NORCOR 1975, 12–13).

The third key dimension of timing at Balaena Bay involved spill response measures. Spill planners had always intended in-situ burning to be the primary countermeasure at the end of the experiment (NORCOR 1975, 124). In January 1975, however, they adjusted plans to “extend the tests as long as possible, which necessitated a re-evaluation of the clean-up procedures”

(NORCOR 1975, 124). Researchers predicted the highest levels of combustion efficiency would occur prior to the ice's break-up, with the prospect becoming much more challenging in open water conditions (NORCOR 1975, 124). Given that extending the tests increased the probability of ice failure, conventional mechanical responses were also prepared and tested as back-up options (NORCOR 1975, 124). The spring thaw in early June 1975 resulted in rapid transformation of conditions. A previously used coring hole in the ice began to re-open and create a "considerable vortex, as both water and oil were flushed down the hole" (NORCOR 1975, 57–60). Initially, personnel installed a "concrete collar" around the first hole "to permit selective drainage, and prevent the loss of oil due to the vortex action" (NORCOR 1975, 60). However, melt holes started to expand in number in "critical locations" of the ice, with significant quantities of surfaced and pooled oil beginning to be sucked into the newly formed holes and reintegrated into the ice (NORCOR 1975, 125). The percentage of the test site covered by these oil pools quickly decreased from almost half to one-third of the area (NORCOR 1975, 125). Given these quickly changing circumstances, researchers decided to commence burning operations two days after they observed the formation of melt holes (NORCOR 1975, 125).

Key to the success of the burning, with 80 percent of the oil removed through the process "with relatively little effort," was the presence of "*ideal surface conditions* and … *proper timing*" (NORCOR 1975, 134; emphasis added). One significant factor was the spill experiment's location in a "small sheltered cove," which significantly extended the ice's longevity due to its lack of movement and the ice having "rotted in place" (NORCOR 1975, 134, 144), exemplifying the tight relationship between siting and timing of experimental spills. This context meant that the "maximum time was available for a clean-up operation" (NORCOR 1975, 144). Researchers noted that "under more typical offshore conditions, the sheet would have failed several weeks earlier, greatly reducing the effectiveness of the clean-up" (NORCOR 1975, 134), and that even a "single crack" that connected the test site with the "tidal crack system would have greatly reduced the effectiveness of the clean-up, and caused a much larger section of shoreline to be contaminated" (NORCOR 1975, 144).

Another vital aspect shaping the successful burn was that the location of the under-ice oil was known with great precision, an outcome of the aforementioned containment strategy. This allowed researchers to conduct regular measurements and sampling of the oil "to determine the timing of burns" (NORCOR 1975, 144). As a result, researchers concluded that while it was difficult to predict combustion efficiency for a major in-ice spill with much precision, "even with reasonable care and unlimited resources, it is doubtful if more than 70 percent of the oil could be burned in fast or stationary ice, and possibly 30 to 40 percent in the moving pack" (NORCOR 1975, 144). In these sections, researchers implicitly acknowledged the unlikelihood of responders easily replicating such scientific success in real-world conditions.

Concerns about real-world feasibility of burning also linked to findings from both the Balaena Bay and earlier experiments that presence of surfaced oil on ice could dramatically accelerate the timing of ice sheet collapse. During the spill experiment near Ottawa in late 1972, researchers observed the gradual impact of oil's absorption of sunlight reshaping surrounding snow and ice formation, melting some of the snowfall and later integrating into the ice (Scott and Chatterjee 1975, 11). Most notably, scientists found that all of the ice in the pond with spilled oil melted a full two weeks prior to the ice in the control pond, indicating a pronounced difference due to albedo. A researcher observed an identical process during a small under-ice spill near Resolute in mid-1974. Once on the surface of the ice, the pooled oil started to absorb sunlight, transforming it into a "wick" for the remaining oil in ice that would then progressively "draw it up at a faster rate" (Dotto 1974b). Extrapolating this, the researcher involved in the Resolute study expressed significant concern that the lowering of albedo by the surfaced oil would melt ice cover, warm the water, and dramatically reshape the atmospheric water vapour and heat balance in the area (Dotto 1974b).

The Balaena Bay experiments expanded and appeared to corroborate many aspects of these findings. There, researchers discovered that natural processes of "brine rejection" through ice formation were impeded by the presence of oil, forming a boundary that prevented its drainage and in turn meant that the brine channels would open in the spring "somewhat earlier than normal, and thereby permit the upward migration of oil" (NORCOR 1975, 39). At this point, the reduced albedo caused by the surfacing oil was deemed "the most significant factor in advancing the melt," with a 7°C average temperature difference between the oil film and surrounding water (NORCOR 1975, 103). Even when the rising oil was "barely detectable," only visible as a "slight discolouration in the snow," albedo was reduced by an estimated 30 to 50 percent (NORCOR 1975, 99). Such findings indicated a significant feedback loop on several related fronts, with oil rising through brine channels absorbing sunlight, heating the area, and spreading in pools to quickly cover the surface of the ice.

Although clean-up efforts worked to remove the oil and ended the experiment, researchers estimated that the oiled sites would have been ice-free two to three weeks before the sheet's break-up and failure (NORCOR 1975, 60, 105), echoing the Ottawa experiment's findings (Scott and Chatterjee 1975). Despite these major unknowns and challenges, a subsequent study described the Balaena Bay findings as "encouraging" as it demonstrated the temporary freezing of oil in the ice, which could also "be used as a platform" to conduct clean-up responses (Comfort and Purves 1982, 2). Although it was not tested in this later experiment, researchers speculated that a "well-timed visit" after such a spill could enable in-situ burning to remove up to 90 percent of surfaced oil (Comfort and Purves 1982, x). However, this suggestion did not meaningfully engage with the extreme temporal control produced through the Balaena Bay experiment, nor later findings that such a response would be "extremely limited" in multi-year ice (NORCOR 1977, 47). This modeling warned that such ice was likely to move too much for sufficiently thick pools of oil to form atop the ice to an extent that would facilitate ignition, a problem that would only worsen in following years due to continued weathering of the surfaced oil, making it even harder to burn the "thin films spread over a large area" (NORCOR 1977, 46–47). This outcome would mean that all the remaining oil would "still be on the ice surface in a weathered state in the water, still trapped within multi-year floes or on shore" (NORCOR 1977, 47). The timing of the Balaena Bay and related oil-in-ice experiments was exceptionally important to the success of the scientific endeavours.

Throughout the extensive work of experimental spills, scientists actively produced time and temporality, helping to materialize highly preferential conditions for testing. There were many specific motivations for this, including another means to minimize potential socioecological impacts and avoiding the effects of poor weather conditions on sampling efforts. Planners developed highly specific contingency plans with strict go/no-go parameters to ensure that weather, winds, and waves were conducive to testing and broader containment goals; several major spill studies, including BIOS and the Beaufort Sea dispersant trials, were called off during their first attempts due to undesirable conditions.

In particular, researchers found that winds had major impacts on burning and dispersant application, requiring extremely precise helicopter piloting and broader coordination. While such planning was successful in preventing unwanted spread of smoke in some burn experiments, it was found to render findings from a dispersant application study at Suffield incomparable. Meanwhile, efforts to materialize a probable time delay in spill response with techniques such as leaving a spill untreated for up to weeks and even months, along with the common use of artificially weathering spills before discharging, was largely undermined by the more general control exercised by the research; while the oil composition changed somewhat through these processes, major issues of spread and integration with other materialities was largely circumvented. Likewise, the work to simulate spill response close to ice break-up was neutralized by the tremendous level of control researchers exercised over the timing and siting of spills, ensuring that discharges allowed for a maximum time for response. However, these studies did produce the extremely concerning finding that surfaced oil accelerated ice melt due to its low albedo, further narrowing the window for response in real-world conditions.

In combination, these factors meant that experimental spills frequently produced extremely uncharacteristic and improbable temporalities that materially overstated the ability for responders to effectively "clean up" oil when spilled. Building on critical scholarship about capitalist temporalities by the likes of Thompson (1967) and Harvey (2006; 2007), this case study has explored an extremely specific iteration of time-making through the material practices of scientific experimentation. This experimental work was also profoundly temporal in a dual sense, serving as another form of the materialization of the "future eco-perfect," in which scientists extrapolated the management of time within experimental conditions into future real-world spill events. Rounding out this process is the way that temporal production in past experimental "future eco-perfect" spaces is interpreted and applied in the present, frequently ignoring or underappreciating the tremendous work required to produce such temporalities in the first place.

Chapter 4: Oiling

Oil spill risk is not natural or inevitable but the direct result of particular accumulation strategies and state projects in specific socioecologies. Within a capitalist mode of production, the primary motivator of this oil production and spill risk is not the production of use-values but the generation of profit. Oil is often especially profitable due to the production and reproduction of monopoly conditions, which capitalists and states co-constitute through technological innovations. About this dynamic, Mazen Labban (2008) has explained that "in the case of non-reproducible land-based resources, such as oil and gas, 'artificial' monopoly is reinforced by 'natural' monopoly arising from the fact that access to the resource is limited by conditions that capital cannot reproduce elsewhere under given socio-technological conditions of profitability" (42). At the same time, given that non-human natures play a foundational role in shaping labour productivity and capitalist competitiveness, oil that is geologically easier to extract—like in the vast fields of Saudi Arabia—provide a further advantage over more costly competition, such as the low-quality and highly recalcitrant oilsands of Alberta and Venezuela (Claes et al. 2015).

While the consumption of oil itself has caused sizable spills—such as groundings of freight ships and ferries, or the breaching of storage tanks—the largest and most consistent source of pollution occurs through the production and transportation of oil as a commodity, including from offshore oil rigs, oil tankers, and pipelines. Researchers have readily acknowledged this reality in the rationales for many scientific studies about spills over the decades. For instance, in the introduction to a report about the Balaena Bay experimental spill in the mid-1970s, scientists wrote: "In response to the increasing demand for hydrocarbons, offshore drilling and production platforms, submarine pipelines and tankers are all being proposed for the Beaufort Sea. *Even with improving technology, oil spills are inevitable*"

(NORCOR 1975, 3; emphasis added). Similarly, the opening to the Arctic Marine Oilspill Program's planning document in the late 1970s about experimental spills outlined:

> Recently there has been increasing offshore petroleum exploration in the Canadian Arctic and in the East Coast waters such as the Labrador Sea. These exploration activities, and future production facilities, bring the remote but real possibility of accidental discharges of crude oil and natural gas into the arctic marine environment. Although most discharges would probably be quite small, there is a possibility that a significant amount of petroleum could be discharged into the environment as a result of a blowout incident, as occurred at Santa Barbara or more recently in the North Sea. Moreover, when production facilities are in place, there may be tanker or pipeline accidents. (AMOP 1979, 1)

We can therefore best understand oil spill science in general terms as primarily a corollary of oil industry activities and efforts to improve competitiveness through the commercialization of profitable reserves, especially through the development of new "frontiers." But as argued in Chapter 1, we must also understand oil as a materiality and oil spill science as a practice of knowledge production in far more granular terms, appreciating the extraordinarily complex and diverse manifestations of oil once spilled.

Compared to the tremendously precise work required to site and time a spill experiment, the question of actually spilling the oil may seem trivial. Like with other aspects of this research approach, we can most easily detect the importance of producing "future eco-perfect" conditions through the encountering of scientific challenges in the field. In 1978, about 1,800 litres of Norman Wells crude was spilled under multi-year ice near Melville Island in the Central Arctic (Comfort and Purves 1982, i), as prior testing had indicated that oil would surface through multi-year ice rather than remained locked in or underneath it (Milne et al. 1977). Shortly after the spill in June 1978, aerial surveillance observed "a considerable amount of oil on the ice surface," especially near a "large crack" in the ice that crossed one of the spill sites (Comfort and Purves 1982, ix). However, in late 1978 and early 1979, researchers attempted site visits in order to conduct tests but “due to problems with logistics and weather, these missions failed to conclusively identify the test sites and to determine the amount of oil still trapped within the ice” (Comfort and Purves 1982, ix). Scientists later reported that “data were not obtained in the fall of 1978,” which impeded future comparisons of oil surfacing (Comfort and Purves 1982, x). These circumstances required an additional site visit in fall 1979, a full 15 months after the initial spills.

Building on techniques used in prior ice studies, researchers established an “experimental field camp” on the ice; however, like with the ice floe study near Resolute, both fog and poor visibility significantly impeded their study and “forced the field crew to remain on site longer than the planned four-day period” (Comfort and Purves 1982, 8). The area had also started to freeze up by that point, along with receiving fresh snow, meaning that “no evidence of oil on the surface of any of the three test sites could be found” and rendering it impossible to gather observations of surfaced oil (Comfort and Purves 1982, 8, 29). Once again, this meant that it was “not possible to determine the quantity of oil that had surfaced” (Comfort and Purves 1982, 9).

Specifically determining the rough outline of the area of the oil remaining in the ice required drilling within a “closely spaced grid pattern and observing whether the cuttings were oiled” (Comfort and Purves 1982, 8). These coring efforts found only two sections of the first site that warranted taking samples, with the other two cores having no detectable oil in them (Comfort and Purves 1982, 9). The second site proved far more productive, including a range of heavily oiled cores and samples (Comfort and Purves 1982, 15). However, like with the first site, the third site proved to be fairly fruitless, with only two cores taken that contained insignificant volumes of oil; as a result, researchers deemed that it was “not possible to define an oiled area of ice” for this cracked section of ice (Comfort and Purves 1982, 15). Through this coring process, they estimated that at the first and second site, the area of oiled ice was about 400 percent larger than the initial under-ice oil pools, representing a massive horizontal spread that could have dire repercussions in situations of full-scale spills (Comfort and Purves 1982, 30).

Researchers also appeared to struggle with managing the diverging results of the Griper Bay trials. They acknowledged "some scatter" in the findings and attributed it to the small volume of the discharges, along with "natural variability and the adverse conditions under which the tests were conducted and the samples collected" (Comfort and Purves 1982, 22). Large cracking through one of the spill sites was the most significant of "local differences" that may have obscured and complicated results (Comfort and Purves 1982, 30). Further, the scientists noted that potential sampling error could have occurred due to evaporation of the oil within the air space of the sample container itself, suggesting higher than actual claims of weathering effectiveness (Comfort and Purves 1982, 22). Laboratory analysis of the sampling also reported that water-in-oil emulsions were formed in the containers that required breaking—"often with difficulty"—or approximating their composition (Comfort and Purves 1982, 51). To retroactively reconcile these differences, scientists advised that the three differing sites be interpreted as "the range of behaviour that is possible" (Comfort and Purves 1982, 31).

Reiterating the tremendous complexity of such a study came in the form of an assessment of Arctic spill response conducted three decades later for the American Petroleum Institute and the Joint Industry Programme on Oil Spill Recovery in Ice, which expressed some skepticism of the merits of the Griper Bay experiment. While noting that it was "the only known field test involving oil and multi-year ice" (Potter et al. 2012, 133), the report cautioned that the test took place "under what was though to be old ice" and that its results "may not be truly representative of likely behaviour under multi-year ice (older than 2 years) as the test ice sheet was relatively thin and may have been second-year ice" (Potter et al. 2012, 11). As a result, the relative quickness of oil surfacing and evaporating in the Griper Bay experiment may not be generalizable given the unknown state of the ice, as second-year ice would still have some brine channels that could have accelerated the process.

While often unremarked upon, decisions about oil type, volume, and discharge system involved in experimental spills have had major effects on the behaviour, effects, and fate of oil. In the case of the Griper Bay testing, the selection of a crude oil extracted more than 1,300 kilometres away—rather than an oil that might be more representative to the region—appeared guided by the oil's use in the previous Balaena Bay experiments (Comfort and Purves 1982, 1). However, as discussed in Chapter 1, even relatively minor differences in the composition of an oil can have sizable impacts on its spill behaviour. The volume of the oil spill was also noted as a possible contributor to the scatter encountered in the resulting data; researchers explicitly caveated the work by stating it is "difficult and probably incorrect" to deem any of the three sites as "being typical," reflecting that: "perhaps each spill was not large enough to avoid being significantly influenced by natural variations in the ice and snow cover" (Comfort and Purves 1982, 31). And although not detailed, the method of discharge invariably shaped the way that the oil spread underneath the ice, further complicating sampling efforts.

This chapter examines the many different approaches used in experimental spill work concerning the actual spilling of oil itself. While featuring elements of the "future eco-perfect" construction of conditions discussed in the previous two chapters, this case study also contains elements of the approach examined in the next two as well: that problems and unknowns are ignored, enabling extrapolation of results beyond what may be scientifically justified. Through minimizing the incredible diversity and difference of oil type, volume, and spill method to outcomes, this scientific work appealed to a universal and far less complex future than what real spills often represent. It also emphasizes the complexity and unpredictability of oil as a materiality and the importance of analyzing it in such terms.

Type

As with other aspects of experimental spill design, the choice of oil used in spills varied extensively, shaped by many competing factors, and having significant impacts on scientific outcomes. Many experimental spills were riddled with difficulties and discrepancies between diverse types of oils, putting into question the potential extrapolation of results. In other cases, researchers explicitly warned of the specific characteristics of the oil they had used and recommended testing using other oils to account for what could be considerable variability.

One of the most immediate priorities was to use oil that researchers anticipated to spill in the area due to its nearby production or transportation. For example, the Crater Lake in-situ burning experiment used a small volume of crude oil from the Beaufort Sea, specifically from the Nektoralik K-59 well, which Dome had drilled in September 1976 (D. F. Dickins Engineering 1979, ii; LTLC Consulting and Salmo Consulting 2013, 4). Scientists also used small quantities of Beaufort crude in several experimental spills near McKinley Bay in the early 1980s. For the emulsified oil-in-ice research in 1982, the oil used was from the Kopanoar 2I-44 well, drilled by Dome within a particularly oil-rich field in August 1980 (LTLC Consulting and Salmo Consulting 2013, 4; Drummond 2011, 2). Two years later, the small-scale dispersant trial used oil from the Tarsuit field, where Gulf had drilled four wells between 1978 and 1984 (Timco and Frederking 2009, 36; LTLC Consulting and Salmo Consulting 2013, 4–5, 7–10). In each of these experimental spills, researchers used oil extracted from the Beaufort Sea to evaluate the effectiveness of burning and dispersants, along with the behaviour of emulsified oil-in-ice, potentially achieving the highest degree of realism possible given potential blowouts or batch spills in or from the region.

Other experimental spills had similar linkages to choice of oil type. Many of the major marine spills in the 1970s and 1980s involved tankers transporting crude oil from other countries. The choice of oil in several of the experimental spills of this era can be well understood within this context. Skimmer testing on Canada's East Coast and adjacent regions, where many of these real-life spills had occurred, frequently used oil from the Middle East, including a "light Arabian crude" in Bedford Basin (Solsberg et al. 1976, 66), heavy Iranian crude in Quebec City (Solsberg et al. 1977, 6–7; Abdelnour et al. 1978, 46), and a light "Persian Gulf crude oil" in St. John's (Gill and Ryan 1979, 498). Several more experimental spills were conducted using Venezuelan crude—which was another major source of imported crude throughout much of the 20th century and the oil type spilled in the *Arrow* disaster of 1970—including in the St. Lawrence shoreline testing of 1998 (Lee et al. 2001, 324). Refined fuel oils, which had also been spilled many times in real-world disasters, were similarly tested, such as a BP-produced home heating oil in Hamilton Harbour (Solsberg et al. 1976, 70), marine diesel oil near McKinley Bay (Energetex Engineering 1981b, 52), and Bunker C in the Holyrood refinery settling pond (Technical Services Branch 1984, 7). The Svalbard shoreline testing of the late 1990s used a heavy fuel oil as it was "similar to that carried by almost all ships, and so with a high potential to be spilled" (Guénette et al. 2003, 254).

Scientists most meaningfully recognized and accounted for the significance of different oil types in experimental spills when they attempted to artificially simulate a specific oil type (Seakem Oceanography 1990, 2). Along with using Norman Wells oil in the second lake spill in the Mackenzie Delta, researchers spilled oil from Alberta's Pembina field as it served as the "closest approximation to Prudhoe Bay crude oil available at the time" (Snow and Scott 1975, 528). Similarly, during the Newfoundland Oil Spill Experiment of 1987, the oil was directly modified to better simulate blowout conditions, using Brent crude that had been "treated" by adding a small volume of slack wax in order to better simulate waxy Grand Banks oil (Thornton et al. 1992, 3–4). Demonstrating the significant variability of outcomes based on oil types, it was found that the addition of wax meant that the oleophilic (or sorbent surface) type skimmer—which "do not perform well with high parafin-based oils" due to their "low adhesive properties"—failed to work, with "no measurable recovery" (Tennyson and Whittaker 1989, 102).

Attempts to improve realism in testing by manipulation of the oil itself also occurred through its preparation before a spill. Personnel often heated test oil ahead of discharge to simulate its state during a blowout or pipeline spill (Dickins et al. 1981, 184), with heating tools including propane torches applied to insulated oil drums (Mackay et al. 1974, 114) and an immersed hot water radiator within an insulated wooden holding tank (NORCOR 1975, 18–19). Researchers deemed this kind of intervention especially necessary in the case of testing skimmer effectiveness with emulsions, with a tank used to weather oil for a week prior to testing in Bedford Basin heated to reduce the possibility of freezing resulting in premature emulsion breaking (Solsberg et al. 1976, 68). Conversely, in a few skimmer tests, oil was intentionally left in frigid conditions to simulate delayed response (Technical Services Branch 1984, 19; Gill and Ryan 1979, 498). Through the selection and preparation of oil, researchers attempted to improve the realism and representativeness of spill experiments.

However, many studies used oils that had less connection to the site where testing was happening. For instance, Alberta crude was frequently used in East Coast testing, despite the far more likely context of offshore oil development in Jeanne d'Arc Basin and international tanker imports from other countries. Skimmer testing in Hamilton Harbour used a Shell-produced crude oil from Alberta (Solsberg et al. 1976, 70), while the dispersant testing near Halifax used the medium-gravity Alberta Sweet Mixed Blend (ASMB) that had transported from a refinery (COAATF 1986, i, 4). Likewise, the spill experiment conducted in pack ice in 1986 off the coast of Nova Scotia opted to use ASMB, rather than the much denser and more viscous Bunker C oil of the *Arrow* and *Kurdistan* spills (S. L. Ross Environmental Research and D. F. Dickins Associates 1987, 13). Scientists also discharged Alberta crudes several times in Ontario during the early 1970s to evaluate oil's behaviour in snow and improve predictive capacities for spills along the proposed Mackenzie Valley pipeline route (Mackay et al. 1974, 107–108; 114).

While nominally closer to the oil that researchers planned to spill, similar disparities existed in the routine use of Norman Wells crude in early spill experiments. Despite a potential Mackenzie Valley pipeline expected to carry crude from Prudhoe Bay and the Beaufort Sea, many early spill experiments in the region instead used oil produced in Norman Wells. In August 1972, scientists spilled Norman Wells crude oil into the tributary of Caribou Bar Creek in the Northern Yukon (Snow et al. 1975, v). A few weeks later, the same type of oil was spilled into a small lake located in a floodplain of the Mackenzie Delta (Snow and Rosenberg 1975a, vii). And early the following year, scientists again spilled Norman Wells crude into a lake in the central region of the Mackenzie Delta (Snow and Scott 1975, 528). In these experiments, motivations other than achieving realism became clear.

A common factor shaping oil type was proximity to a refinery that could provide the oil in question. Notably, researchers conducting the early oil-in-snow testing near Norman Wells cited a "convenient source of crude oil" from the local Imperial Oil refinery as a reason to conduct the test in the area (Mackay et al. 1974, 1). Similarly, dispersant testing near Victoria used Prudhoe Bay crude that had the nearby Cherry Point refinery in Washington State had supplied (Green et al. 1982, 73). Other refineries that provided researchers with the oil necessary for spill experiments including the Golden Eagle refinery near Quebec City (Abdelnour et al. 1978, 46), the Petro-Canada refinery in Montreal (Lee et al. 2001, 324), and an Esso refinery in Norway (Guénette et al. 2003, 254). Of several reasons provided for the oil type used in the huge Newfoundland Offshore Burn Experiment—Alberta Sweet Mixed Blend crude, the same used in several other East Coast experiments—a factor included that it was easily available from Ontario refineries, along with being regarded as representative of many crude oils (Environment Canada et al. 1993, 7-4).

Another significant factor in the selection of the oil used at NOBE, along with other experimental spills, was its use in *other* scientific work. For early dispersant testing in Halifax Harbour, the oil used was a light Venezuelan crude from the Tía Juana oilfield, chosen due to its similarity to Kuwaiti crudes used in the Warren Springs Laboratory dispersant testing in the UK (Gill 1977, 392). An additional consideration guiding the selection of oil for NOBE that it was the reference crude for Environment Canada evaluating spill response technologies (Environment Canada et al. 1993, 7-4). And along with its “ready availability” to researchers, a main reason for the BIOS project opting to use a Venezuelan Lagomedio crude was due to its “anticipated use in cold water dispersant effectiveness studies planning for the east coast of Canada” (Dickins et al. 1987, 101). Indicating a circular relationship in oil selection was that the crude used in the 1981 St. John’s dispersant testing was a Venezuelan Lagomedio, explicitly “chosen because of its use in the BIOS project” (Gill and Ross 1982, 256).

These diverse and competing factors—representative of potentially spilled oil, convenience and supply from nearby refineries, use in other scientific studies—were only further complicated by the challenging material realities of fieldwork. There were instances when scientists discovered that they could not successfully use certain oils in scientific research. During the Balaena Bay trials, researchers obtained two types of crude oil—from Norman Wells and Swan Hills, Alberta—for the testing to represent the "probable range of properties" of Beaufort Sea oil, which there was "very little information on" (NORCOR 1975, 12). However, spill scientists used Norman Wells oil for all but two of the tests due to having a far lower pour point that increased "ease of handling at low temperatures" (NORCOR 1975, 12). Similarly, at skimmer testing in Quebec City, crude oil, diesel, and Bunker C were all originally intended to be tested, yet the latter was found to be unusable due to its high pour point, requiring a "thick emulsion" to be created of crude and water to serve "in its place" (Solsberg et al. 1977, 76).

Many other experimental spills proceeded with planned discharges but observed or noted major differences in outcomes based on oil types. Most obviously, skimmer effectiveness varied considerably based on oil used: the testing of the Marco Class V skimmer in Esquimalt Harbour determined that it operated far more effectively with heavier Bunker C oil—recovering an estimated three times more than Peace River crude or diesel—and performance with diesel particularly poor as it was "observed to surface beside and behind the Marco V" (Beak Consultants et al. 1978, 8). More subtle differences noted in technical asides and caveats also pointed to unique properties of particular oils, but also to the kind of contingent thinking that oil spill scientists had to exercise. One set of observations related to the evaporation of spilled oils, by far the most significant medium of mass transfer in most spills. During the discharge of both Norman Wells and Pembina oil into Mackenzie Delta lakes, it was found that Norman Wells had a higher initial evaporation rate (Snow and Scott 1975, 533). Conversely, the burning tests at Crater Lake found that Beaufort oil had far lower rates of evaporation, with researchers recommending that testing involving such oil assume a maximum percentage of evaporation of the oil as 16%, "rather than the 30–40% usually quoted" (D. F. Dickins Engineering 1979, 41).

In other experiments, scientists reported concerns about the potential for varying behaviour and toxicity between oils. The first major oil-in-ice experiment in McKinley Bay in 1979 used Prudhoe Bay oil provided by Atlantic Richfield, with researchers reporting that "properties of this oil are quite similar to those of oil found in the Beaufort Sea" (Dickins et al. 1981, 184). However, later analysis of the burn residue from the experiment cautioned that "assessment be made of the amount and type of PAH in Beaufort Sea oil and in its burned products," especially given that the Prudhoe Bay crude used in the experiment was "known to be relatively high in aromatic content compared to many other crude oils" (Georghiou and Sheppard 1982, 26). Further differences between Prudhoe and Beaufort oils were noted in the 1982 emulsions-in-ice experiment, which reported that Prudhoe Bay oil had been found to have "easily separated back into oil and water," while Kopanoar oil from the Beaufort Sea "forms an extremely stable water-in-oil emulsion" (Buist and Dickins 1983, 1). Unrelated spill testing at Esso's outdoor tank facility in Calgary in 1990 led a researcher to conclude that Prudhoe Bay oil "doesn`t behave like other oils" and that it is "so dense that it tends to whip under the boom" (Lamb 1990).

Researchers observed differences in oil types in a range of other ways. The estimated timeline of biological effects following an oil spill in a Northern lake—a short period of "acute toxicity," a longer "physically deleterious phase" of several weeks, and eventually "chronic eutrophication"—was expected to differ as "lengths and severity of each phase will be dependent upon such factors as volume of oil, type of oil and climate" (Snow and Rosenberg 1975b, vii). Similarly, scientists speculated after the St. Lawrence shoreline spill of 1999 that the sensitivity of bacteria to the particular oil type used "may account for the negligible rates of oil degradation detected" (Lee et al. 2001, 325). Even efforts to engineer a simulated oil spill presented problems in testing; the Newfoundland Oil Spill Experiment warned that certain Grand Banks oils were "much waxier than the test crude and thus will likely be present as very viscous semi-solid mats or droplets rather than comparatively fluid oil used for these tests" (S. L. Ross Environmental Research 1987, 62).

Researchers reiterated such contingencies during the Newfoundland Offshore Burn Experiment that happened several years later. Nitrogen typically makes up between 0.1 percent and 2 percent of crude oil (Fingas 2015, 53), with the Alberta Sweet Mixed Blend (ASMB) used having a low nitrogen content (Ferek et al. 1997, 30–31). As a direct result of this composition, along with the low flame temperatures achieved, there was a low concentration of nitrous oxides and "little or no atmospheric nitrogen is fixed" (Ross et al. 1996, 257). It was consequently concluded that in-situ burning would not result in "significant production of secondary pollutants," especially ozone (Ferek et al. 1997, 30–31). However, this outcome did not account for the possibility of nitrous oxide emissions and ozone formation from the burning of crude oils with higher nitrogen contents than the light ASMB, such as heavy oil and bitumen products (Prado et al. 2017, 15).

The particular qualities of the oil used was similarly significant in the measurements of volatile hydrocarbons like benzene, which posed potential health risks to spill responders (Bowes 1996). Measurements of benzene and TPHs were "generally very low" during NOBE; however, the crude oil used did not have a high benzene content to begin with, while the artificial weathering process further reduced the pre-ignition presence of the volatile fraction (Bowes 1996). Scientists further emphasized that NOBE was a "highly controlled experiment in which a partially weathered, relatively low-benzene crude oil was fully contained within a boom at all times" (Bowes 1996). Further, while analysis of the burn residue was positive—concluding that it was "appealing that a large weathered oil slick could potentially be reduced down to a relatively small amount of burn residue without causing an increase in aquatic toxicity"—researchers cautioned that the results were "limited" given that it only used one type of oil, requiring more research with other oils (Blenkinsopp et al. 1997, 279).

Despite the best efforts of researchers to standardize practices and outcomes, the type of oil used in experimental spills continued to present a constant problem that defied simple answers. In particular, the significant diversity of oil behaviour and effects encountered in various experimental spills highlighted the serious difficulties of extrapolating findings from research using one type of oil to an actual spill that may use an entirely different one. "Future eco-perfect" conditions were further advanced through decisions to use certain oils over others due to their ease of handling and availability, while measurements of response byproducts were directly shaped and limited by the type of oil chosen for the spill. Such differences take on even more importance today, given the dramatic shift towards dilbit production and shipments that have occurred over the last few decades, introducing an entirely new and heavier materiality to spill response which have only started to be tested at small scales. However, the findings from historical experimental spills are rarely qualified on such a basis, with the general confidence produced through tightly controlled studies applied to any and all oils.

Volume

Although often minimized through standardized yet opaque metrics like barrels and gallons, many massive spills in the 1970s exemplified their catastrophic potential, with the worst including 11 million litres spilled from the *Arrow* in 1970 and more than 7 million litres from the *Kurdistan* in 1979. In several instances in the late 1980s and early 1990s, enormous spills occurred in international waters (such as the *Odyssey* and *Berge Broker* disasters) or other countries (like the *Braer*, which ran aground in Scotland) while carrying oil to Canada, further confirming the serious risks to the country's coast). Referring to the *Berge Broker* spill of 20 million litres of crude oil an estimated 600 kilometres off the coast of Nova Scotia, the head of a federal review panel on tanker safety noted that: "If the storm had come two days later it could have been a catastrophe quite close to the Canadian shore. It's a very large spill. We would class it as a catastrophic spill if it happened here" (Spears 1990).

Major spills have also occurred from offshore oil and gas operations, such as the release of nearly 400,000 litres of diesel in the southern Beaufort during a 1985 storm (Birchard and Nancarrow 1986, 375; see also Gill et al. 1985b). While large tanker disasters have been significantly curbed due to improvements in ship design, regulations, and technologies, there have still been many sizable spills in recent years from pipelines, trains, and other marine vessels involving millions of litres of oil products (*CBC News* 2015). Although smaller than Canada's worst historical spills, there continue to be major releases of oil into water bodies (*CBC News* 2016).

Yet for a variety of reasons—most obviously the desire to maintain control of the spill for requirements of permits, scientific study, and public perception—experimental spills have tended to use small volumes of oil for their studies, with even the largest on the low end of routine spill risk. Such decisions necessarily shape the processes and outcomes of scientific research.

Scientific reports rarely directly acknowledged these issues. However, there were occasional and instructive exceptions to this lack of acknowledgement that help demonstrate why the question of volume matters to experimental outcomes. Researchers caveated findings derived from the spilling of a "very small amount of oil" into a Northern Yukon creek in 1972 with the warning that "if the oil pollution were severe and chronic … comparably more pronounced and persistent effects would be expected" (Snow et al. 1975, 4).

Scientists similarly attributed observations of rapid evaporation following a 1978 spill experiment off the BC coast to the small volume used, with researchers speculating that it would take far longer for equivalent evaporation in larger spills (Green et al. 1982, 117). Even at the relatively large shoreline component of BIOS involving 15,000 litres of oil, it was warned that a bigger spill "could increase the effects" (Sergy 1986, 23) and that "caution must be exercised in the extrapolation of results about oil fate from small scale intertidal plots to real world events" (Sergy 1985, 573). Spill scientists most explicitly noted this issue of scale in a follow-up study of a coastal saltmarsh spill that took place in 1986. Researchers wrote:

> Applying management recommendations from an experimental study to an actual spill situation is complicated by differences in scale. Although this study documents some recovery from all treatments by saltmarsh vegetation by the fifth post-treatment growing season, many of the mechanisms by which recovery occurs (e.g. seeding in and expansion of rhizome networks) might conceivably operate more quickly in small treatment plots surrounded by undamaged vegetation than in marshes suffering substantial disruption of vegetation over large areas. (MacKinnon and Lane 1993, vi)

In part due to the recognition of the difficulties of scaling up small-scale findings, the researchers cautioned that the use of dispersants for shoreline spill management remained "still open to question," highlighting that toxic effects and persistent behaviour of oil would likely be far more pronounced in larger spills (MacKinnon and Lane 1993, vi).

The particulars of spill volume on experimental results were further reiterated in a unique manner during the first McKinley Bay under-ice testing in 1979, where researchers spilled about 19,000 litres of crude oil across three discharges under the landfast ice. Given the possibility that a blowout often releases natural gas, as well as oil, researchers used compressed air "for safety and logistics reasons" to simulate the impacts of gas on oil behaviour (Dickins et al. 1981, 183–184; Purves 1978, 10). However, researchers discovered during one of the combined discharges that the compressed air line to simulate the natural gas had become obstructed by an ice blockage (Dickins et al. 1981, 185). In the springtime, when the ice started to melt and brine channels opened up to allow for oil surfacing, it was found that oil had become especially concentrated in the spill plagued by the issue of reduced simulated gas flow, leading to the "most dramatic migration" of oil to the surface (Dickins et al. 1981, 187). Even slight differences in quantity of materials spilled—in this case, simulated natural gas—led to sizable differences in outcomes, reiterating the profound importance of volume to scientific findings.

Far more often, however, scientists did not acknowledge the volume and scale of experimental spill work with any level of detail. Instead, researchers regarded outcomes as seamlessly representative and extrapolatable, as if much larger volumes of oil would merely increase the impacts in a predictably linear manner. This factor was especially noteworthy when it came to the supposed "self-cleaning" potential of an ecosystem, in which processes of physical weathering—evaporation, dissolution, sedimentation—and chemical transformation by biodegradation and photooxidation can ostensibly rid much of the oil. Yet the capacity for an ecosystem to process such contamination varies enormously based on the quantity of the pollutant, in conjunction with many other factors such as temperature, nutrient supply, and sunlight. Even if some fractions of the oil do get removed through evaporation, for instance, the persistence of toxic compounds in the ecosystem can pose significant lethal and sublethal threats to organisms, especially with large volumes of oil. The size of spills also shapes the ability for personnel to successfully apply response measures.

In this analysis, experimental spills are divided into three categories of size: small, between 1 litre and 999 litres; medium, between 1,000 litres and 9,999 litres; and large, above 10,000 litres. However, there are important subdivisions within these categories. Most notably, the total volume of oil that scientists spilled often occurred through many smaller spills as part of the same broader experiment. In some cases, the total quantity of oil discharged also differed from the quantity originally planned, typically for technical reasons; in a similar vein, initial response methods successfully reduced the volume of oil remaining, requiring different approaches to address the remaining oil. In a few cases, particularly in spills conducted for skimmer testing, volume of oil used was poorly reported or not reported at all. Despite these differences, it is possible to identify clear trends and limitations in this experimental work, with controlled spills typically involving an extremely small volume of oil that prevented straightforward comparisons with larger spill events.

As to be expected with any new area of scientific inquiry, many of the smallest experimental spills took place at the beginning of investigations into oil behaviour and effectiveness of response methods. One of the smallest experimental spills was a tiny six litres of crude discharged into two mesocosms to assess dispersant use (Green et al. 1982, i). While explicitly framed as a “first step in going from a laboratory study to an open ocean study,” researchers cautioned against extrapolating from the results, noting that the testing site was “a large container by laboratory standards, but a very small one on the scale of an open ocean spill,” and that the testing “does not reflect the concentrations which would be found in a real oil spill”

(Green et al. 1982, 3). While scaling up over time, many of these early spills remained tiny; initial oil-in-snow research started with a small 180 litres at the landfill near Scarborough (Mackay et al. 1974, 107–108), followed by 360 litres at Dorset (Mackay et al. 1974, 114) and 630 litres in Norman Wells (Mackay et al. 1974, 125). Similarly, the burning experiment near Rimouski in 1973 conducted three incrementally larger spills—170 litres for the first test, 285 litres for the second test, and almost 420 litres for the third (Coupal 1976, 5–6)—for a total of 1,750 litres of oil. However, researchers did not exclusively use small spills in the early days of spill experiments. In at least two later cases, scientists reduced already small volumes of oil to even smaller volumes due to the particular constraints of testing.

One of these was the small-scale dispersant testing in Mackenzie Bay in 1984. The specific scale of the testing was highly intentional. Unlike previous efforts, which had sought to measure the effectiveness and impacts of particular dispersants at scales roughly approaching real-world conditions, this experiment was explicitly designed to "provide northern people with actual experience in applying dispersants on oil, and to evaluate the viability of using small scale spills to determine dispersant effectiveness" (Dickinson et al. 1985, 1). As a result, researchers planned to spill an estimated 360 litres of crude oil and diesel fuel via 16 spills, over the course of two days (Dickinson et al. 1985, 1). However, as discussed in Chapter 2, the volume of oil discharged was quickly downsized due to the first spill of 20 litres quickly touching the sides of the containment booms and undermining the study's goals (Dickinson et al. 1985, 10). Subsequent spills were only 4 litres each, with a total of 48 litres of oil spilled over the course of the experiment: one-fifth of the initially planned spill (Dickinson et al. 1985, 10–14). A similarly proportioned decrease in spill volume took place at the St. Lawrence shoreline experiment in 1998. Although the initial plan was for 1,200 litres of oil to be spilled (Grenon et al. 2001, 1467), the volume of oil was significantly reduced to about 200 litres, spilled into “relatively small plots” at a dose of only 12 litres per plot (Venosa et al. 2002, 278; Grenon et al. 2001, 1467; Lee et al. 2001, 323). These were again miniscule spills that were supposedly representative in some form of real-world disasters.

Many of the mid-sized experimental spills were conducted between 1975 and 1980 for the purposes of skimmer testing. Spills into the Holyrood refinery settling pond neatly set the parameters of this larger scope of experiment, ranging from 1,000 litres to test the Morris MI–80 skimmer—of which only 200 litres was recovered (Technical Services Branch 1984, 38–39)—to a total of almost 5,000 litres for the Little Giant skimmer, split between 10 tests of 300 to 600 litres each (Technical Services Branch 1984, 13–15). Like with the latter’s testing, most of the large total volumes were subdivided into smaller discharges to evaluate skimmer performance: in 1976 experiments in the St. Lawrence River in Quebec City, about 2,300 litres of oil was spilled for 58 current skimmer tests (Solsberg et al. 1977, 89–92). However, in some cases, the larger volume of oil was discharged at once; to continue testing work of the ACW-400 skimmer that had been started at the Holyrood refinery, researchers “dumped overboard” more than 2,000 litres of crude into a boomed area all at once (Gill and Ryan 1979, 498). While significantly larger than aforementioned small-scale spills, these still represented a marginal and highly controllable volume of oil.

Researchers also used similar sized spills to assess the behaviour of oil in thick ice. In March 1986, scientists conducted three 1,000-litre spills well east of Nova Scotia (Buist and Dickins 1987, 373). They designed a “modest field program” to “validate the results” of previous laboratory and tank test work seeking to better understand the dynamics of oil in pack ice that had occurred during the 1979 *Kurdistan* disaster (S. L. Ross Environmental Research and D. F.

Dickins Associates 1987, 5). Unlike the situation at Griper Bay, the chosen scale of the test proved appropriate for the inquiry, allowing for observation of oil migration through brine channels (Buist and Dickins 1987, 378) and ensured sufficiently thick and concentrated oil to facilitate in-situ burning (Buist and Dickins 1987, 375). However, observations about the behaviour of the oil in ice—such as surprising lack of emulsification and the effective containment function of the ice itself—necessarily related in part to the small volume of oil used in the experiment.

The East Coast was also the site of several other medium-sized spills in the 1980s for testing of dispersants and other spill-treating agents, including two spills of 1,500 litres each (3,000 litres total) near St. John's and 10 spills of 800 litres each (8,000 litres total) between Nova Scotia and Sable Island (Gill and Ross 1982, 255; Goodman and MacNeill 1984, 146; Seakem Oceanography 1990, 3). Although taking place well outside of Canada, the Svalbard shoreline spills of 1997 led by Environment Canada researchers demonstrated the highly planned and incremental staging of many of these medium-sized spills. In total, researchers discharged 5,500 litres of oil in various volumes—900 litres at the first site, 2,200 litres at the second site, and 2,400 litres at the third site—and across different shoreline lengths and total areas (Sergy et al. 1998, 81). Researchers carefully calculated the volume of oil spilled on each plot to ensure that it was less that the "saturation capacity of the sediments," in order to prevent initial tidal action from washing away the oil (Guénette et al. 2003, 254). Further, researchers designed these "relatively large experiment plots" to minimize the unwanted redistribution of oil to uncontaminated areas by tides and waves, with any relocation occurring "within the same oiled section" (Guénette et al. 2003, 255).

Increasingly larger volumes of spills became harder to manage in the field. The incremental approach helped to mitigate this: at the Halifax dispersant trials in 1983, researchers tested three different dispersant formulations over three days by creating two 2,500 litre spills—one as a control plot, the other as an experimental plot—totalling 15,000 litres (COAATF 1986, 5–8; Gill et al. 1985a, 479). The Beaufort Sea dispersant testing of 1986 demonstrated how using the same volume of oil could quickly spiral out of control. Scientists aborted the first attempt at the experimental spill due to technical and weather issues, despite having already spilled 5,000 litres of oil. This meant that only 10,000 litres remained for the second successful experiment, meaning that "it was not possible to complete the remainder of the trial as originally planned" and requiring modification of the rest of the experiment in order to "come as close as possible to achieving" the experiment's original goals (Swiss and Vanderkooy 1988, 9, 18). As a result, researchers discharged four oil slicks of 2,500 litres each, about two kilometres apart from each other, a spill size that they had specifically "optimized" for the purposes of data collection and "most importantly, dispersant application" (Swiss and Vanderkooy 1988, 9–10).

The BIOS project of 1981 served as a transition project between these large spills and the three biggest in Canadian history. As already outlined, BIOS involved three major discharges: a shoreline study with various treatments, and a nearshore dispersant study that compared treated and untreated spills. Each of these spills involved about 15,000 litres (Sergy 1986, 12), totalling 45,000 litres for the entire project. However, these higher volumes of oil proved increasingly difficult to manage, especially in the case of the untreated spill. After evaporation, natural dispersion, and manual recovery, about half of the 15,000 litres of oil—between 7,100 and 7,600 litres—became stranded on the shoreline (Sergy 1985, 571). Later analysis suggested that the volume of stranded oil was lower, about 5,300 litres, with the remainder that was "not directly accounted for" assumed to have been "lost to the ocean and the atmosphere by dissolution and evaporation" (Owens et al. 1987b, 109, 121).

While BIOS is remembered as the most significant spill experiment conducted in the Canadian Arctic, the Balaena Bay spills were even larger in volume. Between October 1974 and May 1975, researchers discharged a total of 54,000 litres of crude oil in nine controlled spills beneath the ice at the main Balaena Bay site, along with another 1,500 litres spilled in two discharges at the more northern site to evaluate the impacts of currents on oil-ice interactions (NORCOR 1975, 1–3). Most of the experimental spills were between 6,300 litres and 8,300 litres per discharge, although several were significantly smaller due to testing constraints such as the simulated open-water conditions (a 400 litre spill) and the final test being transformed into two much smaller experiments (400 litres and 200 liters) because "full discharge posed too great a threat" to other studies happening in Balaena Bay at the same time (NORCOR 1975, 12–13). Similarly, scientists downsized the currents experiment north of Cape Parry from original plans "in response to concerns expressed by local residents" (NORCOR 1975, 115), a factor they deemed as having "hampered to some extent" the study and resulting in inconclusive data.

The volume of the experimental spill also shifted over time due to the initial significant success of in-situ burning in the springtime. Researchers started a second burn on the day after the main burn. However, they reported that "although almost equally violent, it was of much shorter duration," less than 4,000 litres was removed, with some of the smaller pools of oil deemed "impossible to ignite" (NORCOR 1975, 129). Over time, researchers found that burns decreased rapidly in effectiveness as the available oil dropped in thickness, with estimated burn volumes declining to 4,000 litres, 2,000 litres, and 1,000 litres, respectively (NORCOR 1975, 2, 133). Once again, the volume of oil spilled and responded to at Balaena Bay was highly contingent based on the needs and controls of researchers.

The very largest of the experimental spills took place in 1987 and 1993, both off the coast of Newfoundland. The first, titled the Newfoundland Oil Spill Experiment (NOSE), spilled almost 70,000 litres of oil to test the performance of various skimmers and booms, with such a large volume deemed necessary to "provide realistic contained slick area and thickness" (S. L. Ross Environmental Research 1987, 6). This experiment cost an estimated $1 million and involved "nine vessels and their crews plus 150 scientists, observers and officials from Canadian and U.S. government agencies" (*Globe and Mail* 1987). However, researchers reported that skimmers only collected 8,500 litres of oil, constituting about one-eighth of the total oil that they had spilled (S. L. Ross Environmental Research 1987, i–ii). If accurate, this outcome meant that researchers lost more than 60,000 litres of oil to the ocean; eighteen hours afterwards, aerial surveillance observed that thick patches of oil had was "rapidly dispersing," and that "only small brown patches and sheen remained" (Tennyson and Whittaker 1989, 103).

Until the similarly named Newfoundland Offshore Burn Experiment (NOBE) of 1993, it was the "largest experimental oil spill in Canadian waters (Thornton et al. 1992, 3–4). As with the NOSE and the stated desire to achieve necessary size and thickness, scientists asserted that the originally planned volume of 100,000 litres of oil—through two spills of 50,000 litres each—was needed to produce usable air quality measurements, one of the primary areas of focus for the experiment (D. F. Dickins Associates 1992, 8). However, the actual volume was "slightly less than this," as issues with the containment system cut the second spill short (Fingas and Lambert 2018, 286). In the end, the first spill was 48,300 litres while the second spill was 28,900 litres, totalling 77,200 litres and making it by far the highest-volume spill experiment in Canadian history (Fingas and Lambert 2018, 286).

From the smallest to the largest experimental spills, all used meticulously planned volumes of oil constantly calibrated to scientific and technical requirements. This specific control of volume directly shaped the processes and outcomes of spill experiments. Unlike real-world spills—in which the scale of an incident is often unknown, with estimates evolving over time, including over the course of weeks and months—this degree of control combined with other aspects of spill design to create near-ideal conditions for study and response. Although rare, a few studies directly acknowledged that the volume of oil spilled had material consequences on the outcome of such work, shaping factors like the persistence, toxicity, and movement of the oil. Yet many more studies did not, obscuring the production of these “future eco-perfect” conditions that overstated the ability for much larger spills to be managed and responded to.

Discharge

In conjunction with the precise siting, timing, and selecting of the type and volume of oil, scientists planned and conducted the physical release of the oil into a water body with a focused meticulousness that sidestepped the frequently chaotic and unpredictable quality of blowouts and batch spills. These engineering decisions materialized a scientific desire for control that directly shaped the behaviour and outcomes of this experimental work.

As discussed in the earlier section on containment measures, a major priority for researchers was ensuring a necessary thickness and distribution for them to burn or recover the oil while also maintaining full control over the spill. In the case of in-situ burning, this priority was exemplified in early experiments such as the Crater Lake testing, where the volume of oil was specifically chosen and spilled into the contained area to establish a thickness of about five millimeters (D. F. Dickins Engineering 1979, 7), and the oil-in-snow testing at McKinley Bay, where oil was "weighed and poured as evenly as possible" into the trench (Energetex Engineering 1981b, 53). The emulsions-in-ice testing at McKinley Bay in 1982 used a diver to manually direct the under-ice hose within the containment skirt to create a "relatively uniform oil coating of the ice," leveraging the specifically chosen volume of 350 litres to establish a one-centimetre layer across the entire test area (Buist and Dickins 1983, 5, 8). Such homogeneity was vital to the success of the experiment but highly improbable in the case of real-world spills in which such carefully directed discharging is impossible.

This dynamic was most apparent during the NOBE of 1993. Researchers designed the oil discharge system with tremendous specificity to "avoid unwanted mixing of oil below the water surface" (Environment Canada et al. 1993, 7-5), and spilled the oil through a skimmer, allowing for the immediate reversal and clean-up if the discharge had to be suspended (Environment Canada et al. 1993, 7-8). For the purposes of maximizing safety and ease of recovery in case of an emergency situation, it was determined that "at any point in time only a portion of the total oil volume will be on the surface of the water" (Environment Canada et al. 1993, 7-9). The initial volume of oil spilled before starting the ignition was also far smaller than planned, with this further limitation ensuring that responders would have to recover a reduced volume of oil in an emergency (D. F. Dickins Associates 1992, 15, 25; Christopher and Vanderkooy 1993, 2; Fingas and Lambert 2018, 290).

Oil spilling continued at a controlled rate of 850 litres per minute, with occasional pauses to ensure proper control (Christopher and Vanderkooy 1993, 2). However, oil pumping had to be paused "several times because the fire often spread back to the discharge point" (Fingas and Lambert 2018, 292) so that the fire itself "did not progress past the bridle on the boom," the section of the boom when the oil entered (Fingas and Lambert 2018, 300–301). Yet scientists cut the controlled rate of 830 litres per minute down to 550 litres per minute after 20 minutes of the test, a reduction that was "initiated to control the burn area inside the boom" (Christopher and Vanderkooy 1993, 2). These careful measures worked effectively, with no oil losses below the fireproof boom detected by the submersible unit that personnel manoeuvred underneath the spill (Fingas and Lambert 2018, 299). Planners clearly produced such exact controls, deemed necessary for completion of the scientific work.

This highly managed approach was also ubiquitous in skimmer testing, which frequently developed discharge systems to ensure the oil was presented immediately to the recovery unit, rather than requiring that it chase the oil as actual spill conditions would usually require. Along with working to improve effectiveness, such efforts related to the broader goals of reducing environmental contamination. For instance, federal skimmer testing guidelines specifically required that for mobile skimmers, "oil must be presented to the skimmer while in motion in a manner to minimize the amount of oil entering the environment," ensuring that discharges only occurred after the skimmer had reached its test speed and had stopped by the time it slowed (Solsberg et al. 1976, 77). Oil was discharged immediately in front of skimmers tested in Hamilton Harbour (Solsberg et al. 1976, 70), Burrard Inlet (Solsberg et al. 1977, 5) and Esquimalt Harbour (Beak Consultants et al. 1978., i, 30).

In other instances, scientists made additional efforts to further concentrate available oil. During Quebec City skimmer testing, researchers artificially prevented the identified problem of oil "submerging and emulsifying unnecessarily" with the installation of a plywood spillway (Solsberg et al. 1977, 74; Abdelnour et al. 1978, 46). In the case of weir-type skimmers, oil that was accumulating in front of the units was also "frequently … either paddled or otherwise helped to flow … to speed up the process since it was known that the oil would eventually find its own way into the skimmer" (Solsberg et al. 1977, 74). The spill discharge system itself worked to augment effectiveness of the skimmers being tested.

Like with the burning experiments, ensuring a minimum thickness of the spilled oil to ensure adequate performance was also essential to skimmer testing. For example, each of the spills at Quebec City in late 1976 sought to produce a "uniform slick thickness" of either one millimetre or ten millimetres (Solsberg et al. 1977, 72), with stationary skimmers tested with oil discharged at a "predetermined thickness" into a square booming arrangement (Solsberg et al. 1977, 78). During trials of the "Skim-Pak" skimmer in 1980 at the Holyrood refinery, personnel spilled crude oil at thicknesses ranging from 6 to 18 millimetres (Technical Services Branch 1984, 9). This aspect mattered especially in the testing of certain skimmers that exhibited declining oil recovery with increased slick thickness (Solsberg et al. 1976, 13). It was also found to be especially difficult to establish with water-in-oil emulsions—which represent one of the more difficult materialities encountered in spill response—with an uneven spread of a one-millimetre thick slick caused by complications of surface tension meaning that "any results gained would be more a measure of random encounter with large sessile drops than of the true pick-up capacity of the machine" (Solsberg et al. 1976, 69–70).

Even establishing level oil slicks for testing required a great deal of work. The priority of establishing slicks of certain thicknesses directly shaped the timing and volume of discharges, with conditions closely monitored and adjusted as required. In Hamilton Harbour, researchers spilled oil for one minute prior to recovery efforts beginning (Solsberg et al. 1976, 72). They used similarly exact discharge procedures in continued skimmer testing in Bedford Basin a few years later. Due to the testing objectives and the relative effectiveness of the skimmers, scientists found it to be necessary to "continuously add oil at a predetermined rate during a run to maintain the required thickness" (Solsberg et al. 1976, 69). While further evaluating a skimmer in its mobile capacities, researchers restricted testing in particularly thick oil to only one minute at a time—rather than the standard two minutes—in order to "minimize oil losses" (Solsberg et al. 1976, 69). And in Quebec City testing in 1976, "the risk and consequences of oil loss were weighed" based on an array of variables, and the oil spill planned for between 30 seconds and five minutes (Solsberg et al. 1977, 74).

While distinct in intended outcomes, the positioning of discharge points was also extremely important for dispersant testing. Like with other response methods, this often related to technical requirements, particularly when involving discharges from boats. For example, the first day's oil spill for the 1981 dispersant trials in St. John's took place while the vessel was moving, producing a "large area over which the not-so-maneuverable sample boats were required to move" (Gill and Ross 1982, 261). This led to the second day of testing opting to spill oil from a "point source" and proceed to "sample in the neighbourhood of the centroid" (Gill and Ross 1982, 261). At the Halifax dispersant trial two years later, the boat that spilled the oil carefully discharged the oil upwind of the intended location and moved with the "slowest possible forward motion" to ensure that the spills were "identical" in size and thickness (COAATF 1986, 8). And during the 1986 Beaufort dispersant testing, oil was discharged from an ice-strengthened Canmar tug using a specially designed system (Swiss and Vanderkooy 1988, 5), with the spill commenced while the vessel was at "the slowest possible speed upwind," ensuring that the boat itself would not become oiled and improving "the chances of controlling slick geometry" (Swiss and Vanderkooy 1988, 10–12).

Although most experimental spills discharged oil from boats, the BIOS project opted for a different approach that exemplified engineering precision. While dispersant application methods were a major focus of scientific research at the time, the study's interest was on its impacts on marine organisms, and in particular whether its application in Arctic nearshore conditions would "reduce or increase the environmental effects of spilled oil" (Sergy 1985, 571). This focus led to researchers opting to discharge an exact pre-mixture of oil, dispersant, and seawater through a "subsea diffuser pipe laid near the bottom" of the bay, an approach that was chosen for "better control of the oil and to enhance the formation and distribution of the dispersed oil cloud" (Sergy 1986, 15; Boehm et al. 1987, 134). Planners selected the precise location of this pipe after extensive testing and observations (Dickins et al. 1987, 101). Further, the output from the pipe had to closely replicate a dispersed oil cloud similar to if it had been dispersed from the surface, requiring meticulous design and calibration of the piping and orifices (Dickins et al. 1987, 101–102). Initial testing of the discharge using dye found that anticipated currents were "unreliable" and "highly variable," carrying the substance in the opposite way than scientists had expected (Dickins et al. 1987, 103). As a result, planners relocated the placement of the discharge pipe to the other end of the bay, and reinforced it along the bottom of the bay floor using steel bars to prevent its movement due to currents or waves (Dickins et al. 1987, 103).

This discharge placement had significant impacts on the scientific outcomes. Observers noted that initial "concentrations of oil in the water column were much higher than expected or previously recorded when dispersants were applied to a floating oil slick" (Sergy 1986, 15), about five times greater than expected at points (Dickins et al. 1987, 106). Due to the underwater discharge method of the treated oil, volatile fractions of the oil that would have evaporated from a surface slick were instead transferred to the benthic zone, exposing organisms to "abnormally severe" (Sergy and Blackall 1987, 5) and "unusually high concentrations" (Sergy 1986, 15). It was also suggested that the underwater discharge led to dispersed oil reaching greater depths than if the oil had been sprayed onto the surface—with a dense layer of the ocean limiting vertical mixing into deeper zones (Sergy 1985, 573)—and leading to the mixture having "rapidly contaminated subtidal sediments" (Sergy 1986, 15).

The subsequent scientific literature on the spill consistently caveated its dire findings based on this difference in application methods (Boehm et al. 1987, 134). Compared to the untreated spill that researchers had discharged on the water's surface, creating an "example of medium severity," the underwater release of the oil treated with dispersant produced "relatively severe" impacts and "extreme conditions compared to those normally expected" (Sergy 1985, 574). Given this conclusion, researchers claimed that the results from dispersants on sampled organisms "may be considered as a worst case example," with "more realistic conditions" only reached farther away from the discharge point (Sergy 1985, 574). While creating some negative outcomes, many key unresolved aspects concerning the dispersant formulation and application were also logistically circumvented through this approach, with its project manager explaining:

> As such, it must be remembered that the dispersed oil spill scenario assumed the existence of application and technology and an effective cold water dispersant. The fact that the state-of-the-art is not now so advanced does not however affect the study results or fundamental conclusions. In designing the project, it was also assumed that if the results on dispersant use were not negative, technology would be stimulated to overcome the deficiencies which still exist in both product and delivery systems. (Sergy 1985, 574)

In particular, the premixing of the oil with dispersant ensured that the response measure achieved its greatest level of effectiveness, compared to highly uneven real-world applications, with ensuring the proper mixture of oil with dispersant frequently serving as one of the most complex problems that the response method faces. Many other spill experiments similarly materialized an extremely improbable effectiveness, with pre-mixing also used in dispersant testing in Victoria (Green et al. 1982, i, 6) and in the Beaufort Sea (Dickinson et al. 1985, 1). This interventionist approach also involved the particular application of treatments to spilled oil, producing near-idyllic hybrids of oil and response method.

Burning experiments demonstrated this especially clearly. At Rimouski in 1973, scientists applied a pre-soaked mixture of peat and diesel to the oil prior to ignition; they carefully selected this ratio of peat to oil to diesel based on previous testing to ensure the "optimal combination" (Coupal 1976, i–1). At Balaena Bay, concerns about evaporation removing light volatile fractions of the oil pool and reducing the ignition potential led researchers to pour six drums of gasoline onto the pools prior to attempted burning (NORCOR 1975, 126). This intensive control of oil discharge—including the premixing of treatments and accelerants—also extended into and conjoined with the application of response methods, similarly circumventing some of the most challenging aspects of spill response. Ignition of oil continued to serve as a frequent example of this: at Rimouski, a torch soaked with gasoline was used to light the pool of oil (Coupal 1976, 1), while the trench burns at McKinley Bay were started by placing a piece of paper towel that was on fire into the middle of the trench (Energetex Engineering 1981b, 53).

Likewise, at Balaena Bay, scientists ignited oil with a small volume of gasoline or naphtha poured onto paper towel or a piece of sorbent, even a week after the burning experiments started and when the oil was "heavily weathered" (NORCOR 1975, 2, 126). There was also extreme levels of involvement when the oil failed to successfully ignite. Due to the fire not spreading between the remaining oil on the third day of burn attempts at Balaena Bay, it was necessary to individually ignite each one (NORCOR 1975, 129). Similarly, during one of the igniter tests, at Crater Lake, the igniter missed the oil by an estimated 3 metres and "had to be manually placed in the pool" (D. F. Dickins Engineering 1979, 18). Researchers also mopped up remaining oil at the Crater Lake igniter testing with sorbent pads, pushed into a corner of the pool with pitchforks, and then lit on fire (D. F. Dickins Engineering 1979, 18). While proving the potential for burning oil, even in adverse conditions, these acts materialized an impossible degree of intervention for real-world incidents. Simply put: responders cannot resolve most large-scale spills by lighting a piece of paper towel on fire.

The three factors discussed in this chapter—type of oil, size of spill, and method of discharge—were all determined by scientists in accordance with particular research and logistical requirements, as well as in conjunction with the broader siting and timing of experimental spills. Each of these measures significantly shaped the outcomes and findings of the studies, often materializing "future eco-perfect" conditions. Significant differences in oil behaviour and effects were noted between various types of oil, which were selected for a wide array of reasons including proximity to anticipated production, reference to other studies, and availability from nearby refineries. The same goes for the size and scale of experimental spills, with the volume of oil spilled having sizable effects on outcomes: a reality seldom acknowledged in the scientific literature itself. Extreme levels of control were exercised over the quantity of oil discharged, frequently chosen and adjusted to ensure proper containment. Planners also carefully selected and positioned the discharge methods to achieve scientific goals, most notably in the systems used at NOBE and BIOS, with the latter requiring extensive work to place the underwater pipe system and using a premixture of oil and dispersant that maximized its effectiveness.

Like with the previous two chapters, this focus on oiling has highlighted how these measures collectively produced a highly unlikely set of conditions that overstated the real-world applicability of results, materializing the “future eco-perfect.” It has also reiterated the specific relationship of spill science with anticipated oil production and transportation, with types and discharge systems designed to account for the likelihood of large blowouts and batch spills once oil industry development was underway. It was not a pursuit of use-values as an end in themselves that primarily propelled this high-cost investment but rather the generation of profits for companies in ceaseless competition within and outside the industry.

While understandable from the perspective of an abstract scientific desire to help reduce potential socioecological effects, it is necessary to more critically reflect on the role that such scientific work can provide to the oil industry that has long faced serious crises of legitimacy over the real or perceived lack of spill response capacity. Through this work, spill scientists help to produce the research that companies later enroll into impact assessment applications and other regulatory filings, along with generating a broader sense that responders can effectively address spills. At the same time, however, this experimental work also involved the management of undesirable elements scientists had to contain—typically by ignoring and downplaying—to facilitate the assertion of scientific confidence about spill response capacities. The next two chapters assess this opposite but closely related production process.

Chapter 5: New Natures

In mid-March 1979, the British oil tanker *Kurdistan* broke in half during a fierce storm and in thick pack ice encountered in the Cabot Strait while carrying about 30 million litres of bunker oil from the refinery at Port Hawkesbury to Quebec (McNeil 1979). The winter cyclone created especially large waves in the Cabot Strait and along the edge of pack ice, with wave height estimated to exceed eight metres during the storm and "best described as awesome weather conditions" (Hans 1981; Vandermeulen and Buckley 1985, 13). This break-up happened despite the *Kurdistan* having been "strengthened for movement through ice" several years earlier (Gray 1979b). As with the *Arrow* disaster, an early assessment determined that the accident did not represent a significant spill threat, with an oil pollution officer for the federal environment department telling media that "sheens are extremely thin and do not contain enough oil to cause noticeable damage" (*Globe and Mail* 1979c).

A month later, the situation was evidently far worse than originally thought, with the *Globe and Mail* reporting that "five weeks ago everyone who took part in the successful salvage of a broken oil tanker's stern section was celebrating - but that party is long over and the drudgery of cleaning up the 7,000 tons of bunker C fuel oil spilled when the Kurdistan broke in two on March 15 is still going on" (Gray 1979a). The disaster had contaminated more than 1,100 kilometers of shoreline (Duerden and Swiss 1981, 215), with shoreline oiling extending all the way to the south shore of Nova Scotia (Vandermeulen and Buckley 1985, 13). Some 550 people were reported to be manually recovering oil from the shoreline using rakes and plastic bags; however, the "sticky black oil" continued to wash onto the shore, with "the winds and tide keep bringing globs of oil back on to beaches that have been already cleaned up" (Gray 1979a). This meant that spill response teams had to return to beaches as many as six times to re-clean areas, a pattern described as "discouraging" (Gray 1979a). In total, responders collected more than one million bags of oiled debris from the shorelines and had to bury them in landfills, strip mines, and newly created disposal sites across Cape Breton (Duerden and Swiss 1981, 215–219).

By mid-September, the Coast Guard declared that the shoreline clean-up of the *Kurdistan* disaster on both Nova Scotia and Newfoundland coasts was concluded (*Globe and Mail* 1979a; *Globe and Mail* 1984). Yet as with many other spills, this conclusion did not mean that all of the more than seven million litres of oil had been physically recovered and removed from the impacted sites. Rather, research by C-CORE scientists found that while some oil continued to be enmeshed in pack ice near Cape Breton, "much of the oil is still missing" (*Globe and Mail* 1979b). There was still ambiguity about how exactly the oil had disappeared and then suddenly reemerged a month later (Vandermeulen and Buckley 1985, 29). Further, unknown quantities of oil remained in the bow of the ship, which artillery fire from a Canadian Armed Forces destroyer had sunk (Rowland 1981; French 1983). Further uncertainties emerged around wildlife impacts. Researchers estimated that 80 percent of the birds killed by the spill had died at sea and therefore official counts did not include them. Canadian Wildlife Service calculated a death total of 12,000 to 25,000 birds (Duerden and Swiss 1981, 219).

Although the *Arrow* spill had included some aspects of interaction with ice, the *Kurdistan* disaster was described as "Canada's first oil-in-ice spill" (Vandermeulen and Buckley 1985, 29). This presence of ice represented "almost insurmountable difficulties" for recovery (Duerden and Swiss 1981, 218). Even identifying the oil with remote sensing become a major issue (Trites 1985, 46–47; Reimer 1980, 79), a problem exacerbated by the "very dynamic" characteristics of ice movement and composition in the Cabot Strait (Trites et al. 1980, 36). The oil also interacted with ice in diverse ways. Some of the pack ice was seen to carry a relatively even deposit of oil, likely an outcome of the initial breakup of the *Kurdistan*; other oil collected on top of floes as "small blobs and splatters" that were often sunk into melt pools, resulting from oil being splashed up onto the ice by wave action (C-CORE 1980, 47). Further, it was found that oil that had been "thrown up on floes" led to accelerated melting, with the oil warming as much as 12 degrees Celsius and leading to the melting of surrounding ice that would in turn enable the oil to spread and eventually create "micron sized oil particles" (C-CORE 1980, 42). At sea, large floes were described as ridden with "large flattened blobs or discs of oil lying on floe surfaces … floating in a water-filled crater in the floe-surface" (Amero and Ahern 1980, 109). This process was also found as oil arrived on shorefast ice in the form of large "oil blobs and droplets," a finer cover of "droplets and particles," and a "roughened or pitted surface" that "were often surrounded by or consisted of a fine-veined network of oil particles spreading out over the ice surface (Vandermeulen et al. 1980, 105–106). This "heavily eroded pitted ice surface" was not observed on non-oiled ice, leading researchers to conclude that it was the outcome of oil particles acting as heat sinks for sunlight that increased the melting of ice (Vandermeulen et al. 1980, 109).

Making matters worse was the specific oil-ice mixtures that the spill created. Unlike studies of other spills, researchers found that the *Kurdistan* mixtures manifested as coherent oil droplets that were "quite weathered, with a fairly firm external texture," with the water's cold temperature helping the droplets retain their structure and prevent oil smearing (Vandermeulen 1985, 51–52). Initially, the integration of oil into the pack ice manifested as "concentrated bands or streaks" but over time became "dispersed and diluted in the pack," with such mixing into finer particles determined to occur through interaction of loose and drifting ice floes (C-CORE 1980, 40). The main mechanisms by which this happened was the "mechanical grinding" of oil in ice, reducing oil to "particles from a few centimetres in diameter down to micron sizes" (C-CORE

1980, 41). Waves in the stormy ocean produced "an effect equivalent to a ball mill," with "churning chunks of ice [that] rapidly reduced oil blobs to very fine dispersion with a relatively uniform distribution" (C-CORE 1980, 42).

Observers described the "fragmentation or particularization" of oil that occurred through grinding and melting as "an unexpectedly new phenomenon, one that will likely cause considerable problems in cleanup" (Vandermeulen 1985, 52). The most concerning iteration of this mixture was the "finer particulate form" of oil that "will never be cleaned up," with response technologies requiring a minimum mass or depth to successfully remove (Vandermeulen 1985, 52). However, while the tendency of oil in pack ice was towards smaller particles, it was also found that upon melting of the ice there was a behaviour of some of the particles being herded by the ice to reform "larger particles or blobs" (C-CORE 1980, 47). Although there were many failures and unknowns in the *Kurdistan* response, the spill had "paid a dividend in acquired knowledge" through the scientific studies conducted of it (*Globe and Mail* 1979b), once again making clear the potential importance of "spills of opportunity." However, the resulting findings themselves proved to be extremely dire, with C-CORE (1980) concluding that "there is no existent cleanup technology which could successfully cope with oil-ice mixtures of the type observed" (iii).

Rather than merely dealing with the problem of oil in water, the *Kurdistan* disaster demonstrated the many complex and intractable agglomerations, compounds, and residues could form through the process of a large-scale spill. New natures were frequently encountered—but rarely focused on—throughout experimental spill work of the era. Such findings represented highly uncertain implications for response efforts and broader ecosystemic processes; in contrast to the oft-invoked narrative of merely cleaning-up or recovering spilled oil, these processes demonstrate that spills and various interventions frequently *produced* highly complex and confounding outcomes and materialities that would ultimately lead to oil's persistence and likely have impacts well beyond the spill event itself. However, scientists overwhelmingly ignored or downplayed them in the major conclusions of experimental spills, relegated to a potentially unfortunate addition to otherwise natural systems that would eventually break down and filter them out. This process of shielding experimental spill work was a distinct but equally important aspect of the materialization of the "future eco-perfect" in these sites.

We can usefully analyze this process by returning to Marxist geographer Neil Smith's (2008) concept of the "production of nature." Specifically, Smith (2008) argued that within capitalism, society generally conceives of nature as both *external* and *universal*, simultaneously constituting much of the non-human world, while also—and paradoxically—determining internal "human nature" itself. Highlighting the conflict between these two understandings, Smith (2008) wrote: "The contradiction between these externalist and universalist conceptions has grown into a hallmark of capitalist ideologies of nature" (22). Smith and other Marxist theorists like him contended that this capitalist ideology of nature obscures the reality that nonhuman forms and relations are only known and developed through processes of *human interactions* and specifically *labour*.

Without denying "the power or existence of 'natural' processes," noting that "gravity, biological process, chemical and geological change cannot be summarily suspended" (Smith 2007, 23), Smith (2008) argued that "where capitalism is unique is that for the first time human beings produce nature at a world scale," citing Marx and Engels' contention in the 1840s that "the nature that preceded human history . . . today no longer exists anywhere" (77). Raymond Williams (1980) similarly wrote that "we have mixed our labour with the earth, our forces with its forces too deeply to be able to draw back and separate either out" (83). Such a claim is even more clearly true in the era of climate change, ocean acidification, radionuclide contamination, and countless other thoroughly global dynamics produced by historically recent socioecological developments. For instance, the Mariana Trench, the deepest point in the world's oceans, has been found to contain "extraordinary" quantities of persistent organic pollutants (POPs), with the lead scientific researcher of the study explaining: "We still think of the deep ocean as being this remote and pristine realm, safe from human impact, but our research shows that, sadly, this could not be further from the truth" (Carrington 2017).

This production of nature approach can help bring clarity to the conflicts and complexities of spill science and response. As discussed, responders rarely remove spilled oil from the water or shoreline; even if it is, they then must bury, incinerate, or return it to a refinery for re-processing. Instead, through "natural" processes such as evaporation and dissolution—with even these seemingly innate occurrences shaped by climate change and other decidedly non-"natural" factors (Konapala et al. 2020)—along with major interventions like in-situ burning and chemical dispersants, *new* non-human forms and relations are produced, yet become enfolded into the capitalist ideology of a pre-existing, resilient, and self-purifying nature. This process *naturalizes* significant socioecological reconfigurations and shifts (Moore 2017, 296) within an external category of nature, which has various baselines, thresholds, and niches but is ultimately "seen as limiting, non-dynamic and generally stable" (Watts 1983, 235). As Michael Watts (1983) has written: "What emerges is a rather mechanical, billiard-board view of the world in which individuals, organisms, populations and critical environmental variables interact or interface" (235).

As a result, the oil spill is framed as something that enters, damages, and is eventually removed by humans and/or processed by an external nature, rather than being seen as an active *production of* socioecological forms and relations that often results in widespread death, bioaccumulation and sub-lethal impacts such as genetic damage and reproductive collapse, and dramatic reconstitution of ecosystems including the wholesale replacement of species by others through secondary succession. This is the capitalist production of nature in motion, but that capitalists and states constantly deny through its ideological mystification of nature itself. While we could examine many possible examples of this dynamic in spill situations, this case study examines three of these new natures produced through experimental spill work: the microbial and metabolic; residues from burning and mixing with snow or ice; and emulsions of water with oil. In the latter instance, dispersant application attempts to intentionally produce an oil-in-water emulsion—in contrast to the water-in-oil emulsion that manifests as "chocolate mousse" in its most pronounced case—but can often fail to achieve this goal. In combination, these diverse outcomes reiterate the centrality of *production* in nature and scientific inquiry, and the necessity of downplaying this process to develop "future eco-perfect" testing.

Metabolic

Spill scientists have long heralded microbes and metabolism as an efficient and low-cost, if not free, means of cleaning up oil spills, without the potentially controversial use of measures like burning and dispersants. Unlike such interventions, the use of biodegradation offers great appeal due to minimal labour requirements, instead allocating the burden onto nature itself. For instance, a newspaper report on the efforts of Amoco Canada to respond to a pipeline spill in Alberta in 1990 with bacteria and fertilizer heralded that the company was: "enlisting a cast of billions to help it clean up a 2.8-million-litre crude oil spill in muskeg near here. And they won't have to pay the laborers $10 an hour" (Henderson 1990). While focusing on the use of bacteria to remediate the contaminated soil of gas service stations—rather than large-scale spills from pipelines and tankers—a 2004 *Toronto Star* article also encapsulated this sentiment, reporting that "the hydrocarbon-munching microbes work 24-hour shifts for nothing" and quoting an oil spill expert who had previously worked on the Exxon Valdez response who estimated that "the bugs can save 75 per cent on cost" (Currie 2004).

Such potential has taken on far greater focus in recent years due to the possibility of its contribution to "natural attenuation," which is the "remediation of a contaminated site by natural processes alone, without human intervention" (Lee et al. 2015, 24). In a best-case scenario, these processes can efficiently dilute the most toxic compounds to sub-lethal levels and convert some of the lighter fractions of oil into less harmful or even neutral outputs. However, there can be significant limitations to these natural processes, with a recent review of the potential of oil-degrading bacteria that it is "affected by many environmental factors that hinder its practical application, limiting the large-scale application of the technology" (Xu et al. 2018, 1). Other recent studies have produced similarly sobering results, with normal or straight-chain alkanes (n-alkanes) preferentially biodegraded while more complex alkanes (branched and cycloalkanes) and aromatics often left largely intact, especially larger PAHs (Schreiber et al. 2019; Ferguson et al. 2020; Cobanli et al. 2022; Ellis et al. 2022), along with "refractory compounds" like asphaltenes and resins that will "probably persist in the environment for decades" (Lee and Levy 1989, 484–485). For instance, despite suitable conditions for biodegradation to take place in Lake Wabamun after the 2005 spill, a study indicated that the Bunker C oil and formation of "tar balls" meant that "the prognosis for extensive natural bioremediation over the short term, say 5–10 years, is poor, and these laboratory tests indicate that a large proportion of the spilled oil will persist even under optimum conditions for biodegradation" (Foght 2006, 24). This issue is especially pronounced in cold and low-energy environments, with small-scale shoreline studies in the mid-1980s concluding that "although biodegradation of oil proceeds at low temperatures, the rate is clearly affected" (Lee and Levy 1989, 484). Similarly, research conducted in ice conditions in Greenland found that "given the environmental context characterised by a dark Arctic winter, sea ice cover and the weak intensity of ultraviolet light in subsurface seawater, the low in situ biodegradation potential of polycyclic aromatic compounds over 2.5 month is an alarming discovery" (Vergeynst et al. 2019, 466).

However, the three decades of experimental spills in Canada indicated that issues with microbial degradation and broader metabolic processes were not limited to poor or partial clean-up potentials. The arrival of oil to an ecosystem often introduced strange and surprising microbial processes, which researchers never fully resolved in terms of origins or responses. While not necessarily detrimental, an early example of this manifested during small-scale dispersant testing in the late 1970s near Saanich Inlet. By the end of the study, the appearance of the dispersed oil had changed into "flocculant particles several millimetres in size," observed as "whitish in colour," growing as large as one centimetre in size (Green et al. 1982, 15–16, 36). Through closer examination of this "blizzard of particles" (Green et al. 1982, 125), it was found to be made up of bacteria and a "large quantity of extracellular material," likely the product of an overabundance of hydrocarbon-degrading bacteria that responded to a lack of nutrient inputs (nitrate and phosphate) necessary to reproduce by storing carbon as "extracellular polysaccharide material" (Green et al. 1982, 38). From this, it was concluded that biodegradation would be even more productive "in the natural environment where a continual supply of nutrients would be available" due to continual water movement, which would also reduce the presence of the "flocculent material" due to the remedying of nutritional "starvation conditions" (Green et al. 1982, 38–42, 55). However, researchers did not remark on what this finding could mean in the context of low-energy ecosystems lacking the guarantee of nutrient resupply, preventing the workings of this desired biological fix.

Another remarkable and unexpected discovery related to the formation of "algal melt ponds" on the ice following in-situ burning of the surfaced oil during the Balaena Bay experiments of the mid-1970s (Adams 1975, 20). First spotted as "dark areas of a few centimetres" below the ice surface in June 1975, these ponds quickly developed as an "abundant mixed algal community" that researchers had not found to be present in any surrounding non-oiled area (Adams 1975, 20). Researchers speculated that part of this rapid growth, with the "size of the plants increased from day to day," could have been accelerated by the slight presence of nitrogen in crude oil—as nitrogen is an essential input for algae—and the new availability of metals like vanadium or zinc as the crude was combusted and soot settled on the ice (Adams 1975, 30). Researchers found that these algal melt pond had "considerable" impacts on the ice sheet, with the dark brown algae offering "strong radiation absorbing" due to its far lower albedo, and the possibility of heat generation from metabolism (Adams 1975, 31). The effects of this dynamic were found to be tremendous, with a report chronicling: "Several melt ponds were observed in which the algae melted down through the ice a depth of about l m and then fell into the water below, leaving a hole somewhat resembling a seal breathing hole" (Adams 1975, 31).

This meant that in addition to the accelerated melting caused by the surfacing oil itself, the rapid growth of algae in the new conditions could also reduce the amount of time to deal with an under-ice spill prior to melt. However, the exact mechanisms of this algae growth and "ecological danger" remained poorly documented and understood, resulting in "uncertainty as to the effects that enhanced production and modified floral and faunal composition over a wide area might have on the total ecosystem" (Adams 1975, 32–33). During the return of spill scientists to Balaena Bay in 1981, they further observed that a "very active blue-green micro-algal flora has developed in both the oiled plots" (D. F. Dickins Engineering 1981, 32). And as part of the first McKinley Bay experimental spills, biological studies of the significant impacts of the oil spill on algae that grow in and under the ice were also conducted, regarded as "the first known sampling program to elucidate the effects of oil released from a sub-sea blowout on Arctic biota" (Dickins et al. 1981, 188; Acreman et al. 1980). In all of these studies, the formation and risks of algae due to oil's introduction were noted and probed to some extent, but largely regarded as an isolated phenomenon that would not necessarily pose serious problems in future spills. Researchers effectively discarded the threat that it could pose to accelerated melting and loss of burning potential, reproducing these broader "future eco-perfect" conditions through scientific priorities.

Observers also noted algae formation in the early experimental spills in Mackenzie Delta lakes. In the study at "Lake 4," they found the production of a type of blue-green algae from previously non-existent levels, "possibly in response to the addition of crude oil to the system" (Snow and Rosenberg 1975a, vii). Previous studies had indicated that this type of algae bloomed in nearby lakes that the "organic enrichment" of oil had already polluted, including the lake that served as the floatplane base for Inuvik (Snow and Rosenberg 1975a, 6, 11). Meanwhile, at the similar spills at "Lake 4C" and "Lake 8," researchers found that there were "significant differences" between the experimental and control areas in each lake, including levels of total dissolved nitrogen, and particulate carbon and nitrogen (Snow and Scott 1975, 529–30). It was suggested that these increases were likely caused by "microbial and phytoplankton blooms," a process that was not observed in the control sites, with the speculated growth of microbes with nitrogen fixing capacities leading to increases in dissolved nitrogen in the water (Snow and Scott 1975, 533). Depending on environmental conditions, such developments could lead to long-term and unpredictable shifts in ecosystems if introduced at the far larger scale and concentration brought by a real-world spill.

The production of new natures was not limited to the scale of the microbial. Many shoreline studies focused on the various effects of plants on biodegradation, in some cases opting to remove vegetation altogether to prevent its competing for nutrients. However, in plots where personnel did not remove plants, significant changes in their growth were frequently detected due to biostimulation, or the addition of nutrients to facilitate biodegradation. During the St. Lawrence shoreline study of 1998, researchers found that the dominant bulrush in the area was “tolerant to the oil, and its growth was significantly enhanced above that of the unoiled control by the addition of nutrients” (Lee et al. 2001, 323). Observers described the vegetation in plots that had been fertilized as growing “taller and much deeper in green color” than adjacent untreated examples (Venosa et al. 2002, 267). In particular, researchers found that the addition of ammonium nitrate caused such significant plant growth that they “toppled over” in all plots due to “growth stimulation” (Lee et al. 2001, 325). As is often the case with the production of new nature at spill sites, this new growth came at the cost of a reduction in total species diversity among other organisms, in this case plants (Lee et al. 2001, 327). Similar growth was detected during the small spill in a coastal salt marsh near Halifax in 2000, where it was found that new “pioneer species” were replacing original vegetation in paths that had been used by researchers, while the unsampled areas of the plots that received nutrient treatment produced vegetation that was “greener and more abundant … than that surrounding the marsh” (Garcia-Blanco et al. 2007, 5). While not surprising that fertilizer would benefit plant growth, these developments often directly reshaped the composition of ecosystems, yet another iteration of how spills and response actively produce natures.

Researchers detected other long-term effects on vegetation upon returning to Balaena Bay in 1981, where they had conducted the oil-in-ice experiment several years earlier. Although much of the oil had been removed through evaporation and burning, there were several long-term effects of its presence noted. A layer of weathered oil that had contacted salt marsh grasses produced “small depressions or craters” that “large numbers of isopods” were using at high tide (D. F. Dickins Engineering 1981, 23). At the same time, the revisiting of the site observed “minimal reproductive development” in polychaetes and bivalves that resided in the experimental site, but researchers claimed that such changes were not due to the oil itself (D. F. Dickins Engineering 1981, 82–83). Instead, scientists asserted that “observed differences in animal health and condition are due to some undetermined natural and/or anthropogenic stress in the environment - not oil induced” (D. F. Dickins Engineering 1981, 130). The important function of time and temporality of impacts was briefly alluded to, however, with a cautioning that “the possibility that current conditions reflect some previous and since departed contamination by oil can not be eliminated without further study” (D. F. Dickins Engineering 1981, 130). Despite severe lack of clarity about the fate and effects of the spilled oil, these new natures were discarded by researchers as unrelated to the introduction of vast quantities of toxic compounds into the local ecosystem. Here, scientists produced “future eco-perfect” spill conditions through tactical invoking of uncertainty, with a mysterious “some undetermined natural and/or anthropogenic stress” appealed to instead.

Scientists similarly filtered out the production of new toxic natures from spill experiments during the BIOS project, despite the impacts of oil on benthic organisms a major priority of the research work. Researchers found the immediate impacts of the discharge of the premixed oil and dispersant on benthic organisms was “very noticeable,” with the “most dramatic” being their emergence and movement from the sediment that “suggested an attempt to avoid the oil” (Sergy 1986, 17; Sergy and Blackall 1987, 6). These efforts proved unsuccessful, and “soon all visible animals were immobilized or narcotized and lay in unnatural postures” (Sergy 1986, 17). Over the following weeks, observers noted that predators were eating “stressed organisms (Sergy and Blackall 1987, 6). They also reported that the effects of dispersed oil could worsen the exposure to predation and lead to “over-harvesting by other animals” (Sergy 1985, 574). Further, researchers found both short-term and long-term bioaccumulation of oil in the benthic organisms, especially through feeding processes of both filter and deposit feeders (Sergy 1986, 19), and that organisms exposed to “even very low levels of dispersed oil at relatively great distances from the original source produced high body burdens at levels similar to those in animals exposed to the high concentration dispersed oil mass” (Sergy 1985, 573). Scientists additionally observed sublethal impacts in some species, with oil residues in the sediment pointed to as the “probable cause” (Sergy 1986, 17). Deposit feeders that resided in sediments contaminated with oil had “elevated body levels, even two years after the spills, thus reflecting the continued influence of the low-level oil residues in the sediment” (Sergy 1986, 19).

Such findings appear to be the opposite of the “future eco-perfect.” However, scientists filtered out these dire findings through a generalized downplaying of the toxic threat and production of nature through oil spills. Scientists concluded that neither the control or experimental discharge caused “significant mortality of benthic organisms during the period of observation nor brought about any significant change in the benthic community structure,” and that most organisms “recovered during the next two weeks” (Sergy 1986, 17). Observers reported that bioaccumulation “fell quickly when exposure ceased,” followed by a “marked decrease” in the following weeks and “returning to near background levels within a year” (Sergy 1986, 19). Despite the many competing findings that suggested significant short-term and long-term impacts, researchers confidently discarded them and concluded that the “experimental results offer no compelling ecological reasons why dispersants should not be used …. while consideration must be given to increased acute effects and bioavailability of oil to subtidal benthic fauna, these effects will usually have relatively minor impact” (Sergy 1985, 575). Along with constructive aspects of spill experiments like siting and oiling processes, scientists also asserted the “future eco-perfect” through disregarding the production of new and frequently toxic natures that can linger for years and decades.

Residues

Another class of new natures involved the byproducts of burning and the interactions of oil with snow and ice. Unlike the microbial and metabolic productions, these combinations did not directly involve biological processes; however, they also posed significant threats to ecosystems that scientists often similarly ignored as future threats in the case of large-scale real-world spills.

One of the major potential benefits of in-situ burning is that it removes sizable volumes of oil from the water surface, transforming it into a combination of outputs, largely carbon dioxide and soot. But along with eventual precipitation of particulate matter downwind, in-situ burning leaves unburned and weathered oil that can sink, collectively described as in-situ burn (ISB) residues (Fingas 2018, 41). Analysis of the *Deepwater Horizon* blowout calculated that burning generated tens of thousands of barrels of these residues during response efforts, “most or all of which eventually sank to the seafloor” (Stout and Payne 2016). Notably, this analysis estimated that thousands of kilograms of polycyclic aromatic hydrocarbons were deposited on the seafloor of the Gulf of Mexico, which "additionally exposed benthic resources to these hydrocarbon-bearing particles" (Stout and Payne 2016, 199).

This new nature of burn residue was frequently encountered during experimental spill experiments, requiring various methods of monitoring and response. Following the Rimouski burns—which used peat as a wicking agent—researchers found the residue was composed of "lumps of intimately mixed peat and oil (heavier fractions)," with no trace of the diesel remaining (Coupal 1976, 5). They also reported that manual recovery of this residue from the ice was "very easy to make" as it did not stick to the surface (Coupal 1976, 8). With that said, the residue itself was heavy, totalling over 600 pounds between the six spills (Coupal 1976, 3–5). The burn experiment at Crater Lake involved similarly straightforward recovery of the viscous residue. After the aerial igniter testing, observers reported a thin layer of residue floating in the pool that they estimated as "no more than 10%" of the oil's original volume (D. F. Dickins Engineering 1979, 11). Due to its accessibility, personnel then collected and took the residue and debris left to a nearby dump for disposal (D. F. Dickins Engineering 1979, 18). In both studies, the extremely small size and effective containment of the experiments allowed for researchers to recover these residues without any issue.

Such efforts became more difficult as experiments increased in scale. At Balaena Bay, scientists described the 2,000 to 6,000 litres of oil and burn residue left on the ice as "very viscous" and unable to "readily support combustion" (NORCOR 1975, 129). After several "small burns" were ignited to try burn off the remaining oil, clean-up switched to working to physically remove the burn residue, with it "hosed, scraped and shovelled into oil drums or pits cut into the ice, where it was burned with gasoline" (NORCOR 1975, 129). This part of the process proved to be "very time consuming and labour intensive," (NORCOR 1975, 134). It was found that only 200 litres of residue could be collected by a two-person crew in a 10-hour shift (NORCOR 1975, 129).

About a week after the final burn, the increasing precariousness of the ice rendered the residue collection "very hazardous," and researchers suspended the work (NORCOR 1975, 129). Over the following days, a small volume of residue swept onto the shore in the form of "tarry clumps or balls," of which about 600 litres was removed with shovels (NORCOR 1975, 129). Researchers observed about 1,000 litres of oil in the tidal zone, but a visit in mid-1975 found "very little evidence of oil along the beach" (NORCOR 1975, 133). There was no evidence of burn residue sinking reported and they considered it "doubtful if much oil was lost to the water," with only 3 percent of the oil reached the shoreline (NORCOR 1975, 133). The burning only dispersed small quantities of residue—"varying in consistency from a grease to a heavy tar"—across the snow surrounding the burn sites (NORCOR 1975, 126). However, scientists never confirmed the eventual fate of the residue, allowing them to claim that there were no observable effects.

Following the burn experiments at McKinley Bay in mid-1980, scientists collected and analyzed samples of the burn residues and soot to compare the mutagenic properties—or changes in the DNA of an organism—to fresh and weathered crude oil (Georghiou and Sheppard 1982, i). They deemed this focus especially necessary given the rise of "mutagenic and carcinogenic compounds" released into the marine environment, including "markedly increased" volumes of aromatic hydrocarbons found in aquatic sediments, "very largely due to anthropogenic sources" resulting specifically from combustion (Georghiou and Sheppard 1982, 1–2). This research found that the Prudhoe Bay crude is "demonstrably mutagenic, as is its weathered and burned residues, with the soot demonstrating the greatest mutagenicity on a relative concentration scale" (Georghiou and Sheppard 1982, i). Scientists also found that polycyclic aromatic hydrocarbons, or PAHs, were not present in the pre-burn crude oil but were "produced through the combustion process" (Georghiou and Sheppard 1982, i). However, they concluded that there remained "insufficient evidence" to determine the biological risks of Arctic in-situ burning, necessitating more research (Georghiou and Sheppard 1982, iii). Following the NOBE burns of 1993, analyzed residue was found to contain a lower quantity of PAHs than in the original crude oil, but that a "proportionately high amounts of multi-ringed PAHs were present," indicating a "slight increase" in their presence (Fingas and Lambert 2018, 347; Christopher and Vanderkooy 1993, 2–3). This finding suggested that burn residues could pose a long-term threat to ecosystems.

The inverse dynamic of burning is the interaction of oil with ice and snow. However, like with the byproducts of in-situ burns, researchers have also found these interactions produce complex residues that pose varying temporal issues. As discussed in Chapter 4, while beneficial in some respects—such as providing a time delay in the necessity of spill response and a temporary platform to organize efforts from—experimental spills that specifically sought to understand the behaviour of oil in snow identified the production of unique amalgamations. For instance, scientists recognized that a pipeline spill during winter would be significantly different than in warm summer conditions, with the behaviour of oil "profoundly influenced by the presence of snow" as it will "tend to be more viscous and it will thus flow less freely" (Mackay et al. 1974, 72). During the Beare Road Landfill spill in 1972, it was observed that, despite additional snowfall and freezing rain, sunlight was penetrating to the layer of oil below, heating it up, and then creating an upward melting effect that resulted in "a thin layer of ice over the spill with a void region between it and the oil" (Mackay et al. 1974, 109). Another spill at the landfill during the summer, conducted to compare seasonal outcomes, confirmed that a 15-fold spatial expansion of the previous spill was due to the role of snowmelt (Mackay et al. 1974, 112). As a result, it was determined that the worst time for a spill to occur would be during the spring snowmelt as there would be no chance to physically recover oil from the snow, meaning that "the chance of contaminating nearby water bodies would be high" (Mackay et al. 1974, 112–113). Further oil-in-snow testing in Ontario found that, unlike cold oil, spills of warm or hot oil were suspected to create water-in-oil emulsions with the snow that it melted, raising its viscosity and forming a "crust" from the re-congealed snow that "effectively hindered further spreading" (Mackay et al. 1974, 124–125). Because of these findings, it was determined that "a winter spill from a Mackenzie Valley pipeline may be easier to deal with than a summer spill," with the potential bonus of the snow acting "as an absorbent for the oil, facilitating clean up" (Mackay et al. 1974, 125). Spilled oil would remain "stable" in sub-zero temperatures, enabling physical removal of the emulsions from the area to process elsewhere, but the report warned that, if left, "once spring began, the melt water would cause considerable spreading of the oil" (Mackay et al. 1974, 125). Scientists described the oil penetration pattern during another experimental spill, this time in Norman Wells, as developing in a "random" pattern, materializing as "small vertical 'rivulets' of oil" (Mackay et al. 1974, 126).

Researchers also found that evaporation—which tends to account for the bulk of natural oil removal after a spill—became significantly impeded if the oil was under snow or ice. During trench burn testing at McKinley Bay, researchers speculated that by limiting evaporation and increasing the proportion of the volatile fraction remaining in the oil, snow cover could produce greater potential for burning (Energetex Engineering 1981b, 7). However, actual burn tests found that successful burns could only occur in a "maximum snow content" of one-third of total material, otherwise combustion would fail (Energetex Engineering 1981b, 57). During an earlier spill under thick ice near Resolute, a researcher had also found that the most toxic fractions of oil—which typically evaporate within hours or days if spilled onto open water—was "still evident in the water 30 days after release," resulting in extensive killing of marine life (Dotto 1974b). Many other studies related to the behaviour of oil underneath ice itself, especially the initial process of the oil hitting the bottom of the ice and merging into a combined frozen materiality. At Balaena Bay, testing found that the movement and behaviour of oil beneath the ice depended largely on the stage of ice growth, with oil "encapsulated or entrained" within the ice if it was still growing, and that the oil pooled in particular places based on "irregularities" on the underside of the ice itself caused in large part by differences in the snow cover above it (NORCOR 1975, 32, 36). Observers also reported that a singular plume transformed into much smaller particles that would then fill depressions and create "almost parallel rivulets of oil" underneath the ice, where it became frozen in place (NORCOR 1975, 1; Milne 2010, 75). This identification of new oil "rivulets" echoed the findings of the prior Norman Wells spill.

Several field and laboratory studies followed directly in the wake of the Balaena Bay experiments and recommendations, one of which advised that "studies of the entrainment and migration of oil in second and multi-year ice are of prime importance" (NORCOR 1975, 145). This led to the creation of a laboratory experiment to test the effects of gas that was injected under ice, along with oil (Purves 1978). Going into study, researchers reiterated that "it is hoped and anticipated that the ice cover would trap the oil in deep under-ice pockets over a relatively restricted area" (Purves 1978, 1). However, it was feared that gas may play two related roles: firstly, creating a "perfectly level under-surface of a gas bubble" for the oil to spread across, meaning that "the concentrating effect of the rough ice under surface would largely be lost," and secondly that the gas may penetrate through the ice and facilitate even earlier oil surfacing (Purves 1978, 1–2). The laboratory experiment proved the first prediction correct. Once the gas rose to hit the ice's underside, it "immediately fused into a singular circular bubble with a sessile-appearing edge" (Purves 1978, 10). The oil that followed formed a flat pool underneath this gas bubble and "grew in lobes and tentacles to eventually coat" much of the bubble's surface (Purves 1978, 10). This meant that the formation of a gas bubble "greatly increases" the spread of oil underneath ice, undercutting the previous benefits of studies that had identified rough and uneven ice as helping contain it (Purves 1978, 17). While burn residues and the interactions of oil with ice and snow—crusts and void regions, oil rivulets, impeded evaporation, and increased toxicity—were generated through extremely different processes, both shared the tendency of contributing to the production of new nature that posed uncertain possibilities, especially at larger spills in less ideal conditions. Like with microbial and metabolic productions, such results were also largely side-stepped in summaries and recollections of the scientific work, a necessary step to sustain the notion of a seamless filtering of oil pollution through an abstracted resilient nature that is only ever interacted with rather than actively produced.

Emulsions

One of the major complications of any spill response involves the production of emulsions, or the mixture of two liquids that cannot typically be combined. When it comes to oil in water bodies, emulsions specifically require the presence of wave action (Fingas et al. 1979, 36). In the case of dispersant application, a formulation of surfactants (short for "surface active agents"), solvents, and stabilizing additives is discharged to reduce the surface tension between water and oil, enabling the formation of smaller oil-in-water emulsions (also known as surfactant micelles). Crucially, “dispersants do not reduce the amount of oil entering the environment” (Dupuis and Ucan-Marin 2015, 13) but rather remove it from the surface—decreasing the risk of oiled birds and near-surface organisms—and diluting tiny droplets into the water column into lower-toxicity concentrations. However, dispersant testing through experimental spills found that this desired production of nature was often far more difficult than assumed based on prior laboratory studies.

While an extremely small experiment, the dispersant effectiveness in enclosures near Saanich Inlet provided a warning of less-than-desired outcomes. Researchers conducted two weeks of sampling of the two enclosures to evaluate oil behaviour and fate, with dispersant added to the control enclosure after one week (Green et al. 1982, 6). However, this application only led to a “few percent of the surface oil” becoming emulsified in an oil-in-water mixture, while the “remainder stayed unchanged as a surface slick” (Green et al. 1982, 15). Even this assessment was overly generous: after one week, a mere 0.8 percent of the oil was dispersed (Green et al. 1982, 45). Meanwhile, the oil that had been dispersed from the beginning—releasing the oil in a premix with the dispersant—resulted in dispersal of only 6 percent of the oil, doubling to 12 percent by the end of the experiment (Green et al. 1982, 45, 57). It was also found that the oil treated with dispersant had slower removal of volatile fractions, taking up to two weeks compared to only one to two days for the control spill (Green et al. 1982, i, CONFIRM). Instead of evaporation, it was indicated that biodegradation was responsible for the removal of volatile fractions (Green et al. 1982, 50). Given that volatile fractions of oil are the most acutely toxic, scientists regarded this discovery as “not a good aspect of chemical dispersion,” as it would potentially expose organisms in the water column to significant quantities of compounds such as benzene and toluene (Green et al. 1982, 50).

During the subsequent Royal Roads testing, the dispersant worked as intended, with the oil "easily and obviously dispersed into the water column when it was sprayed" (Green et al. 1982, 117). Yet researchers described the resulting dispersal as "low compared to those expected for complete dispersion, which, as visual observation confirmed, was not achieved" (Green et al. 1982, i). Observers only found dispersed oil at depths up to five metres below the surface, which they attributed to a combination of the "buoyancy of the dispersed oil droplets and the limited vertical turbulence in the coastal locale of the experiment" (Green et al. 1982, 118). Researchers added that a major complication was locating oil "in thick enough patches to make spraying worthwhile" (Green et al. 1982, 117). A contributing factor to incomplete dispersion was that the oil slick "broke into many small patches, some of which were missed by the spray boat" (Green et al. 1982, 121), despite the useful presence of aerial surveillance to guide application (Green et al. 1982, 85). There was also visual and calculated evidence of dispersed oil returning to the water surface, or what researchers dubbed "creaming out" (Green et al. 1982, ii, 117). They attributed this behaviour to mixing action causing "large oil droplets which did not form a stable dispersion" (Green et al. 1982, ii).

However, the production of oil-in-water emulsions was not simplified by increasing the size of the experiment. At a much larger scale, the dispersant testing near Halifax in 1983 encountered similarly disappointing results. There was some near-immediate dispersion in locations where the interaction worked as planned (COAATF 1986, 37). However, overall rates of dispersion were "significantly lower than those previously reported"—ranging between 0.5 to 12 percent—with some of the dispersed oil thought to have resurfaced later in the process, indicating incomplete dispersion (COAATF 1986, 36–38). Researchers concluded that it was "very difficult to determine accurate dispersion efficiencies … primarily due to the heterogeneity of the dispersed cloud" (COAATF 1986, 36). One speculated reason for this issue was the possibility of an inconsistent dispersant application from the helicopter bucket (COAATF 1986, 36–38). Widely differing spray passes and dispersant quantities applied only compounded this issue (COAATF 1986, 5). Yet another problem was widely varying sea states, which impacted the mixing of the dispersant and oil (COAATF 1986, 37). As discussed further in the next chapter, there was also significant divergence between the chemical analyses and radiotracer results of the dispersant effectiveness. Even the more favourable results from the latter analytical approach, however, represented deficient effectiveness rates—between 2 and 40 percent—which researchers described as "somewhat lower than expected and may be a function of the sea states encountered and/or the method of application" (COAATF 1986, i). In particular, these numbers were far lower than what scientists observed in laboratory conditions, with researchers noting that "all three products have effectiveness values measured in the laboratory of greater than 80%, such high values were not achieved in these trials" (COAATF 1986, 109). Based on the failures of the Halifax testing, one of the major recommendations emerging from the experimental work was for future efforts to include "judicious application of dispersant to the slicks at times when more wave energy is available" (COAATF 1986, ii).

Scientists specifically designed the 1986 Beaufort Sea dispersant experiment in relation to the 1983 Halifax experiments that had produced dispersant results "far lower than necessary to adequately protect the environment" (Swiss and Vanderkooy 1988, 2). Like with the Halifax testing, there were sizable differences in dispersant effectiveness based on the specific formulation. Both the control and test slicks treated with BP's formulation saw rapid declines in areas of thick oil, which was the main metric of success in the experiment, with the estimated volume dropping by half in less than an hour after the spill and dispersant application (Swiss and

Vanderkooy 1988, 23–24). By comparison, it took about three hours for the test slick treated with three runs of Exxon's formulation to reach the same level of estimated dispersion (Swiss and Vanderkooy 1988, 23–24). Both of the multi-hit test runs saw continued decline in thick oil visible on the surface after the second application—including a 12 percent decline in only seven minutes in the first test slick—which was interpreted as showing that there was a "significant amount of oil left on the surface after the first spray pass which had not interacted with dispersant (Swiss and Vanderkooy 1988, 23–24, 28). Researchers argued that these observations "support the belief that significant dispersion was occurring upon application of the chemicals," resulting in a "coffee coloured dispersed oil cloud" under each treated slick, particularly after initial application (Swiss and Vanderkooy 1988, 28, 32). This meant that the tested oil "can be dispersed, to a certain degree, at relatively low water temperatures" (Swiss and Vanderkooy 1988, 33).

However, rather shockingly, it was concluded that "there is still no clear evidence that dispersants are as effective as they need to be for environmental protection purposes" (Swiss and Vanderkooy 1988, 1) and that "no strong conclusions on the efficacy of using dispersants as a countermeasures tool can be drawn from this trial" (Swiss and Vanderkooy 1988, 31). Referring to the remote sensing of the four oil spills, researchers pointed to the untreated slick having "exhibited an even greater rate of reduction than the treated slicks" as suggesting that the experiment "does not provide a convincing argument for the use of dispersant as a countermeasures technique" (Swiss and Vanderkooy 1988, 28–29). Although the wave height was significantly greater during the discharge of the control slick than the test slicks, providing a possible explanation for the difference in outcomes, it was noted that the first two untreated slicks on the aborted day of testing "exhibited similar reductions in thick oil with time," despite taking place in “lower sea states” (Swiss and Vanderkooy 1988, 29). Researchers admitted that it was “unclear why the sprayed slicks did not dissipate more quickly than the control nor why the addition of more dispersant, achieving very high D:O ratios, did not increase the observed effect” (Swiss and Vanderkooy 1988, 31). In these cases of failed dispersant testing, the new natures left behind were in the form of untreated and unmodified oil. However, given that this discharged oil was never recovered, it invariably produced nature in unobservable and unknown ways.

We can contrast this gap in scientific knowledge, the product of technical failure, with the opposite form of emulsion production. While chemical dispersants are specifically deployed to form oil-in-water emulsions to displace spilled oil into the water column and accelerate its eventual biodegradation, the inverse of this is the formation of water-in-oil emulsions—often termed “chocolate mousse” in its most extreme iteration—which can create many issues in spill response and limit the exposure of oil to biodegradation (Fingas et al. 1979, 40). When a viscous oil is subjected to wave action and forms an emulsion that is mostly water, the result can be “extremely stable, and may persist for months or years after a spill” (Fingas et al. 1979, 37). Experimental spill work found that many different processes could produce emulsions, signalling the extreme complexity and unpredictability of spill response. For instance, water-in-oil emulsions frequently posed recovery challenges when testing skimmers (Solsberg et al. 1976, 7–8, 68–70), requiring separation prior to storage and eventual disposal.

Researchers encountered recurring problem of emulsion formation during oil burning experiments involving helicopters, often developing in conditions of snow and ice already discussed in part. At Crater Lake, observers found during one of the tests that the helicopter’s downwash “herded the slick in all directions, and formed some temporary emulsions” (D. F. Dickins Engineering 1979, 18). In particular, they concluded that the helicopter’s position at below 15 metres from the ground created downwash that was “so severe as to likely coat the snow edges of the melt pool with oil and generate extensive emulsions” (D. F. Dickins Engineering 1979, 21). Researchers encountered similar issues during oil-in-ice experiments in McKinley Bay in late 1979, which was followed in the summer with testing of air-deployable igniters in the surfaced oil. This time dropping the igniters from a lower altitude than at Crater Lake, researchers observed that downwash from the helicopter led to the water and oil splashing, particularly impacting the “less viscous oil, that which had just recently migrated through the ice” (Energetex Engineering 1981a, 19). However, helicopters were not the only presence that could lead to such emulsion formation. At Balaena Bay, it was observed that fierce winds and waves also spread and splashed the oil onto nearby snow and thereby created larger and interconnected pools of oil, as well as creating oil-in-water emulsions that proved difficult to reverse (NORCOR 1975, 56–57). Emulsions were also the focus of in-ice experiments to evaluate the patterns of surfacing in the springtime.

A major inspiration for this focus on water-in-oil emulsions was the real-world dispatching of Canadian Conair planes for aerial dispersant application to the catastrophic Ixtoc I blowout in the southern Gulf of Mexico in June 1979 (*Abbotsford News* 1979a). The ability for aerial application by Conair DC-6s in such a response was explicitly demonstrated by “two major overland experiments of dispersant spraying in Canada in late 1978 in Quebec and in early 1979 in Abbotsford, B.C.” (Lindblom et al. 1981, 259). Two Conair planes discharged a huge quantity of dispersant onto the spill over the first month-and-a-half, using the same formulation and logistical approach “which had been put through tests over Sumas Prairie earlier this spring” (*Abbotsford News* 1979a). The company added a third Conair aircraft to the sorties in early August 1979, with Conair president Les Kerr reporting that they were “still getting good results” from its aerial application (*Abbotsford News* 1979c; Lindblom et al. 1981, 260). In total, almost 500 aerial missions were flown by the three Conair airplanes during the blowout response (Lindblom et al. 1981, 261). Although some degree of water-in-oil emulsification occurred during the blowout and spreading of the oil, some spill scientists reported that they never developed into the "true 'chocolate mousse' heavy emulsions," which was regarded as "most fortunate, since it made possible effective dispersant treatment to proceed for 6 months," including of oil that had spread on the water for an enormous distance and time (Lindblom et al. 1981, 261). Elsewhere, however, scientists described spill response as having produced "significant quantities" of such emulsions and complicated response approaches (Buist and Dickins 1983, 1).

As a result, researchers planned a dedicated experimental spill project to assess the behaviour of water-in-oil emulsions in first-year ice, in contrast to standard crude oil. Development of stable emulsions was feared to "drastically alter past conclusions regarding the fate and behaviour of oil within sea ice," as extremely viscous oil would not surface via brine channels in the ice and "may not appear on the ice surface until it is too late to mount an effective in-situ burning operation" (Buist and Dickins 1983, 1). During this test, scientists found that both the emulsion and crude similarly broke into "discrete globules" shortly after exiting the hose but did not spread significantly before meeting the ice above (Buist and Dickins 1983, 19). However, they also found emulsion discharges formed as an "irregular 'lumpy' texture," producing what researchers described as a "rather grotesque appearance" (Buist and Dickins 1983, 19). It took only 48 hours until both the emulsion and crude spills were "almost completely incorporated" into a thin layer of new ice below the oil, with ice crystals first visible within the emulsions only 24 hours after the spill (Buist and Dickins 1983, 21). Come springtime observations in mid-June 1982, observers discovered that there were major differences in ice surfacing between the emulsion spill sites and the crude control site, with the latter "considerably more advanced" in its development (Buist and Dickins 1983, 32). It took a full three weeks for the emulsion sites to achieve the same level of surfacing, with the state of the ice at that point "almost rotted completely through to the original oiled layer" (Buist and Dickins 1983, 32). This meant that much of the emulsified spills only became exposed enough for in-situ burning a mere 24 hours prior to ice break-up (Buist and Dickins 1983, 32).

The main impediment identified was the inability for highly viscous emulsions to migrate up brine channels, meaning that "significant emulsion surfacing was not possible even when a clear passage to the surface was available" (Buist and Dickins 1983, 34). As a result, the emulsion could only surface when the ice had melted sufficiently for sunlight to warm it and rise through the remainder of the ice, which in turn enables evaporation and other processes. However, even this development was not guaranteed. Emulsions that were trapped under ice any thicker than 165 centimetres or so "may not appear until breakup is advanced" (Buist and Dickins 1983, 51). In both of these situations, spill response methods such as in-situ burning or manual recovery would be rendered effectively impossible. Further, building on the work of previous studies and the finding that emulsions do not migrate upwards through brine channels due to their viscosity, it was "presumed that emulsions spilled under multi-year ice would take much longer to surface," as much of the ice would not become thin enough to facilitate ablation (Buist and Dickins 1983, 52). There were also major variables recognized between different types of oil and their tendency to form emulsions, leading to the researchers recommending that "the oils found and used in Canada's offshore areas should be classified according to the stability of the water-in-oil emulsions they form," in order to sufficiently understand and prepare for a wide range of outcomes (Buist and Dickins 1983, 54).

Scientists developed further findings about the complexities of this new nature during the Beaufort Sea dispersant testing. Along with concluding that dispersants were still not effective enough to be recommended for real-world application, this experimental work discovered the unexpected formation of a "phenomenon known as 'emulsion balls'" on the water surface that were found to interfere with oil dispersal and produced an "overall reduction in dispersant effectiveness" (Swiss and Vanderkooy 1988, 1). This "large number of 'grape-sized' balls of oil which covered the surfaces of the sprayed slick" had been encountered before in testing and had also been termed "herdy balls" or "pea floc" (Swiss and Vanderkooy 1988, 22). Researchers interpreted the presence of these emulsion balls as a sign that other mechanisms—rather than only dispersion—were underway, and that there was a likelihood that dispersed oil was forming into these balls rather than entering the water column as intended (Swiss and Vanderkooy 1988, 28).

Such formation only occurred in the thick sections of dispersed slicks, not the untreated control (Swiss and Vanderkooy 1988, 30). Laboratory analysis conducted following the experiment confirmed this observation, finding they "form only in the presence of dispersant and are a water-in-oil-in-water emulsion" (Swiss and Vanderkooy 1988, 28). Efforts to collect samples of the emulsion balls from boats repeatedly failed as "upon being touched, they burst apart and dissipated leaving no remnants of the original structure" (Swiss and Vanderkooy 1988, 22). Given this behaviour, scientists speculated that "over time and with prolonged exposure to more wave action, these balls would release their oil to the sea possibly in the form of dispersed droplets or as a sheen on the water's surface" (Swiss and Vanderkooy 1988, 31). Only making matters worse was that the emulsion balls impeded the production of usable infrared imagery of the spill, which was heavily relied on to assess dispersant effectiveness (Swiss and Vanderkooy 1988, 1, 30). In this particular instance, the unpredictable quality of these new natures became acutely clear, with efforts to intentionally produce oil-in-water emulsions effectively backfiring and unexpectedly creating an unknown nature that not only materialized a significant recovery impediment but actively obstructed the ability for researchers to even track and evaluate dispersant effectiveness.

While distinct in specifics, all of the various natures described in this chapter—from ground-down oil particles, to fertilized shoreline vegetation, to viscous and PAH-laden burn residue, to the routinely unsuccessful attempts to form oil-in-water emulsions—were riddled with uncertain impacts and trajectories. Making any assertion of confidence about the behaviour, effects, and fate of oil in water bodies required the downplaying and marginalization of such possibilities. In contrast to the three previous case studies—which argued that the siting, timing, and oiling of experimental spills actively constructed "future eco-perfect" conditions—this aspect of scientific work involved the discarding of unwanted residues that challenge the ability to claim that spills can be effectively responded to, with such findings disregarded in contemporary recollections of the work.

We can theorize such production of natures and later conjunctural co-production in its afterlives often years or decades after its generation with reference to the scholarship of ruination, rubble, and failure (Stoler 2013; Peyton 2017; Carse and Kneas 2019). In these studies, scholars pay specific attention to the unpredictable aftermath of development. Gastón Gordillo's (2014) work on rubble—a concept developed to attend to "name what is created by the destruction of space" (5) while transcending the "early modernist preoccupation with ruins"

(57)—proves especially relevant to this focus on the production of non-human nature. Explicitly working in conversation with the analytical approaches of Anna Tsing, Ann Laura Stoler, and Walter Benjamin, Gordillo (2014) worked to highlight the ways that seemingly discarded waste or byproducts have their own afterlives, stressing that "inanimate matter such as rubble can be considered to have an afterlife, or 'a history of its own.' And this afterlife of rubble is, indeed, determined by history and the constellation" (20). These natures—often considered the product of some genre of failure—are not merely incidental but "constitutive of the spatiality of living places" (Gordillo 2014, 11).

We can also think about the new natures and byproducts examined in this case study in such terms. Oil spill experiments are a forecasting and simulation of large-scale failure. However, the experiments themselves have produced many new natures and forms of hydrocarbon-based "rubble" through the attempted biodegradation, burning, and dispersing of carefully spilled oil. Scientists have tended not to assess these new natures with any great detail or concern, instead relegating them as unfortunate but necessary byproducts of spill response that an abstract nature will eventually process. Yet theories of the dynamic materializations of ruination, rubble, and failure, demand that we view these processes as what they are: the production of new natures that will have dynamic and complex interactions with organisms and matter for years and decades to follow.

Chapter 6: Scientific Unknowns

In 2018 and 2019, a flurry of news articles was published in national and international outlets about a seemingly novel form of scientific research being conducted in northwestern Ontario. The likes of *Globe and Mail*, *BBC*, *Atlas Obscura*, *Science* and *Canada's National Observer* detailed with a shared tone of intrigue that scientists were *intentionally spilling oil* at the International Institute for Sustainable Development Experimental Lakes Area (IISD-ELA) near Kenora, seeking to better understand the specific effects of dilbit and heavy oil in freshwater ecosystems (Semeniuk 2019; Ogden 2018; Williams 2019; Davis 2018; McSheffrey 2018). The specific threat of dilbit pollution had become especially evident with the catastrophic spill from an Enbridge pipeline into Michigan's Kalamazoo River in 2010, along with rapidly increasing exports of the commodity via pipelines and railways spanning the continent. As media outlets reported, “much of that oil is moving through hard-to-reach expanses of boreal forest, just like the ELA” (Semeniuk 2019) and that “Canada has had multiple spills into boreal forest and wetlands” in recent years (Ogden 2018). Further, a Royal Society of Canada report on oil spills in marine and freshwater aquatic environments had been initiated in 2014 to fulfill a condition of the National Energy Board's approval of the Northern Gateway pipeline proposal (Lee et al. 2015, 4). The main recommendation from the industry-funded review and report was that much more scientific research was required to understand the impacts of oil in water, especially “in high-risk and poorly understood areas, such as Arctic waters, the deep ocean and shores or inland rivers and wetlands,” with the *Deepwater Horizon* catastrophe of 2010 in the Gulf of Mexico serving as a worst-case outcome (Lee et al. 2015, 26).

The multi-year research programs at ELA aimed to fill some of these scientific gaps, with involvement by scientists and researchers from universities, government, industry, private consultants, and the IISD (Stoyanovich et al. 2019; Cederwall et al. 2020; Palace et al. 2021;

Black et al. 2021; Rodriguez-Gil et al. 2021; Timlick et al. 2022). The wide range of foci in these studies was creatively represented in the various project titles: the Freshwater Oil spill Remediation Study (FOReSt), FLOating Wetland Treatments to Enhance Remediation (FLOWTER), and Boreal Lake Oil Release Experiments by Additions to Limnocorrals (BOREAL). Despite these different focuses—shoreline clean-up, floating treatment wetlands, the physical fate and biological effects of oil—all of these spill studies shared the same emphasis on achieving *greater realism* through expansion of experiments from the laboratory to the field. The ELA served as an ideal site for this work, frequently praised as serving as a "natural laboratory" or "living laboratory" (McSheffrey 2018; Semeniuk 2019; Orihel 2019) for decades of experimental work in its 58 lakes investigating algal blooms, acid rain, mercury contamination, and much else (Schindler 2009). For example, a chemist with the federal environment department explained to *BBC* that in laboratory environments, "there are technical problems with what we call scaling – how you go from a small scale to a big scale," and that "Boreal gives us an opportunity to do work not at full scale, but very close to it… and really get a good handle on what happens in these natural settings" (Ogden 2018). Similarly, in an article for *Canadian Geographic*, an ecotoxicology professor from Queen's University wrote that the goal of the BOREAL study was to "to answer important questions about the fate, behaviour, and effects of dilbit in freshwater ecosystems under various outdoor conditions, including sunlight, wind, and thunderstorms—*questions that can't be answered effectively in the laboratory*" (Orihel 2019; emphasis added). *Globe and Mail* also reported that "laboratory testing with individual species is not enough to predict the full impact of an oil spill on an entire wetland, lake or river system" (Semeniuk 2019).

These studies produced many compelling findings about dilbit: that it has a "propensity" to sink in freshwater lakes (Stoyanovich et al. 2019, 2621), can cause significant damage to phytoplankton and zooplankton (Cederwall et al. 2020) and an "immediate and sustained loss of insect emergence rates," (Black et al. 2021, 8), may not have not serious short-term effects on fish at low concentrations (Timlick et al. 2022), and could potentially be biodegraded through microbial activity (Kharey et al. 2024, 10). However, there were also several unanticipated variables that influenced outcomes. Multiple studies, for instance, noted that the background presence of zinc in the limnocorrals, speculated to have been caused by the use of zinc-plated minnow traps to attract fish (Rodriguez-Gil et al. 2021, 11), may have contributed to higher benthic toxicity (Black et al. 2021, 8) and damaged fish gills (Timlick et al. 2022, 2752). Another study that found little change in microbial activity attributed the "generally static trends" to an assortment of factors including "the scale of the enclosures and inherent heterogeneity of the enclosure environment, made more complex with environmental factors and variables," adding that "*the deployment of the enclosures themselves* was a factor in microbial community shifts" (Kharey et al. 2024, 10; emphasis added). Even the timing of fish collection for the study, about one month after spawning, may have shaped observations of oil's effects on reproductive systems, which would have been more obvious before or early in the spawning season (Timlick et al. 2022, 2755).

Once again, researchers constantly encountered unexpected variables that tainted findings. Noting these complex factors and uncertainties does not diminish or undermine the results of this extensive research effort. Like with smaller-scale laboratory research, such variables are not necessarily a limitation, if adequately acknowledged and claims to confidence restricted accordingly. However, scientists frequently produce oil spill science with the goal of extrapolating its findings to far wider scales, helping to successfully predict risk and inform regulations across entire regions and conditions. In particular, this work is frequently produced to satisfy environmental assessments and other regulatory requirements for proposed oil industry projects to proceed, such as the Beaufort Sea Project. For example, the Eastern Arctic Marine Environmental Studies (EAMES) program started in the late 1970s was specifically focused on producing "sufficient data" for use in environmental assessment processes ahead of offshore oil and gas exploration near Baffin Island (Dome Petroleum et al. 1982, 2.16–2.17), with "regional environmental clearance" replacing site-specific environmental assessments, requiring "large, integrated studies of whole ecosystems that would enable the assessment of potential impacts over large areas" (Sutterlin and Snow 1982, iii). Despite opposition by the oil industry to the program's cost structure ("Notes From Meeting" 1977), they eventually acknowledged that these studies were "embodied within a massive and thorough Environmental Impact Statement" that "resulted in the permission to carry out exploratory drilling, which got underway in 1979" (118).

Such goals and processes are not conducive to the entertaining of major uncertainties, especially when multi-billion projects and revenues are involved. In contrast to the many unknowns that often riddle experimentation, reviews of environmental assessment processes have found that potential uncertainties are frequently downplayed and "never discussed in depth" (Aksamit et al. 2020, 318), with the language of "likely" or "unlikely" impacts described as "not sufficient to understand impact probability" (Aksamit et al. 2020, 327). Scholars have called into question the scientific data quality used in these processes, with potential impacts "unknown rather than nonexistent" (Carter 2020, 109–110) and "not significant, despite evidence presented to the contrary" (Cameron and Kennedy 2023, 121). Studies have found that industry and regulators manage uncertainties in this way in all parts of the assessment process, meaning they never meaningfully address them (Aksamit et al. 2020, 329). In particular, the use of highly technical “toxic thresholds” within assessment processes have the effect of “displacing a politics of confrontation” and “push effective action into the realm of standardized methods, certified results, acceptable levels, and codified assessment models” (Bond 2022, 9). Although contested, these complex scientific metrics and practices are often set by the proponent itself, shaping the “language of protest against it” (Li 2015, 204).

Another relevant aspect of this knowledge production process is that proponents clearly seek the approval of the proposal, and that “while assessments can lead to changes in project design, rarely do they lead to the denial of industrial activity” (Arsenault et al. 2019, 121; Li 2015, 198). Analysis of recent oil industry assessments in Saskatchewan found that the processes “seldom involved detailed reviews or public participation” (Carter 2020, 76), with the emphasis on simply getting the project approved (Carter 2020, 82). Scholars have also critiqued the recent development of “strategic environmental assessments” (SEAs) for serving as a means to accelerate project-specific approvals, rather than question whether industrial activity should occur at all (Carter 2020, 112). The inclusion of Indigenous knowledge in such regulatory processes has often been become caricatured and marginalized, functioning to supplement conventional scientific practices (Dokis 2015; Cameron 2015, 182–185; Hoogeveen 2016; Wilson and Inkster 2018, 519; Baker and Westman 2018; Arsenault et al. 2019; Dokis 2023). Scientific knowledge production is “privileged in the EA process and this tends to marshal support for development, even if Indigenous knowledge contests the science and the proposed development” (Collard et al. 2020, 7). In particular, this scientific knowledge often *asserts* certainty about potential effects, despite many remaining unknowns.

This issue was regularly exemplified through the attempted production of control plots to compare outcomes of various treatments to baseline conditions and processes. For instance, despite the Mackenzie Delta region having an estimated 500,000 lakes, researchers working to site an experimental spill in the early 1970s noted that "it was not possible to find two lakes at the same latitude which were sufficiently similar in terms of fauna and flora so that one could be a control system for an experimental study of the other" (Snow and Scott 1975, 527). As a result, scientists had to compare oil spill impacts to pre-spill baseline conditions, which was "unsatisfactory as year-to-year variations in biomass and species life-histories are not known" (Snow and Scott 1975, 527). Building on the findings and shortcomings of the previous study, researchers partitioned adjacent lakes for two additional spill experiments to "obtain experimental and control areas within the same lake" (Snow and Scott 1975, 527). While deemed similar in their "physical and chemical regimes," the two lakes had entirely different organisms in them (Snow and Scott 1975, 527).

These challenges frequently led to compromises in experimental processes. The search for appropriate bays to use for the Baffin Island Oil Spill (BIOS) project hinged on the goal of representing much wider Arctic conditions. Scientific studies of various bays conducted throughout 1980 found little existing hydrocarbon contamination and "confirmed the pristine nature of the study area" (Sergy 1986, 10; Sergy and Blackall 1987, 3). However, planners quickly realized during the BIOS planning process that "financial, political and logistic realities constrained an ideal design," with inevitable variations between the bays resulting in a decision to proceed with the testing on the basis of "pseudoreplication" (Sergy and Blackall 1987, 4; Dickins et al. 1987, 100). Similarly, while a major benefit of the Svalbard testing was that the setting offered the potential for a "full-scale oilspill experiment with all the environmental variables in play" (Sergy et al. 1998, 74), the particulars of land-use conditions "eliminated the possibility of true full-scale replication of the experiment" (Guénette et al. 2003, 254). However, differences between the spill sites were factored into the experimental design and were deemed "not of great significance to the final outcome" (Guénette et al. 2003, 254; Sergy et al. 1998, 78).

The challenge of establishing controls in supposedly pristine and uncontaminated areas was further demonstrated at later shoreline studies. During the St. Lawrence shoreline spill of 1998, scientists treated four unoiled control plots with fertilizer formulation to assess impacts without the presence of oil (Lee et al. 2001, 323). However, they discovered that unoiled plots contained a pre-existing hydrocarbon presence, requiring a statistical correction to account for this background contamination in all tested plots (Venosa et al. 2002, 270–71). This issue was confirmed in a return to the site two decades later, with researchers concluding that the "detected concentrations represent baseline concentrations, rather than residual oil from the oil spill experiment," with such conditions deemed "not surprising" due to the experimental spill taking place in a "heavily travelled shipping corridor" (Schreiber et al. 2023, 5). Yet this effort to establish baseline controls was further complicated by the original study having not reported the background oil concentrations in the control plots, "so that it is impossible to say how the concentrations of the present study compare to those 21 years ago" (Schreiber et al. 2023, 5). A similar problem was again encountered in the coastal salt marsh study of 2000, which found that control plots already contained hydrocarbon presence from another source, requiring data corrections that were justified on the assumption that "these background hydrocarbons were generated as a result of previous and/or ongoing exposure to a different oil source" (Garcia-Blanco et al., 2007, 7). The complex materialities of socioecologies—including those assumed to be "natural"—constantly confounded attempts to establish reliable controls and scientific parameters. The remainder of this chapter zooms in on three distinct sets of scientific knowledge produced through experimental spills, focusing on the various unknowns and difficulties encountered along the way and on the attempts to transform them into coherent and extrapolatable knowledge.

I examine the continual encountering and management of scientific complications during historical experimental spill work, arguing that the flattening and ignoring of complications is another key process of materializing the "future eco-perfect." Specifically, it will look at the emergence and management of scientific complications and unknowns experienced during spill experiments that focused on three distinct issues: burning, dispersants, and shorelines. In each of these, the ability for scientists to produce rigorous findings that could be applied to far more general conditions was complicated by the movement and transformations of oil, but these complications were frequently pushed to the side, and scientific certainty instead asserted. Materialities confounded generalizability in oil spill science.

Burning

One of the most visible and concerning aspects of in-situ burning of oil is the huge black smoke plume that it can generate, particularly if the burn site is close to urban areas. However, such air pollution tend to be justified as preferable to the alternative of leaving oil on the water surface; the author of the report about the Rimouski burn experiment of 1973 noted that they were "well aware" that the smoke was a "form of pollution" in itself, but that it was "felt, however, that the total damage to the environment is only a small fraction of that which is done by oil in water" (Coupal 1976, 6). Given its often tremendous scope and complex behaviour, smoke from in-situ burning proved extremely difficult to sample with any level of accuracy or reliability. For example, at Rimouski, air samples collected at incremental distances from the burning detected no carbon particles, while ground surveys indicated no carbon deposits in the immediate vicinity, leading researchers to speculate that sedimentation "took place a great distance from the test site" (Coupal 1976, 3). However, this conclusion was only based on inference, not concrete data generated through widespread sampling mechanisms: an impossibility given the limits of the study and enormity of even a small burn. Similar conjecture was present in several other burn experiments (NORCOR 1975, 111; Georghiou and Sheppard 1982, 8–9). Developing any greater level of confidence would require a far better resourced and equipped experiment to physically sample the products of burning.

Spill planners designed the NOBE of 1993 to do exactly that. Unlike most previous efforts, it was an enormous experiment that involved more than two dozen sponsors, with the project developed and led by Environment Canada and including major participation by the US Minerals Management Service, Canadian and US Coast Guards, industry organizations like the American Petroleum Institute and Canadian Association of Petroleum Producers, and US spill response organizations (Environment Canada et al. 1993, 7-1). A series of 30 mesoscale in-situ burns had been conducted in the early 1990s leading up to the NOBE—largely at the US Coast Guard facility in Mobile, Alabama, along with an Esso tank test facility in Calgary—with emissions and pollutant measurements a main focus (NIST 1994, 39; Christopher and Vanderkooy 1993, i). Primarily, testing at NOBE was expected to allow for the "identification and quantification of the chemical species associated with and generated by the burning of oil on the open ocean (particularly smoke and gaseous emissions)," which was deemed especially important given that such compounds "have not been adequately characterized and never quantified, making it difficult if not impossible to estimate environmental risk" (Environment Canada et al. 1993, 1-1). However, planners noted that the volume of soot in the smoke plume was “usually ignored” in such studies, “largely because of the difficulty of measuring it with precision” and that “most of it will be airborne and will dilute rapidly to negligible concentrations” (Environment Canada et al. 1993, 2-6). Many aspects of smoke formation remained unknown as well, including the process by which individual particles developed into “larger agglomerates” (D. F. Dickins Associates 1992, 19). As a result, several “properties of interest” included “total smoke particulate and its chemical composition, the optical properties of the smoke, and the aerodynamic size of the smoke particles” (D. F. Dickins Associates 1992, 19).

Scientists would conduct detailed measurements of air emissions, water pollution, and “operational parameters relevant to in-situ burning” (Environment Canada et al. 1993, 1-3). Air sampling would include measurements of particulate size, PAHs, VOCs, metals, carbon dioxide and monoxide, sulphur dioxide, and nitrous dioxide (Environment Canada et al. 1993, 6-1). In particular, one of the “primary interests” of the NOBE was to better understand the “nature and concentrations of PAHs” from in-situ burning conducted in “realistic field conditions” (Ferek et al. 1997, 3). Theoretical models used to predict environmental outcomes of burning—such as smoke plume trajectories and pollutants—could also be tested through this process (Environment Canada et al. 1993, 1-1; D. F. Dickins Associates 1992, 19–20). All of these learnings would help provide regulators with the “necessary information” to develop “pre-approval” for rapid application of in-situ burning in real-world spills (Environment Canada et al. 1993, 1-2). More bluntly, Amoco personnel described this as a process of “convincing the regulatory bodies that the processes are viable to implement, that the environmental risks are known, and that they are minimal” (Christopher and Vanderkooy 1993, i).

As discussed in Chapter 3, this project was a massive logistical undertaking. A wide array of “state-of-the-art” sampling and monitoring technologies were to be used, with over 200 sensors and samples in total and an estimated 2,000 parameters evaluated (Christopher and Vanderkooy 1993, 1; Fingas 2013, 6; Fingas and Lambert 2018, 287), including “remote controlled boats, helicopters and an ROV (submersible) that will be deployed beneath the slick” (Environment Canada et al. 1993, 1-3). Environment Canada’s Emergencies Science Division specifically built four remotely piloted sample boats for the experiment (Environment Canada et al. 1993, 6-2). This division also created remote control helicopters to conduct air sampling “without endangering the lives of response personnel” (Environment Canada et al. 1993, 6-6). Such devices helped to resolve long-standing issues with sample collection at oil spill sites, including the remoteness and geography of the incident (Li et al. 1995, 117).

Despite these extensive efforts, sampling also faced limitations at NOBE. Several years after the experiment, it was concluded that “most of the data collected concerns the composition of the emissions from the fire rather than their downward dispersion” (McGrattan et al. 1995, 7). While undoubtedly useful, this data production remained narrowly focused given the wider scope of the study’s ambitions. The major exception to this was the work of monitoring the smoke emissions, made up of particulate matter and gases, that was conducted by the University of Washington’s Cloud and Aerosol Research Group of the Department of Atmospheric Sciences, using a Conair C-131A research aircraft (Ferek et al. 1997, 1; McGrattan et al. 1995, 7). During the burning, the airplane flew across the smoke plume and a bag captured the smoke, allowing for “essentially point sampling of the smoke at various locations” (Ferek et al. 1997, 4). Many other instruments, filters, and sampling devices were used to collect measurements on the airplane, including lidar (Ferek et al. 1997, 4–6). While largely successful, these testing approaches were deemed “relatively inefficient” for particles over the size of 5 um, meaning the PM 10 results were “not accurate” (Ferek et al. 1997, 5). Measurements of the organic carbon in its vapour phase was “highly variable,” with some of the sampling thought to have potentially been contaminated with ship exhaust (Ferek et al. 1997, 31). In particular, scientists regarded concentrations of PAHs as “quite low” in most samples, with the highest concentration found in a “background sample taken downwind of the ship exhausts” (Ferek et al. 1997, 32). Due to the possible contamination of the sampling, scientists concluded that PAH estimates were “highly uncertain” (Ferek et al. 1997, 46). Like with previous burn testing, gases like carbon monoxide and sulfur dioxide proved “difficult to quantify” due to their low levels, requiring researchers to estimate measurements based on ratios to other gases and compounds (Ferek et al. 1997, 34). Researchers also reported “limited measurements” of volatile organic compounds (VOCs), but added “it appears that little unburned hydrocarbon vapor escaped the flame zone” (Ferek et al. 1997, 34).

The distant spreading of smoke also proved to be difficult to track, with it occurring in a highly uneven and unpredictable manner (Ferek et al. 1997, 2). Researched attributed part of this complexity to a process described as “self-lofting,” in which smoke rises due to the dark carbon particles functioning to “strongly absorb visible light,” meaning that smoke rose the farther it travelled downwind (Ferek et al. 1997, 42; McGrattan et al. 1995, 9). About 30 kilometres downwind of the burn, some parts of the smoke plume rose to more than 800 metres, which was “possibly due to solar heating of the smoke” (Ferek et al. 1997, 22). Researchers thought a dynamic of “enhanced plume dispersion caused by the unexpected lofting” accounted for the miscalibration of the predictive modelling and the experimental outcomes (McGrattan et al. 1995, 12). It also meant that scientists did not detect “high concentrations” of dangerous “submicron, respirable particles” at sea level, a factor that related to the “stable atmospheric conditions" that the burning took place in, preventing the smoke from "mixing back down to the surface" (Ferek et al. 1997, 45).

Researchers only speculated at the eventual fate of the particulate matter and gases, however, reporting that plume "rose quickly above the marine boundary layer and remained above the surface for at least 40 km downwind (and likely for a much greater distances)" (Ferek et al. 1997, 1). They also found the concentration and composition of the smoke plume was in constant flux, rendering it difficult to produce firm conclusions. After more than an hour of migrating downwind, the smoke was found to reduce in concentration by almost 10 times, which "approached the EPA standard" (Ferek et al. 1997, 22). Yet this decrease over distance did not occur "in any simple fashion" due to a combination of the "variability in the burn rate of the oil and the very slow dispersion of the smoke" (Ferek et al. 1997, 40). For instance, the highest particle mass concentration was found about 8.5 kilometres downwind of the burn, while a "fairly dense parcel of smoke" was located about 14 kilometres away (Ferek et al. 1997, 40). Further, "considerably more organic and unidentified fractions" were identified in the smoke about 90 minutes from the burn site, with researchers writing about it that "it is uncertain whether there was enough organic carbon present in the vapor phase to begin with to account for the additional condensed organics indicated by that sample or whether the sample was contaminated" (Ferek et al. 1997, 24).

Similar uncertainties were present in the sampling that examined the impacts of in-situ burning on aquatic organisms (EVS Consultants 1995, v). Although an array of sampling was intended to be collected throughout the course of the experiment, using remote-controlled boats, some samples could not be collected due to issues with the sampling technology (EVS Consultants 1995, 30). This meant that "several of the anticipated samples either could not be collected or did not contain sufficient volumes" to conduct the same toxicity tests as researchers had previously done on laboratory-generated samples (EVS Consultants 1995, 30–31). Although the samples that were collected indicated "much lower" levels of PAHs and total petroleum hydrocarbons than the laboratory-generated samples (EVS Consultants 1995, 32), it was acknowledged that such a difference could have resulted from "increased mixing and dilution in the water beneath the oil slick" compared to the "confined nature" of the laboratory (EVS Consultants 1995, 32). This possibility did not remove the contaminants but merely distributed them into the water column. Like with the partial analysis of the smoke, the ultimate fate and effects of these potentially toxic byproducts remained unknown, with the absence of evidence claimed as indication that in-situ burning "did not adversely affect the underlying water column beyond those effects already associated with the unburned oil" and that concerns about aquatic toxicity should not prevent the use of burning (EVS Consultants 1995, v). Rather than acknowledge the many outstanding scientific unknowns and err on the side of caution, these studies instead largely discarded complexities and *asserted* scientific certainty, helping to project a "future eco-perfect" spill response.

Dispersant

The history of dispersant testing through experimental spills experienced similar complexities and uncertainties. Spill expert Merv Fingas (2002) explained this with particular clarity, contrasting fieldwork with laboratory testing:

> [M]easurements of dispersant effectiveness at sea are very difficult to make and are very subject to many types of errors. When testing dispersant effectiveness in the field, it is very difficult to measure the concentration of oil in the water column over large areas and at frequent enough time periods. It is also difficult to determine how much oil is left on the water surface as there are no methods available for measuring the thickness of an oil slick and the oil at the subsurface often moves differently than the oil on the surface. (2)

Similarly, a review of extensive dispersant use during the *Deepwater Horizon* (DwH) response reported that:

> As Corexit was widely used during the DwH spill mediation, it may be assumed that field samples containing oil were also exposed to Corexit, whether tracked or not. To complicate matters further, the indirect effects of Corexit on oil distribution and weathering often cannot be distinguished from direct effects on organisms or organic matter distribution, even in experiments. For example, smaller oil droplet size due to Corexit addition might make the oil physically more bioavailable because the surface:volume ratio is increased, thereby permitting better access to the oxygen and nutrients required for biodegradation. However, the presence of Corexit may impact the ability of bacteria to degrade the oil, or favor bacteria that degrade Corexit, potentially leading to decreases in oil biodegradation rates (e.g., Kleindienst et al. 2015a,b). As a result, the specific impact of Corexit on the fate of the DwH oil is not always clearly identifiable. (Passow and Overton 2021, 115)

Many different approaches and tools have been devised over the decades to confront such issues. Early testing in Halifax Harbour harnessed a "jury of three observers" to evaluate dispersant effectiveness using a series of metrics including oil floating on the surface, oil particles in the water column, and oil collecting along the side of the vessel (Gill 1977, 392). While positive results were generated through this testing, especially when using the "newer breed of dispersant concentrates" (Gill 1977, 393), researchers described a "loss of precision once the test moves outside the controlled environment of the laboratory" (Gill 1977, 394). Specifically, they did not use scientific instrumentation in the testing as "such data would only be useful in the event that it could be correlated with environmental factors such as wind, current, time, depth and sea state" (Gill 1977, 394). Instead, scientists produced results from visual observation of the oil in the water and collected in measuring cans, which was far from exhaustive given the underlying objective of dispersants.

Testing that took place near Victoria a few years later attempted to introduce scientific instrumentation to improve data production. This, too, proved extremely challenging. At Saanich

Inlet, personnel hand-lowered by rope a National Bureau of Standards-designed sampler for the purposes of conducting florescence spectroscopy analysis several times per sampling period (Green et al. 1982, 6–8). However, researchers abandoned this process after the third day of sampling on account of being "exceedingly tedious"—requiring them to change and clean the tool for each sample—and replaced with a pumping system (Green et al. 1982, 9). Meanwhile, an "underwater microscope apparatus" used did not produce images of sufficient quality to "make them very useful in quantifying the dispersion droplet size and concentration" (Green et al. 1982, 12). By the conclusion of the testing, it was determined that at least half of the oil that remained in the water existed as a fine dispersion, but with a droplet size far too small to document with the underwater photomicroscopy apparatus (Green et al. 1982, 65). The second phase of this dispersant testing at Royal Roads also encountered issues with monitoring the dispersed spill. Tracking the spread and fate of the spills proved incredibly difficult, requiring complex technologies and processes, yet researchers noted that "while it is obvious that the clouds grew with time, the irregular shape of them makes any observations of the rate of growth of the clouds far from obvious" (Green et al. 1982, 110). They also deemed impossible the detection of any longer-term processes like microbial degradation and photo-oxidation due to the "difficulty of finding the oil more than a few hours after dispersal" (Green et al. 1982, 3) as its "fluorescence could no longer be distinguished from background" (Green et al. 1982, 73). As with the smoke and aquatic toxicity studies of in-situ burning, dispersed oil escaped complete monitoring, despite technological advances and preparation.

Problems only got worse the more that scientists conducted testing. During dispersant trials at St. John's in 1981, "incomplete imagery, lighting conditions, and greater fragmentation" of the oil heavily curtailed documentation of the control slick on the first day (Goodman and

MacNeill 1984, 147–148). Researchers also found that the sampling equipment was "excessively cumbersome" and "prevented a thorough survey of the slick-covered waters in an acceptable period of time" (Gill and Ross 1982, 262). Only making matters more difficult was that some of the water samples sent to the Esso laboratory for analysis were contaminated by aluminum liners in the vials disintegrating and the interacting with the material, which turned out to be "severe and rendered hydrocarbon analysis impossible" (Goodman and MacNeill 1984, 146). More generally, Esso researchers involved in the experiment noted that subsurface sample collection is typically limited to two metres below wave heights, well below the anticipated 10 metres of dispersant trials, and that "to date no standard technique has been developed to successfully collect water samples under oil spills" (Goodman and MacNeill 1984, 144). They also described a "total lack of data from water column chemistry," preventing its comparison with remote sensing data (Goodman and MacNeill 1984, 143–144).

Given that dispersants are designed to push oil droplets into the water column, scientists had to develop a procedure to allow for collection of uncontaminated water samples before reaching the targeted area (COAATF 1986, 10). Previous efforts to resolve this particular issue during 1981 St. John's experiments found "little success," with the design used found to make the vessel "almost totally unmanoeuvrable" (COAATF 1986, 10–11). Planners developed a new system for the 1983 Halifax trials, resulting in the design and construction of a testing apparatus that mounted a series of sampling ports and specialized tubing at increasing depths to a 10-metre aluminum sailboat mast, which personnel bolted to the bow of the ship (COAATF 1986, 11). However, after its successful use in the first experiment, an "increasing sea-state" led to several fractures in the metal, resulting in the cancellation of the second day of the trials as personnel from Esso and the Coast Guard worked to modify it (COAATF 1986, 11–13). Eventually, personnel removed the bottom five metres of the boom and weighed down the tubing instead (COOATF 1986, 13). Scientists collected copious quantities of samples by this process over the course of the three days of testing, which was then processed and analyzed in a laboratory (COOATF 1986, 31).

However, this technical success did not end the struggle to produce scientific data. Researchers discovered significant differences in oil volumes in the surface slicks, which they attributed to “non-uniformity of the slick thickness, mousse and the sampling procedure used” (COOATF 1986, 23). In particular, scientists dipped sampling pads into the slick at a different rate per test, later acknowledging that “since the slick was not sampled uniformly, bias was introduced into the sampling procedure” (COOATF 1986, 23). Further, they concluded that it was “very difficult to determine accurate dispersion efficiencies … primarily due to the heterogeneity of the dispersed cloud” (COAATF 1986, 36). Processing the resulting samples also ran into difficulties. Despite the extensive work to design an effective sampling apparatus and collect a large quantity of samples, scientists then found that there was extreme variation in results from the chemical analysis that necessitated complex analytical work to render usable (COOATF 1986, 31–35). Further difficulty emerged as results from the radiotracer analysis—with tritium added to the oil prior to the spill —found significantly greater levels of dispersal than the chemical analysis did, with results described as “consistently higher than the chemistry data by factors of 4 or 5” (COOATF 1986, 52). While “fluctuations due to patchiness” of the oil slick were cited as one of the probable causes, it was concluded that “reasons for the discrepancy are unresolved” (COOATF 1986, 52). Despite this uncertainty, researchers sided with the radiotracer results as the more representative of the two, using it to conclude that dispersant application resulted in almost 30 times as much oil dispersal compared to the untreated spills

(COAATF 1986, 52). Importantly, it was this conclusion, not those of the more problematic chemical analysis, which scientists reported in the executive summary of the report (COAATF 1986, i). Once again, they filtered troublesome unknowns out of the scientific process.

Even by the time of the last major dispersant-focused experimental spill in Canada, which happened in the Beaufort Sea in 1986, researchers struggled to make sense of how to produce reliable data. One contributor to this ongoing problem was that researchers had followed the recommendation from the Halifax experiment and abandoned attempts to evaluate dispersant effectiveness through water sampling, replacing that function with aerial remote sensing (Swiss and Vanderkooy 1988, 15). This approach reduced the time- and cost-intensive requirement of chemical analysis, allowing for researchers to concentrate attention on the goal of removing oil from the water surface rather than measuring oil in the "three dimensional water column" (Swiss and Vanderkooy 1988, 15). However, the experiment still used a boat to gather environmental data using a fluorometer, but a combination of wave conditions and the instrument's design "combined to damage the instrument and no subsurface fluorometric data were collected" (Swiss and Vanderkooy 1988, 6). Given that there was no means of collecting the dispersant spray on the water surface itself due to the primarily aerial method, scientists estimated the ratio of dispersant to oil based on the volume of it left in the bucket after each spraying run (Swiss and Vanderkooy 1988, 20). Researchers acknowledged that this method "lacked the precision of a rigorous scientific protocol" but was "compatible with the prime objective" of the experiment, which was to evaluate dispersant effectiveness (Swiss and Vanderkooy 1988, 20). However, the report concluded by admitting that "pending the development of a protocol to obtain a true and complete mass balance, the field measurement of dispersant effectiveness will have a large degree of uncertainty and a very large error factor" (Swiss and Vanderkooy 1988, 32). In combination with the “emulsion ball phenomenon” that plagued remote sensing detection, researchers warned that the major lack of certainty about dispersant behaviour and effectiveness meant that “a decision to use dispersants be taken only after very careful consideration of other alternatives” (Swiss and Vanderkooy 1988, 33).

While not a dispersant test in a strict sense, such a level of caution was abandoned during a similarly motivated experimental spill two decades later. This study specifically sought to examine the intentional production of “oil-mineral aggregates” (OMA). This approach had been observed to form in shoreline studies during the late 1990s, such as after the use of sediment relocation, which physically transfers oiled sediment from a section of the beach that is not regularly exposed to wave action to an area with increased exposure, meaning that oil will be removed into the water over time (Sergy et al. 1998, 75; Owens et al. 2003, 269). Proponents of this method claimed that a “significant fraction of the dispersed oil in OMA is effectively removed from the environment as this oil is more readily biodegraded” (Lee et al. 2003, 286). However, this claim is largely based on uncertain assumptions, with Svalbard researchers having reported that “as the oil removed from the beach was dispersed rapidly over a large region, an accurate estimate of the quantity of oil–mineral aggregation *was not determined due to logistical constraints that limited our data collection efforts*” (Lee et al. 2003, 295; emphasis added). This clear limitation did not stop the scientists from asserting that “because OMA formation increases the surface/volume ratio of the spilled oil, weathering processes are facilitated, particularly biodegradation,” and arguing for a “wide-spread applicability” of the method (Lee et al. 2003, 295).

This production of OMA potential, bypassing many uncertainties, was continued with a small experimental spill in 2008 in which it was tested as an open-water response measure that could effectively replace the use of chemical dispersants with application of mineral mines (Lee et al. 2011). During this study, researchers attempted to assess the effectiveness of dumping calcite mineral fines onto an oil spill in order to drive it into the water column and prevent its stranding on shorelines: this response measure was seen as particularly attractive within ice conditions, where other responses would not be viable (Lee et al. 2011, 2). To test this approach, researchers opted to conducted three spills in the St. Lawrence River in 2008, spraying a slurry of calcite fines onto two of them to compare outcomes to the third control slick. Following the application of the slurry, scientists then used the icebreaker’s propellers to create mixing energy that would result in OMA formation (Lee et al. 2011, 3–4). Visual observations made from the icebreaker “showed remarkable differences” between the experimental and control tests, with the application of the slurry followed by the oil being “quickly dispersed by physical mixing” and the OMA “dispersed into the water column” with “insignificant” resurfacing (Lee et al. 2011, 7). However, like with dispersant tests more broadly, there was no viable means to assess the actual fate of the redistributed oil in the environment. Instead, researchers recovered samples from the experiment and examined their biodegradation in *laboratory* microcosm studies (Lee et al. 2011, 1). This work found significant biodegradation effects after two months of low-temperature incubation, including removal of more than 60 percent of total petroleum hydrocarbon (Lee et al. 2011, 1). Like with most biodegradation studies, PAHs with more than three aromatic rings were “less degraded, due to the recalcitrance of these compounds,” with nutrient addition having no stimulating effect (Lee et al. 2011, 12–13).

Regardless, this experiment was not a true field test in any true sense. While scientists conducted the initial spills in the field, their monitoring of samples occurred in closed laboratory settings. Such scientific design circumvented many of the challenges and unknowns that are present in real-world conditions, such as the impacts of potential sedimentation and burial of the OMA (Zhong et al. 2022), which would impede biodegradation due to lack of oxygen and nutrients. Further, as a previous shoreline study had indicated, closed systems often prevent nutrient losses and overstate biodegradation potential in actual spill situations (Lee and Levy 1987, 414). The unequivocal claim that "mineral fine additions promoted habitat recovery by enhancing both the rate and extent of oil biodegradation" (Lee et al. 2011, 14) was not based on field observations but was the outcome of highly particular testing conditions and conclusions, with many uncertainties once again sidelined. With the exception of the Beaufort dispersant experiment that cautioned against dispersant use due to this scientific uncertainty, most studies that tested dispersants and adjacent responses emphasized their positive rather than negative findings.

Shoreline

At least in the abstract, it would seem that shoreline and nearshore testing would reduce many of these experimental issues given the benefit of solid land enabling greater coordination of sampling and monitoring techniques. At the St. Lawrence experimental spill in 1998, for instance, personnel built an aluminum catwalk above the plots to allow for the conducting of sampling and monitoring without physically impacting the area (Lee et al. 2001, 324); a similar system was established for the coastal salt marsh study in 2000 (Garcia-Blanco et al. 2007, 3). Shoreline spill studies have involved extremely precise testing plots established and maintained in a manner much less feasible for other spill focuses such as dispersants and burning. However, this focus of scientific work often proved to be extremely difficult as well. Sampling results frequently produced significant variation, even within limited approaches.

For example, at the small-scale coastal salt marsh testing near Halifax in the mid-1980s, it was found that the soil chemistry data produced throughout the study was “highly variable, making interpretation extremely difficult,” with blame attributed to a “patchy distribution of vegetation and detritus which may intercept oil, and the variable structure of the sediments which may affect retention of oil in the sediments” (Lane et al. 1987, 1). Researchers described sediment chemistry data produced during this study in similar terms (Lane et al. 1987, 22), deeming attempts to assess algal and bacteria cover “extremely difficult” due to “large differences in light levels below and above the macrophyte canopy, resulting in increased error of estimation” (Lane et al. 1987, 54). Dispersant effectiveness also proved challenging to evaluate. One of the reasons flagged for lack of dispersant effectiveness on the shoreline study was the application method itself, with the backpack spraying approach thought to have coated the vegetation and prevented necessary mixing of dispersant with the oil. This led to researchers concluding that “it is not certain whether this means that dispersants are inherently ineffective in saltmarsh environments or that the method of application prevented the dispersant from reaching and mixing with the oil” (Lane et al. 1987, 19–20). Elsewhere, they described the data as “too variable to confirm this result definitively” (Lane et al. 1987, 55). As a result, it was recommended that further testing be conducted, possibly involving a BIOS-like premixing of the oil and dispersant (Lane et al. 1987, 19), and spraying incoming slicks as they were stranded in marshes (Lane et al. 1987, 57). Until this point, it was determined that dispersant use in such ecosystems “cannot be recommended” (Lane et al. 1987, 57).

There were significant differences encountered between testing in laboratory and field conditions, as well. In the case of the question of algal and bacterial cover, researchers reported “relatively poor correspondence” between the laboratory and experimental spill, with potential factors including insufficient sampling frequency and intensity to account for their "extreme patchiness" and "short term population fluctuations" (Lane et al. 1987, 54). Scientists also found that dispersant application to the coastal salt marsh was *less* toxic in the field than in the laboratory (Lane et al. 1987, 2). Yet this toxicity in the field varied based on vegetation zone and type of dispersant. In particular, researchers identified the midmarsh zone as being "very sensitive to both oil and dispersant," with the combination of the dispersant and oil being more toxic than the oil alone (Lane et al. 1987, 4). Such differences between laboratory and field studies was also highlighted in the small-scale 1984 study of biodegradation potential of condensate, leading to the admission that "in contrast to expectations based on the laboratory results, nutrient enrichment of the oiled sediment did not increase the number of oleophilic bacteria significantly during the first 60 days of the experiment" (Lee and Levy 1987, 414).

Another consistent factor that complicated shoreline studies was the inability to specifically track where the lost oil was actually ending up. Such scientific challenges were especially notable in the larger spill experiments at BIOS and Svalbard. During the BIOS testing of dispersant use in the nearshore, scientists calculated that about 6,800 litres remained stranded on the shoreline, two days after the untreated spill (Owens et al. 1987b, 115). A week later, they estimated that the oil volume on the shoreline had dropped by more than half, to about 3,100 litres (Owens et al. 1987b, 121). However, they also acknowledged that subsurface oil concentration "cannot be calculated accurately due to variability in the oil penetration depth," meaning that a "major portion of the oil unaccounted for could have migrated into the subsurface sediments of the Bay 11 beach" (Owens et al. 1987b, 115). Such uncertainty continued over the following years. Hydrocarbon concentrations in the sediment of Bay 9 appeared to decline significantly in the year after the discharge, but then *increased* again in 1983 (Boehm et al. 1987, 143). The source and processes of this increase remained unclear, with researchers noting that it might have been re-emergence of deposited oil, but that the movement of untreated oil from Bay 11 to Bay 9 “cannot be ruled out” (Boehm et al. 1987, 143–146).

Despite much of the oil becoming more persistent over time, especially due to the “well stabilized formation” of “asphalt pavement” (Sergy 1985, 571; Sergy 1986, 14), long-term monitoring of shoreline contamination continued to prove complicated. After eight years, surface oil in the intertidal zone had decreased to 13 percent of the original volume, with the remaining oil ranging from “relatively fresh to a highly weathered form” (Humphrey et al. 1992, v). However, the process of evaluating oil concentrations were challenging, as merely observing the length of an oiled plot—which became “the easiest to determine”—did not reveal the volume of oil (Humphrey et al. 1992, 35). Researchers also questioned the sampling of Bay 11 sites due to the locations being in “different oiled-beach features in different years” (Humphrey et al. 1992, 35). They estimated that accurately sampling the highly diverse shoreline would require about 8,000 samples collected per year, deeming it “clearly excessive for the value of the information generated” (Humphrey et al. 1992, 35). Researchers encountered related issues during 1983 sampling of the control plots in the backshore experiment, in which a small number of samples introduced sampling bias that effectively disqualified its results (Humphrey et al. 1992, 17). By 1989, scientists concluded that natural processes had removed between 90 to 95 percent of the surface oil (Humphrey et al. 1992, 38). However, subsurface oil behaviour remained “still not well understood,” with only “minimal” monitoring conducted as part of BIOS given that the “extent and degree of oiling could not be estimated by visual or practical means” (Humphrey et al. 1992, 38–39). Given this ongoing lack of information, they feared that extremely slow subsurface oil removal would lead to a “longer-term concern and source of continued contamination" (Humphrey et al. 1992, 39). Major warnings were issued about the ability for researchers to generalize oil concentration calculations to an entire shoreline; in conditions of coarse or mixed sediment—in contrast to fine sediment, which is more resistant to oil penetration—it was deemed that "no acceptable level of sampling could provide adequate statistical confidence" (Humphrey et al. 1992, 39). In an experiment designed to produce findings that industry and states could extrapolate to many shoreline and nearshore regions of the Arctic, even producing reliable sampling between plots of the same study proved impossible.

Smaller experimental spills reiterated these long-term complications of shoreline studies. Researchers conducted field studies in the years following the coastal saltmarsh spill near Halifax in 1986. However, a 1993 review of long-term effects determined that sampling efforts had been highly inconsistent, with samples only taken once in 1988 and 1990, with no samples at all taken in 1988 of plots that had received both oil and dispersant (MacKinnon and Lane 1993, 5). In general, the data produced in 1988 came from sampling conducted by "inexperienced personnel and may have been overestimated," with the 1993 review concluding that personnel had introduced "procedural bias" into several aspects of the study (MacKinnon and Lane 1993, 5, 14). Due to this inconsistent sampling, scientists concluded it was not possible to determine whether sampling issues caused particular outcomes, or whether they resulted from an "unexpected interaction between the experiment and natural saltmarsh dynamics" (MacKinnon and Lane 1993, 10, 14). Further, observations made during the 1990 visit found that processes including "ice-scour, deposition of sod and tidally-transported algal mats, and erosion" was impeding vegetation regrowth (MacKinnon and Lane 1993, 16). Although efforts had been made to minimize trampling of the experimental plots during sampling, it was found that "damage to peripheral vegetation was sometimes sufficient to expose the entire plot to further erosion, ice scour, and pooling," and that trampling damage was "difficult to correct for in sampling because nearly all mid-marsh plots showed signs of it, and it was frequently so extensive as to affect the entire plot" (MacKinnon and Lane 1993, 16).

At a smaller scale, the Svalbard trials reiterated these unknowns, despite the stated priority of "designing for statistically defensible data" (Sergy et al. 1998, 88). Many confident statements were issued in reports about the experiment, which itself was fundamentally shaped by the siting, timing, and oiling of the study discussed in previous chapters. For instance, it was concluded that there was "negligible alongshore oiling of the adjacent clean intertidal beach" after sediment relocation was conducted (Owens et al. 2003, 269), and that the process did not lead to "significant hydrocarbon accumulation" or "unacceptable toxicity levels" in the nearshore benthic sediment or suspended particulate matter (Owens et al. 2003, 269). The testing was framed as helping to again demonstrate "the scientific and operational value of experimental oil spills, particularly as a proving ground for concepts tested in more controlled bench-scale or meso-scale conditions" (Sergy et al. 1998, 88). However, a recent return of Norwegian researchers to one of the oiled but untreated spill plots identified some sampling issues, reporting that there was inadequate description of sampling processes for site visits between the years 1999 and 2008 (Faxness et al. 2012, 7). While the 2011 visit collected 45 samples from the plot, along with six reference samples, prior studies had only collected between three and five samples (Faxness et al. 2012, 7). Researchers added about the plot that there had been no investigation into the effects of oil on organisms in the sediment (Faxness et al. 2012, 14). Although this study only focused on an untreated—and therefore particularly long-lasting—oiled plot, such reflections on sampling process hint at differences in sampling approaches and potential for certainty. A recent reflection on the BIOS and Svalbard trials further highlighted this dimension of scientific unknowns, both demonstrating a "50% or greater reduction in stranded oil volume in the first week or so" but scientists not able to clarify "where the oil went" (Owens et al. 2024, 11). Spill scientists speculated that "most likely much was lost as very thin sheens observed during the tidal water level changes and were readily consumed by microbes in days" or "as dispersed droplets incorporating mineral fines" (Owens et al. 2024, 11). However, this notion was not based on any empirical evidence but rather what researchers saw as possible and even preferable. Like with other response measures, scientists could not accurately monitor the long-term fate and effects of this oil leached from the shoreline into the water, with many hard-to-detect impacts ignored altogether.

Although much smaller and more controlled in nature, the St. Lawrence shoreline spill of the late 1990s that focused on bioremediation techniques also experienced many scientific uncertainties. One report described that its experimental interventions were "effective in stimulating oil biodegradation rates above that of natural attenuation" (Lee et al. 2001, 325). Yet another summary report wrote that the application of nutrients "did not enhance the disappearance of alkanes or PAHs" (Venosa et al. 2002, 261), with alkane degraders found to have "increased only marginally in all treatments" (Venosa et al. 2002, 275). There were clear differences in interpretation even between parallel reports. The local toxicity of oil was also a confounding issue. Scientists reported that while the presence of oil caused "immediate toxic effects," a specific nutrient formulation returned oil toxicity on water fleas to "background levels" after only a week, with "evidence of natural recovery … observed within the experimental period" (Lee et al. 2001, 326). Yet toxicity tests on an amphipod crustacean indicated significantly higher mortality rates both at the time of spill and in the many weeks that followed, a difference that was thought to be related to the type of testing conducted (Lee et al.

2001, 326). Further, there were sharp increases in toxicity levels after 12 and 21 weeks following the spill, with a "seasonal change in species sensitivity" thought to explain it in part (Lee et al. 2001, 326–27).

Two decades later, a return to the site concluded that PAHs were below detection limit, but concentrations of "mid-chain length n-alkanes" between 10- and 36-carbon compounds remained "significantly above detect limit" (Schreiber et al. 2023, 1). Researchers speculated that most of the removal of PAHs would have occurred by tidal washing (Schreiber et al. 2023, 5); however, there was no way of assessing the eventual fate of these compounds in the river, meaning the toxicity was merely redistributed, with the unverifiable hope of eventual biodegradation. Further, they pointed to the aforementioned issue of background oil pollution as accounting for the continued presence of medium-weight n-alkanes, but could not confidently draw conclusions due to lack of comparable data (Schreiber et al. 2023, 8).

Along with this inability to directly compare background oil levels due to lack of reporting during the initial study, several significant limitations hampered the revisit, discussion of which was preceded by "unfortunately" in both explanations (Schreiber et al. 2023, 5). Firstly, the new sampling took place in the fall, which was too late to observe the vegetation's growth, meaning that researchers were "unable to directly observe if the previous addition of nutrients still had an effect on vegetation growth at the site" (Schreiber et al. 2023, 5). Secondly, the specific PAHs that researchers examined in the revisit were different than the set examined during the initial experimental work, rendering it "difficult to compare this data across time points" (Schreiber et al. 2023, 5). Despite these uncertainties, researchers declared that "our study indicates that the previously oil-affected parts of the wetland have returned to their natural state and thereby establishes the upper limit of the recovery time for this site" and that "even the tested 'no treatment' (natural attenuation) approach can be sufficient for the recovery of tidal freshwater wetlands over a period of 21 years" (Schreiber et al. 2023, 9). The many unknowns, notably the eventual fate and effects of redistributed oil, were sidelined in favour of asserting confidence about the potential of "natural attenuation."

Even when scientists deemed biodegradation to be successful, such as in the saltmarsh experimental spill in 2000, the ability to assess and produce viable conditions continued to be a challenge. During that study, while background nutrient supply appeared suitable for such processes to take place, researchers cautioned that such conditions were not necessarily permanent and required additional nutrients through natural processes or artificial means (Garcia-Blanco et al. 2007, 13). Crucially, however, it was stressed that sufficient nutrient supply could "not have been predicted a priori by simply measuring nutrient levels," which would require that an "extensive nutrient dynamics study … be conducted for the environment of interest" (Garcia-Blanco et al. 2007, 13). At the same time, researchers found that the study's activities had major long-term detrimental effects on the local vegetation, as well as the physical removal of the oil. Scientists wrote that: "Even one year after the end of the study, the marsh at Conrod's beach had not recovered its original appearance in areas where trampling and sampling had occurred" (Garcia-Blanco et al. 2007, 5). Despite scientists having significantly reduced the scale and intensity of shoreline spills in the last years of the 20th century, research continued to experience complications due to the tremendous variation of oil's movement and effects within ecosystems, along with the impacts of scientific study itself on the materialities that scientists were observing.

Throughout all of this experimental work—whether focused on burning, dispersants, ice, or shorelines—the underlying goal was to produce "realistic" testing conditions. Even when small spills occurred in southern sites, planners designed them with an eye to the frontiers, working to simulate and provide scientific stepping stones to offshore settings. However, even in initial planning stages, there were constant tensions encountered between the need for control with this desire for realism, most notable during efforts to locate suitable control plots and eventual concessions to parameters of "pseudoreplication." Each specific study focus encountered distinct sets of sampling problems. Attempts to track the spread and composition of the smoke plume from in-situ burning was complicated by dynamics such as "self-lofting" from solar heating of the soot, along with potential contamination from ship exhaust; in the opposite spatial direction, dispersant effectiveness and impacts proved consistently difficult to evaluate, with a wide array of factors—differences in slick thicknesses, sampling bias, extreme differences in outcomes based on testing approach—impeding clear results.

During oil-in-ice studies, regular issues were experienced due to challenges of visibility and sampling procedures—including inability to even locate the oiled plots, and later questioning of whether a major study was even conducted in the type of ice initially assumed—while shoreline and nearshore experiments produced highly variable testing outcomes, including significant differences with similar laboratory studies. Even though there were significant differences between the study types and specific difficulties, many featured similar attempts to sideline and resolve scientific unknowns, with the Beaufort Sea dispersant testing constituting the one notable exception. In particular, lack of clear knowledge about the eventual fate of oil and its many byproducts was routinely speculated to have been resolved through processes like dilution and biodegradation. I highlighted such tendencies in the most recent study examined in this chapter, the small experimental spill and OMA formation in 2008, in which scientists extrapolated closed laboratory results into field conditions to claim highly effective biodegradation processes, despite many real-world uncertainties.

This outline of key scientific unknowns highlights the fundamentally produced character of spill science. As argued throughout this dissertation, such a claim does not in any way seek to disqualify or undermine the scientific processes themselves. Rather, it works to anchor them in material practices and processes that invariably shape the outcomes of the study and suggests that we must exercise caution when attempting to shift and extrapolate this work to other sites and contexts. Failing to attend to the inherent quality of "partial perspective" present in all knowledge production work—instead attempting to assert a universality that can be largely shorn of place, time, and many other contingent conditions—has contributed to a major overestimation of spill response capacities in real-world catastrophes, as exemplified by the *Nathan E. Stewart* disaster and many others like it.

Conclusion: Re-politicizing Spill Risk

This dissertation has argued that historical experimental spill work has contributed to a naturalization of spill risk by dramatically overstating the ability for responders to successfully address spills, as exemplified in the case of the Bella Bella spill of 2016 and other failed responses. However, in contrast to some critical spill analyses that offers a more conspiratorial reading of intentionally manufactured busywork and image management, this approach has specifically focused on the complex and contingent production of scientific knowledge in relation to various experimental requirements and broader sociopolitical expectations.

Specifically, this study has examined experimental spill work from five distinct but related vantage points. Three of them involved the intensive and careful work of siting, timing, and oiling spill experiments. In each of these approaches, researchers actively materialized the requirements for successful scientific experimentation, ranging from ensuring proximity of studies to necessary response tools, to spilling oil when winds and tides guaranteed its limited spread, to adjusting spill volumes to maintain necessary containment. Individually, but especially in combination, these multiple factors tended to produce near-ideal conditions for spill study and response, significantly exaggerating the potential for responders to produce such control during most real-world spill events.

At the same time, this process involved the ignoring, downplaying, and management of new natures and scientific unknowns. While the findings about newly formed residues hinted at the potential for large-scale complications and noxious byproducts in the wake of a spill—such as algae melt ponds and emulsion balls—the continual scientific uncertainties and unknowns impeded the creation of scientific confidence. Without being able to accurately track the eventual fate and effects of soot, dispersed oil, and oil in or under ice, this scientific work often became a "fierce fight to construct reality" (Latour and Woolgar 1986, 243), such as the conclusion from

BIOS that there was “no major ecological reasons to prohibit the use of chemical dispersants on oil slicks in nearshore areas typified by the experimental site” (Sergy 1986, 1).

In combination, these constructions and assertions contributed to a continued confidence in spill knowledge and response that real-world spills routinely contravene. Theoretically, we can best understand this research as materializing “future eco-perfect” conditions that project and extrapolate scientific confidence about the possibility of effective spill response well beyond the tightly controlled conditions of the scientific knowledge production. Despite the fact that many of the spill experiments taking place many decades ago, their scientific uniqueness has continued to permeate contemporary understandings of spill science and response.

These spill experiments were the materializations of multiple contingent factors including specific state projects and regional accumulation strategies in the face of growing awareness and opposition to socioecological degradation, the complexities and requirements of scientific fieldwork in remote and challenging conditions, and the centrality of formalizing findings through the environmental assessment process. Given that these factors have shifted but not radically changed in the decades since the use of experimental spills were used as a primary scientific tool in Canada, a seemingly obvious resolution to the issues raised in this dissertation could be to simply conduct more scientific work in a way that is more sensitive to the extremely variable and uncertain conditions of real-world spills, including through the partial return of the technique at sites such as ELA and the Churchill Marine Observatory, along with vastly improved technological approaches such as computer modelling integrating real-time data.

Considerable research has been dedicated in recent years to a variety of spill response measures such as decanting, sediment relocation, emulsion breakers, and chemical herders, in particular through the Multi-Partner Research Initiative (MPRI) announced in 2016 as part of the federal government's Oceans Protection Plan that has distributed tens of millions of dollars to fund spill research at universities including Concordia University, Memorial University of Newfoundland, McGill University, and the University of Manitoba (DFO 2022). Yet as the history of experimental spill work has indicated, there is a serious possibility that such findings can have their uncertainties and complexities shorn from them to generate conclusions intended for far greater extrapolation than justified.

Like with other aspects of the oil industry—small investments in renewable energy, the rhetorical pivot to "net-zero" that still permits massive greenhouse gas emissions (Hanieh 2024)—the work of oil spill science may be seen as a form of industry and state greenwashing of a sector that simply cannot be addressed through technological fixes. Put differently, by bolstering the scientific credibility of spill response despite many unknowns and issues, spill scientists help to *produce the conditions of heightened spill risk* through their work. Further, given the continued political economic context in which this spill research occurs—routinely acknowledged as a seemingly inevitable increase in spill risk due to expanded transportation of Canadian oil through pipeline, tankers, and rail—there also remains significant questions about the active contribution that such scientific work plays to *legitimating* and *facilitating* such expansion, regardless of the individual interests or motivations of researchers.

Spill scientists consistently acknowledge a bias towards the supposedly inevitable prospect of increasing oil production and transportation in reports and reflections. For instance, an analysis of the potential for microbial degradation of oil in the Northwest Passage grounded its work in the likelihood of increased spills in the Arctic due to more marine shipping taking advantage of receding ice (Ellis et al. 2022). Describing the importance of research into microbial degradation on the West Coast, another study argued this in even starker and more mechanical terms:

> Western Canada hosts large petroleum deposits, which ultimately enter the market in the form of dilbit. Tanker-based shipping represents the primary means to transport dilbit to international markets. With anticipated increases in production to meet global energy needs, the risk of a dilbit spill is expected to increase. (Schreiber 2019, 1)

The 2015 Royal Society of Canada Expert Panel into aquatic oil spills, commissioned by the Canadian Energy Pipeline Association (CEPA) and Canadian Association of Petroleum Producers (CAPP) as part of the National Energy Board's recommendations tied to its approval of the Northern Gateway pipeline, similarly naturalized oil consumption. The opening sentences of the report noted that "Canadians are among the highest per capita consumers of oil in the world" and that "Canada is also one of the world's only developed economies that produces more oil than it demands for domestic consumption," meaning that "to meet both domestic and international demand, the oil must be moved by pipeline, rail, tanker trucks or ship from where it is recovered to where it will be refined and ultimately used" (Lee et al. 2015, 4). In a 2020 presentation, spill scientist and Royal Society panel chair Kenneth Lee directly rebuffed claims that renewable energy could replace oil consumption and resulting spill risk: "What they don't realize is to meet the world's energy demands, we'll be using oil for a long time yet. If we look at the International Energy Agency, they calculate that by the year 2040 we'll still be using oil to meet 27 percent of our energy demand that we need for the world" (7:30–7:55).

Left unnoted in such commentary, however, is that climate policy experts have long criticized the International Energy Agency (IEA) for its conservative outlook on continued fossil fuel production while downplaying the role of renewable energy. Oil-importing and -consuming countries formed the IEA in 1974 "to counteract the new power of OPEC" (Fossum 1997, 30).

While its focus has expanded since that period, its "core function remains as an oil-importers' club that faces OPEC across the oil market," including through the organizing of emergency petroleum reserves that can be shared between members and "advocacy of governance structures for oil that rely on market allocation and which promote investment in new supply" (Bridge and Le Billon 2017, 85; Gardner and Browning 2022). The IEA has also downplayed greenhouse gas emissions from unconventional oil sources such as the Canadian oilsands within the global context, with its chief economist—and now executive director—stating in 2014 that "the additional CO2 emissions coming from the oil sands is extremely low" (Hussain 2014).

Analysis of a public controversy about the IEA's influential *World Energy Outlook* annual report indicated that its forecasting has been "strongly influenced by what the IEA member states want out of an autonomous, global perspective on the future for energy and what they will countenance" (Gaede and Meadowcroft 2016, 619), with IEA researchers telling researchers that "it was simply not realistic to expect the report to take a stance or position far beyond the pale of the informal political boundaries the Agency operated within" (Gaede and Meadowcroft 2016, 622). Other researchers have expressed significant concern about the IEA's underestimation of renewable energy sources and related assumption of continued oil production increases. A report by Oil Change International and the Institute for Energy Economics and Financial Analysis argued that IEA projections represent a "map that leads to climate disaster" (Muttitt et al. 2018, 7). Another analysis described the IEA's projections of solar power growth by 2040 as "conservative," which is "indeed likely to hamper the renewable energy transition" as governments, investors, and power companies become less likely to fund and support solar deployment due to apparent infeasibility (Carrington and Stephenson, 2018, 110; see also Eckhouse 2025).

Likewise, we can understand Lee's invoking of IEA projections in his remarks about the supposed realities of oil production and transportation, along with the need for "alternative response measures" such as dispersants, as inherently political in nature, naturalizing and reproducing particular societal trajectories while marginalizing other potentialities. Although his approach—and similar rationales for spill studies, such as the inevitability of increased exports of dilbit or marine shipping in the Arctic—are likely defended on the basis of being "realistic," they function to provide additional scientific legitimacy to contested futures that warrant far greater critical assessment. For this type of analysis, we can look back to a report that was published more than three decades ago in the wake of the wake of the *Nestucca* and *Exxon Valdez* disasters.

Reducing Oil Production and Consumption

In late 1989, David Anderson, who the BC premier had appointed as special advisor on oil transportation and spills, released a report based on a half-year of community hearings throughout BC's coastal communities, along with written submissions, such as the journal entries that Nicole Gervais submitted about living through the *Nestucca* spill that I recounted in Chapter 2. In total, Anderson made 184 recommendations to improve tanker spill prevention, response, and compensation, a number even more notable given that the focus of the report was exclusively on tanker traffic and did not include comment on the potential of offshore drilling due to the ongoing regional moratorium prohibiting such activities.

A similar exclusion was made of public contributions about reducing spill risk through the lowering of oil *consumption* was also explained by Anderson (1989b) as necessary due to such specifics going beyond his mandate: "The efficiency of wind and wave powered generators of electricity, or the importance of public transit to the overall reduction of the use of oil for transportation in large cities such as Vancouver, are questions that as a consequence will not be addressed at any length in this report" (1). However, unlike the only "hypothetical" issue of West Coast offshore drilling given the moratorium (Anderson 1989b, 2), the issue of oil consumption ended up centrally positioned in the report's summary and initial set of recommendations. Anderson (1989b) wrote that:

> The first, and most fundamental way to prevent tanker accidents is to reduce consumption of products derived from crude oil. This will reduce the traffic of refined products to the coastal communities, and also demonstrate the seriousness of our concern to other parts of the continent which, unlike British Columbia, are dependent on crude oil delivered by tanker. (4)

Remarkably, given that the issue of anthropogenic global warming had only been widely popularized with James Hansen's congressional testimony the year prior, Anderson (1989b) reported that many members of the public had explicitly linked the crisis of oil spills with climate change. He wrote that: "Some pointed out that reducing consumption of oil and developing alternative energy sources would have another desirable effect on the environment, namely the reduction of CO2 emissions into the atmosphere …. the two objectives frequently became linked--indeed, inseparable--in the minds of many speakers" (Anderson 1989b, 13). Due to the "desire of so many participants to let the government know that they considered harmful emissions into the atmosphere and oil pollution emissions into the marine environment as the two compelling reasons for concerted measures to alter oil consumption patterns," Anderson (1989b) frontloaded this issue in the report and provided several recommendations directly related to it, including restoring funding for conservation measures and alternative energy sources, investing in measures to stabilize or reduce oil consumption, and increasing taxes and pricing policies on oil (13–15). About the latter, Anderson (1989b) summarized: "Price and cost are not synonymous terms. The true cost of oil had to include as well the environmental costs to society as a whole of the production, transportation and use of that oil" (14).

While brief in the context of the entire report, this approach to the question of oil spills and the related crisis of climate change remains a surprisingly rare one. Conversely, most contemporary spill preparation is explicitly oriented around *ever-increasing* global oil production, transportation, and consumption, with the issue to be primarily addressed through greater scientific and technical advances such more response bases, better compensation schemes, and improved regulations such as Canadian requirements of oil tankers being doubled hulled, annually inspected, using updated navigational and communications equipment, and mandating pilotage and tug escorts in busy ports (Transport Canada 2023). Although Canada has partially banned the use of heavy fuel oil (HFO) by ships in the Arctic, the ban includes criticized loopholes for sealift and double-hulled vessels, while implicitly understating the risk of any kind of oil spill in the region (Transport Canada 2024; Blake 2024). The base assumption of spill response is that oil will continue to be ubiquitous in Canada for decades to come.

This argument does not imply that some degree of oil spill science and response will not continue to be necessary, particularly in regions where simple alternatives for basic needs do not exist, like sealift and re-supply services in the Canadian Arctic. There remain significant deficiencies in Arctic spill response that states can and should rectify through dedicated funding and resources (WWF Canada 2017; Wilde and Johnson, 2024), along with improving compensation processes for Indigenous communities who suffer "non-economic losses" from a spill when one occurs (DeCola 2020; Wood 2024). Marine shipping and aviation are especially difficult to electrify due to "technical and cost limitations" (IEA 2024, 108), relying on a yet-to-be-scaled combination of alternative fuels, energy efficiency measures, and technological advances (Transport Canada 2022; IEA 2025; Anantharaman et al 2025). Any transition plan will inevitably take time, no matter how ambitious, with some oil remaining part of passenger and freight transportation systems for some years yet.

However, the sociopolitical context in which spill research and preparation takes place is not merely to better respond to existing risks of spills—such as the possibility of a sealift vessel or diesel storage tank spilling in a remote Arctic community—but to anticipate increased risks of spill due to expanding oil production, transportation, and consumption. Improvement in research and preparation may indirectly benefit certain regions, such as the south British Columbia coastline due to investments ahead of the completion of the Trans Mountain Expansion Project; however, these are incidental benefits and do not extend to much of the country's waters. As argued throughout this dissertation, we must also keep in mind the major limits of spill response capacities, no matter how prepared responders are, particularly in less-than-perfect conditions. Anderson's (1989b) report reminds us that more and better spill science and response preparation are far from the *only* means to address the issue. It remains necessary to meaningfully reduce the *total production and consumption of oil products*: the only way to guarantee reductions in spills and improve Canada's chances of meeting international climate commitments. This goal is particularly necessary in Canada, where an estimated 85 percent of oilsands reserves have been calculated as unburnable for the world to remain below 2°C of warming above pre-industrial levels (McGlade and Ekins 2015, 190); the supposed technofix of carbon capture and storage (CCS) remains extremely expensive, energy-intensive, and difficult to scale, leading policy analysts to recommend against reliance on it (Cameron and Carter 2023; Hanieh 2024, 280–283).

Canada now produces about five million barrels of oil a day, two-thirds of which now comes from the Alberta oilsands (Statistics Canada 2024). Roughly 80 percent of the oil produced in Canada is exported, largely to the US (CER 2024a); however, Canada also imports significant volumes of crude and refined petroleum products (CER 2024b; CER 2024c). In total, Canada consumes an estimated 2.4 million barrels of oil per day (Energy Institute 2023, 25), just under half of the total oil the country produces. And while such consumption does not end up in Canada's greenhouse gases emissions inventory, all of the oil exported to the US or Asia is eventually consumed as well, representing between 70 and 80 percent of the oil's lifecycle emissions (Bernstien 2024).

The most effective and efficient way to reduce oil production is through the implementation of restrictive supply-side policies including taxes, production quotas, and bans/moratoriums (Green and Denniss 2018, p. 75). States would also need to significantly reduce oil exports, such as those taking place via the Trans Mountain Expansion Project, to ensure that any domestic reductions are not merely neutralized by increased exports (Hughes 2016; Nuccitelli 2024). States must also end the use of fossil fuel subsidies, such as the $18.5 billion in federal supports spent in 2023 (Levin 2024), and reallocate such enormous resources to a genuinely low-carbon transition. At the same time, however, the issue of oil *consumption* needs to be at the forefront our analysis, given that oil is produced to be consumed. As Emilie Cameron (2012) has argued, the climate and environmental issues of the Canadian Arctic and other so-called frontier regions resulting from industrial production and transportation are inextricably tied to and shaped by pressures generated in the south (112).

More generally, while best known for his identification of the true origin of profit in the surplus-value generated and captured through "socially necessary labour-time" in commodity production (including both products and services), Karl Marx (1971) was equally as concerned with consumption itself. In *Grundrisse*, Marx stressed that production, distribution, exchange, and consumption are not identical but “that they are all members of one entity, different aspects of one unit” (33). While production “predominates” over and ultimately “determines” all other elements in the totality, it is constantly shaped and influenced by changes in the processes of distribution, exchange, and consumption; about this, Marx (1971) wrote: “A mutual interaction takes place between the various elements. Such is the case with every organic body” (33).

This assessment is as true of oil as of any commodity. Consumption through transportation, petrochemical, and other industrial or commercial activities—is oil being used as *produced and intended*: it is oil that has not been lost to spills or other waste, but had its surplus-value realized through exchange and consumed as a refined fuel or raw material, providing “useful energy” and “energy services” to its users (Pirani 2018, 26). The crisis presented by oil spills is that the commodity has *not* reached its destination and been fully consumed through industrial processes of driving, flying, manufacturing, and more, with the issue one of ensuring that oil ultimately remains in its rightful position through its often long and complex journey from reservoir to fuel tank or petrochemical product. Any restrictive supply-side policies will necessarily require corresponding transformations in demand-side usage.

Today, oil consumption largely occurs through the transportation sector, particularly gasoline-powered passenger vehicles, diesel-powered freight carriers including trucks and trains, and jet fuel-powered airplanes. In Canada, transportation accounts for about 60 percent of total oil consumption (CER 2018) and two-thirds in the United States (EIA 2022). Despite claims of a rapid transition away from fossil fuels, oil still accounts for 90 percent of still-growing transportation energy consumption in Canada (IEA 2022, 26), with registrations of “zero-emissions vehicles”—which include both battery electric and plug-in hybrids—still only representing one-sixth of the total (Bonasia 2025). In total, zero-emissions vehicles still only account for one to two percent of Canada's vehicle stock, and are not expected to reach 90 percent market saturation until 2050 (CER 2024d). There are also additional non-emissions concerns with EV proliferation, including their resource-intensity of so-called "critical minerals" and the reproduction of well-documented harms of automobility such as urban congestion, mobility injustices, and traffic fatalities and injuries (Wilt 2020).

The other major consumer of oil is the industrial sector, mostly through its use as a feedstock by the petrochemical sector to produce plastics, synthetics, solvents, and countless other commodities used in households and production (EIA 2022; Government of Canada 2011). Along with increased exports of oil if and when domestic transportation consumption starts to decline (IEA 2022, 226), petrochemicals are expected to become one of the major focuses of the oil industry; Adam Hanieh (2021) has argued petrochemicals "will almost certainly form one of the fastest-growing sources of demand for oil over the next two decades, and there exists no viable alternative to petroleum as a material feedstock—the basic raw material—for synthetic production" (28). Much of the small remainder of oil consumption in Canada is used in resource and primary industries—oil and gas extraction, agriculture, forestry, and fishing—and commercial or public services, with miniscule demand in residential, electricity, and heat generation rounding out the total (IEA 2022, 237).

Industry groups and think tanks tend to highlight interventions like fuel efficiency standards and subsidies for personal electric vehicles (Gross 2023), along with the dubious prospects of hydrogen-based fuels (*Nature* 2022; Odenweller et al. 2022; Hanieh 2024, 293–297). However, it may require many years, if not decades, for these market-driven measures to replace a large majority of the existing oil-consuming fleet, and such efforts could be further undermined through trends such as the ongoing growth of larger passenger vehicles like SUVs and light trucks (Axsen and Bhardwaj 2024). Rather than relying on commodified solutions that are far from guaranteed, the most efficient and just approach involves the rapid improvement of public infrastructures such as urban and intercity public transportation (Wilt 2020; Riofrancos et al. 2023) and rail for both passenger and freight transportation (Torres and Mandel 2023; McDonald 2024), along with increasing high-density housing (Arceo et al. 2025). Urban freight emissions could also be meaningfully curbed through implementation of plans such as the Canadian Union of Postal Workers' "Delivering Community Power" proposal, which would accelerate the electrification of delivery vehicles and expand the use of Canada Post as a "consolidated last mile delivery" to reduce congestion and emissions (CUPW n.d.).

Generally, fuel consumption is greater at faster speeds of transportation, with reducing speeds identified as a key means of reducing costs and emissions in both the marine shipping and air travel sectors (Degiuli et al. 2021; Powell 2024; Miller et al. 2024; Brueckner et al. 2024). Such benefits would require introduction of globally coordinated measures to slow down the transportation and turnover time of commodities, such as the massive quantities of coal, grain, iron ore, oil, and containerized goods carried by maritime vessels (UNCTAD 2024, 25), along with greater integration of wind propulsion in shipping (De Beukelaer 2023; Stafford 2024; Collender 2025). Further, states could place significant limits on sectors that cannot have oil usage easily replaced, such as frequent air travel (Kommenda 2019; Stay Grounded n.d.) and plastics production (Velis 2024; Woodside 2024). The global food system is another major but often less noticed source of oil consumption—from farm machinery to truck and air transportation, to plastic packaging—in need of much greater regulation (GAFF 2023).

Such policy approaches may appear radical and unlikely to take hold given present political conditions. Yet the IEA (2022) appealed in part to several of these measures during its initial response to the Russian invasion of Ukraine in 2022, outlining actions that countries could take to reduce oil consumption given that "demand restraint … is one of the emergency response measures that all IEA member countries are required to have ready as a contingency at all times." These measures included reducing speed limits on highways, allowing for greater work-from-home to avoid unnecessary commutes, restricting car usage on certain days, encouraging car-sharing, promoting public transit and active transportation, replacing air travel with trains, and maximizing the efficiency of freight trips (IEA 2022). Collectively, the IEA (2022) reported that such measures would cut oil consumption by 2.7 million barrels per day over four months in member countries; while still relatively small in the global context, these reductions were framed as only the starting point of a broader transition to a low-emissions world. The rapid expansion of high-speed rail and electric vehicle usage in China also demonstrates the sizable reductions in oil consumption that are possible with strong state intervention (Lin et al. 2021; Healy et al. 2025).

This kind of trajectory could quickly erode the use of oil in society and significantly reduce the chances of oil spills from pipelines, tankers, offshore rigs, refineries, storage tanks, refineries, and marine vessels. However, regardless of design and implementation, many of these changes necessarily implicate the dominant "mode of living" in Canada and much of the advanced capitalist world, including heavy reliance on private and ever-larger automobiles, consumer electronics and appliances, and many other resource-intensive goods and services (Brand and Wissen 2021). These daily practices are deeply engrained and reproduced within social formations (Huber 2013), and often co-constituted through oppressions such as racism and misogyny (Bagget 2018; Nelson 2020; Leedham 2022). As advocated for within the diverse scholarship of "degrowth" (Ajl 2021; Hickel 2021; Schmelzer et al. 2022), these complex social realities require critical analysis of the centrality of oil to many contemporary wants, needs, and desires, including in rapidly industrializing countries like China. Some aspects of our current mode of living may be seamlessly electrified or replaced with alternatives; however, many others may not be: at least, not in a way that is globally just and strives to ensure "decent living standards" for everyone (Hickel and Sullivan 2024). It is difficult to imagine how the North American template of single-family homes, enormous SUVs and trucks, frequent air travel, and the rapid delivery of goods from all over the world can be maintained, let alone expanded, in a climate-constrained world. As Kai Bosworth (2024) has argued, "there is no readymade path to addressing the climate crisis without also *composing new subjectivities*" (513; emphasis in original; see also Hansen 2021).

Such policy approaches are clearly of vastly different focus and orientation than that of historical experimental spills and contemporary spill research. These transformations would not necessarily negate the need for dedicated spill science, either. However, in contrast to the tendency identified by Tania Li (2007) in which "questions that are rendered technical are simultaneously rendered nonpolitical" (7), such scientific work should better position its activities as operating within a particular political-economic trajectory that is not inevitable but socially determined. As Smith (2008) stressed, all human labour and work is inherently a production of nature: the question is "*how* we produce nature and *who* controls this production of nature" (89; emphasis in original). As a result, the objective of genuinely responsible scientific work should be to bolster the rapid production of a genuinely low-carbon transition, rather than risk prolonging or delaying such a transition.

Further, while acknowledging and even celebrating the tremendous potential for knowledge production possible through scientific inquiry (Rose and Rose 1976; César 2018;

Yaffe 2020; Saraiva 2022; Dávila 2024), we must also note the limits and “partial perspective” of such methods, especially against efforts to extrapolate findings beyond the particular experimental conditions in which they were produced (Haraway 1988, 583). Uncertainties and complexities need to be far more carefully handled and communicated to achieve a greater level of collective appreciation for the challenges at hand, with graduated scales developed by Weiss (2003) and the IPCC (Lewis and Gallant 2013) serving as useful templates to ground future research. Along with critical reflection on the effects and limits of experimental design on outcomes, there is also a need to ensure that scientific work is not contributing to an extended lifespan of the oil industry, which is a major contributor to the climate crisis. The socioecological threats of oil pollution and climate change are simply too dire to take any chances on, and require even greater care given these extremely high stakes.

Bibliography

Abbotsford News. 1979a. "Conair Continuing Oil Slick Battle." July 18, 1.

Abbotsford News. 1979b. "Dispersant Tested in Low-Level Flight Over the 'High Seas' Of Sumas Prairie." March 21, 43.

Abbotsford News. 1979c. "Oil Spill War Continues." August 29, 2.

Acreman, J., G. Borstad, and B. Humphrey. 1980. *Dome Petroleum Experimental Oil Spill at McKinley Bay, N.W.T.: Examination of Ice Biota*. Arctic Laboratories Ltd.

Adams, W. A. 1975. *Light Intensity and Primary Productivity Under Sea Ice Containing Oil.* Beaufort Sea Technical Report No. 29. Victoria: Beaufort Sea Project.

Aeppli, Christoph. 2022. "Recent Advance in Understanding Photooxidation of Hydrocarbons after Oil Spills." Current Opinion in Chemical Engineering 36: 1–8. https://doi.org/10.1016/j.coche.2021.100763.

Ages, A. 1975. *The Beaufort Sea Project*. Institute of Ocean Sciences, Patricia Bay. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/53494.pdf.

Ajl, Max. 2021. *A People's Green New Deal*. Pluto Press.

Aksamit, Claire K., Jill A. Blakley, Jochen A. G. Jaeger, Bram F. Noble, and Clinton N. Westman. 2020. "Sources of Uncertainties in Environmental Assessment: Lessons about Uncertainty Disclosure and Communication from an Oil Sands Extraction Project in Northern Alberta." *Journal of Environmental Planning and Management* 63 (2): 317–34. https://doi.org/10.1080/09640568.2019.1579973.

Altvater, Elmar. 2021. "Ecological and Economic Modalities of Time and Space." In *Routledge Handbook on Ecosocialism*, edited by Leigh Brownhill, Salvatore Engel-Di Mauro, Terran Giacomini, Ana Isla, Michael Löwy, and Terisa E. Turner, 101–108. Routledge.

AMOP (Arctic Marine Oilspill Program). 1979. *Experimental Oilspills General Plan*. Environment Canada.

Anantharaman, Mohan, Abdullah Sardar, and Rabiul Islam. 2025. "Decarbonization of Shipping and Progressing Towards Reducing Greenhouse Gas Emissions to Net Zero: A Bibliometric Analysis." *Sustainability* 17 (7): 2936. https://doi.org/10.3390/su17072936.

Anderson, David. 1989a. Letter Sent on July 29, 1989, to Nicole Gervais Acknowledging Receipt of the Journal. File R12730-308-5-E - Volume No. 17, Subseries R12730-17-5-E, Series R12730-8-4-E, David Anderson fonds (R12730-0-X-E), Library and Archives Canada, Ottawa.

Anderson, David. 1989b. *Report to the Premier on Oil Transportation and Oil Spills.* November. https://cmscontent.nrs.gov.bc.ca/geoscience/MapPlace1/Offshore/ReporttothePremieronOilTransportationandOilSpills.pdf.

Appel, Hannah. 2019. *The Licit Life of Capitalism: U.S. Oil in Equatorial Guinea*. Duke University Press.

APOA OSC (Arctic Petroleum Operators' Association Oil Spill Committee). 1978. Meeting Minutes for September 28, 1978. File 369, Box 31, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

APOA/EPOA OSC (Arctic Petroleum Operators' Association/Eastcoast Petroleum Operators' Association Oil Spill Committee). 1982. Meeting Minutes for January 14, 1982. File 380, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

APOA/EPOA OSC (Arctic Petroleum Operators' Association/Eastcoast Petroleum Operators' Association Oil Spill Committee). 1983. Meeting Minutes for January 17, 1983. File 381, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

APOA–OOD/CPA OSC (Arctic Petroleum Operators' Association–Offshore Operators' Division/Canadian Petroleum Association Oil Spill Committee). 1985. Meeting Minutes for October 4, 1985. File 383, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Arboleda, Martín. 2020. *Planetary Mine: Territories of Extraction under Late Capitalism*. Verso Books.

Arceo, Aldrick, Marianne Touchie, and William O'Brien. 2025. "Beyond Density: Examining Overlooked Drivers of Housing and Neighborhood Greenhouse Gas Emissions." *Sustainable Cities and Society* 120 (February):106131. https://doi.org/10.1016/j.scs.2025.106131.

Arsenault, Rachel, Carrie Bourassa, Sibyl Diver, Deborah McGregor, and Aaron Witham. 2019. "Including Indigenous Knowledge Systems in Environmental Assessments: Restructuring the Process." *Global Environmental Politics* 19 (3): 120–32. https://doi.org/10.1162/glep_a_00519.

Axsen, Jonn, and Chandan Bhardwaj. 2024. *Canada's Future Vehicle Emissions Standard (2024-2035): Impacts on Vehicle Size and GHG Emissions.*

Baker, Jenifer M. 1995. "Net Environmental Benefit Analysis for Oil Spill Response." *International Oil Spill Conference Proceedings* 1995 (1): 611–14. https://doi.org/10.7901/2169-3358-1995-1-611.

Baker, Janelle Marie, and Clinton N. Westman. 2018. "Extracting Knowledge: Social Science, Environmental Impact Assessment, and Indigenous Consultation in the Oil Sands of Alberta, Canada." *The Extractive Industries and Society* 5 (1): 144–53. https://doi.org/10.1016/j.exis.2017.12.008.

Barandiarán, Javiera. 2020. "Documenting Rubble to Shift Baselines: Environmental Assessments and Damaged Glaciers in Chile." *Environment and Planning E: Nature and Space* 3 (1): 58–75. https://doi.org/10.1177/2514848619873317.

Beak Consultants, CanGuard Consulting, and Associated Engineering. 1978. *Field Evaluation of the Super Seahawk and Marco Class V Oil Skimmers*. Technology Development Report EPS–4–EC–78–2. Department of Fisheries and the Environment.

Bennett, Mia M. 2016. "Discursive, Material, Vertical, and Extensive Dimensions of Post-Cold War Arctic Resource Extraction." *Polar Geography* 39 (4): 258–73. https://doi.org/10.1080/1088937X.2016.1234517.

Berenshtein, Igal, Claire Bo. Paris, Natalie Perlin, Matthew M. Alloy, Samantha B. Joye, and Steve Murawski. 2020. "Invisible Oil beyond the Deepwater Horizon Satellite Footprint." *Science Advances* 6: 1–11. https://doi.org/10.1126/sciadv.aaw8863.

Berger, Thomas R. 1977. *Northern Frontier, Northern Homeland. The Report of the Mackenzie Valley Pipeline Inquiry: Volume One.* Minister of Supply and Services Canada.

Bernauer, Warren. 2020. "Producing Consent: How Environmental Assessment Enabled Oil and Gas Extraction in the Qikiqtani Region of Nunavut." *The Canadian Geographer / Le Géographe Canadien* 64 (3): 489–501. https://doi.org/10.1111/cag.12611.

Bernauer, Warren, and Jonathan Peyton. 2021. "Energy Extraction, Resistance, and Political Change in Inuit Nunangat." In *The Inuit World*, edited by Pamela Stern, 340–58. Routledge. https://doi.org/10.4324/9780429275470-25.

Bernes, Jasper. 2013. "Logistics, Counterlogistics and the Communist Prospect." *Endnotes* 3. https://endnotes.org.uk/articles/logistics-counterlogistics-and-the-communist-prospect.

Bernstien, Jaela. 2024. "Canada's Uncounted Emissions." *CBC News*, June 20. https://newsinteractives.cbc.ca/features/2024/emissions/.

Bik, Holly M., Kenneth M. Halanych, Jyotsna Sharma, and W. Kelley Thomas. 2012. "Dramatic Shifts in Benthic Microbial Eukaryote Communities Following the Deepwater Horizon Oil Spill.". *PLoS ONE* 7 (6): 1–6. https://doi.org/10.1371/journal.pone.0038550.

BIOSPMC (Baffin Island Oil Spill Project Management Committee). 1980. Minutes of 2nd Management Committee Meeting, February 12, 1980. File 948, Box 77, Subseries 4, Series 15, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Birchard, E. C., and R. Nancarrow. 1986. "The Minuk I–53 Artificial Island Oil Spill." In *Proceedings of the Ninth Annual Arctic and Marine Oilspill Program Technical Seminar*, 375–378. Environment Canada.

Birkenholtz, Trevor, and Gregory Simon. 2022. "Introduction to Themed Issue: Ignorance and Uncertainty in Environmental Decision-Making." *Geoforum* 132 (June): 154–61. https://doi.org/10.1016/j.geoforum.2021.12.003.

Blackall, Peter J., and Gary A. Sergy. 1983. "The BIOS Project—An Update." *International Oil Spill Conference Proceedings* 1983 (1): 451–55. https://doi.org/10.7901/2169-3358-1983-1-451.

Black, T. A., M. S. White, J. M. Blais, et al.. 2021. "Surface Oil Is the Primary Driver of Macroinvertebrate Impacts Following Spills of Diluted Bitumen in Freshwater." *Environmental Pollution* 290 (December):117929. https://doi.org/10.1016/j.envpol.2021.117929.

Blake, Emily. 2024. "As Arctic Heavy Fuel Oil Ban Comes Into Force, Critics Want More." *Cabin Radio*, July 5. https://cabinradio.ca/190927/news/travel/as-arctic-heavy-fuel-oil-ban-comes-into-force-critics-want-more/.

Blenkinsopp, S. A., G. Sergy, K. Doe, G. Wohlgeschaffen, K. Li, and M. Fingas. 1996. "Toxicity of the Weathered Crude Oil Used at the Newfoundland Offshore Burn Experiment (NOBE) and the Resultant Burn Residue." *Spill Science & Technology Bulletin* 3 (4): 277–80. https://doi.org/10.1016/S1353-2561(97)00028-5.

Boehm, P. D., M. S. Steinhauer, D. R. Green, et al. 1987. "Comparative Fate of Chemically Dispersed and Beached Crude Oil in Subtidal Sediments of the Arctic Nearshore." *Arctic* 40:133–48.

Bocking, Stephen. 2007. "Science and Spaces in the Northern Environment." *Environmental History* 12 (4): 867–94. https://doi.org/10.1093/envhis/12.4.867.

Bocking, Stephen. 2019. "Cold Oil: Linking Strategic and Resource Science in the Canadian Arctic." In *Cold Science: Environmental Knowledge in the North American Arctic During the Cold War*, edited by Stephen Bocking and Daniel Heidt, 123–139. Routledge.

Bonasia, Christopher. 2025. "Canada's EV Sales Defy Slowdown Narrative, But Supply Chain Challenges Loom." *Energy Mix*, February 5. https://www.theenergymix.com/canadas-ev-sales-defy-slowdown-narrative-but-supply-chain-challenges-loom/.

Bond, David. 2022. *Negative Ecologies: Fossil Fuels and the Discovery of the Environment*. University of California Press.

Borders, William. 1973. "Canada Oil: Pipeline, Not Supply, Inadequate." *New York Times*, November 8. https://www.nytimes.com/1973/11/08/archives/canada-oil-pipeline-not-supply-inadequate-canada-oil-issue-pipeline.html.

Borst, Michael. 1983. *GemEng Lightweight Fireproof Boom: Oil Containment Testing at OHMSETT.* Technology Development Report EPS-4-EP-83-5. Environment Canada.

Bousso, Ron. 2018. "BP Deepwater Horizon Costs Balloon to $65 Billion." *Reuters*, January 16. https://www.reuters.com/article/world/bp-deepwater-horizon-costs-balloon-to-65-billion-idUSKBN1F50O5/.

Bowes, Stephen M. 1996. "Volatile Hydrocarbon Exposure During In Situ Burning of Crude Oil at Sea." *American Industrial Hygiene Association Journal* 57 (1): 62–67. https://doi.org/10.1080/15428119691015232.

Bosworth, Kai. 2024. "Desiring an Ecological Communism? On Kohei Saito's Slow Down." *Theory & Event* 27 (3): 510–14. https://doi.org/10.1353/tae.2024.a932020.

Brand, Ulrich, and Markus Wissen. 2021. *The Imperial Mode of Living: Everyday Life and the Ecological Crisis of Capitalism*. Verso Books.

Braverman, Harry. 1998. *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century*. Monthly Review Press.

Bregha, François. 1979. *Bob Blair's Pipeline: The Business and Politics of Northern Energy Development Projects*. Lorimer.

Bridge, Gavin, and Philippe Le Billon. 2017. *Oil* (2nd ed.). Polity.

Brosseau, Kevin. 2023. "Memorandum for the Deputy Minister: Postponement of Oil Spill Response Field Trials." Fisheries and Oceans Canada, File 2023-007-00102. Access to Information and Privacy Request A-2023-01243.

Brown, H. M, and R. H Goodman. 1987. *In Situ Burning of Oil in Experimental Ice Leads*. Report No. 64. Environmental Studies Revolving Funds.

Brueckner, Jan K., Matthew E. Kahn, and Jerry Nickelsburg. 2024. "How Do Airlines Cut Fuel Usage, Reducing Their Carbon Emissions?" *Economics of Transportation* 38 (June):100358. https://doi.org/10.1016/j.ecotra.2024.100358.

Buist, I., and D. Dickins. 1983. *Fate and Behaviour of Water-in-Oil Emulsions in Ice.* Arctic Petroleum Operators' Association.

Buist, I.A., and D.F. Dickins. 1987. “Experimental Spills of Crude Oil in Pack Ice.” *International Oil Spill Conference Proceedings* 1987 (1): 373–381. https://doi.org/10.7901/2169-3358-1987-1-373.

Cameron, Emilie S. 2012. “Securing Indigenous Politics: A Critique of the Vulnerability and Adaptation Approach to the Human Dimensions of Climate Change in the Canadian Arctic.” *Global Environmental Change* 22 (1): 103–14. https://doi.org/10.1016/j.gloenvcha.2011.11.004.

Cameron, Emilie. 2015. *Far Off Metal River: Inuit Lands, Settler Stories, and the Making of the Contemporary Arctic.* UBC Press.

Cameron, Emilie, and Sheena Kennedy. 2023. “Can Environmental Assessment Protect Caribou? Analysis of EA in Nunavut, Canada, 1999-2019.” *Conservation and Society* 21 (2): 121–32. https://doi.org/10.4103/cs.cs_54_22.

Cameron, Laura Jean. 1997. *Openings: A Meditation on History, Method, and Sumas Lake.* McGill-Queen’s University Press.

Cameron, Laura, and Angela Carter. 2023. *Why Carbon Capture and Storage Is Not a Net-Zero Solution for Canada’s Oil and Gas Sector*. International Institute for Sustainable Development. https://www.iisd.org/system/files/2023-02/bottom-line-carbon-capture-not-net-zero-solution.pdf.

Campling, Liam, and Alejandro Colás. 2021. *Capitalism and the Sea: The Maritime Factor in the Making of the Modern World*. Verso Books.

Canadian Press. 1986. “Spills, Iceberg Woes Called Inevitable at Hibernia.” *Toronto Star*, January 15. Canadian Major Dailies.

Canadian Press. 2019. “Cleanup Called Off After 12,000-litre Hibernia Oil Spill.” August 2. https://www.cbc.ca/news/canada/newfoundland-labrador/hibernia-clean-up-halted-1.5234329.

Carrington, Damian. 2017. “'Extraordinary' Levels of Pollutants Found in 10km Deep Mariana Trench.” *Guardian*, February 13. https://www.theguardian.com/environment/2017/feb/13/extraordinary-levels-of-toxic-pollution-found-in-10km-deep-mariana-trench.

Carrington, Gerry, and Janet Stephenson. 2018. “The Politics of Energy Scenarios: Are International Energy Agency and Other Conservative Projections Hampering the Renewable Energy Transition?” *Energy Research & Social Science* 46 (December): 103–13. https://doi.org/10.1016/j.erss.2018.07.011.

Carse, Ashley, and David Kneas. 2019. “Unbuilt and Unfinished: The Temporalities of Infrastructure.” *Environment and Society: Advances in Research* 10 (2019): 9–28. https://doi.org/10.3167/ares.2019.100102.

Carter, Angela V. 2020. *Fossilized: Environmental Policy in Canada's Petro-Provinces*. UBC Press.

Castillo, M. 2010. “The Uncertainty of Science and the Science of Uncertainty.” *American Journal of Neuroradiology* 31 (10): 1767–68. https://doi.org/10.3174/ajnr.A2106.

Castree, Noel. 2009. “The Spatio-Temporality of Capitalism.” *Time & Society* 18 (1): 26–61. https://doi.org/10.1177/0961463X08099942.

CBC News. 2010. “Gulf Oil Burn Method Has Newfoundland Roots.” April 29. https://www.cbc.ca/news/canada/newfoundland-labrador/gulf-oil-burn-method-has-newfoundland-roots-1.961240.

CBC News. 2015. “Alberta Pipelines: 5 Major Oil Spills in Recent History.” July 17. https://www.cbc.ca/news/canada/alberta-pipelines-5-major-oil-spills-in-recent-history-1.3156604.

CBC News. 2016. “Here's Why Gogama's Makami River 'Will Never Be Pristine Again.'” August 10. https://www.cbc.ca/news/canada/sudbury/gogama-oil-spill-clean-up-complete-1.3713738.

CBC News. 2019. “U.S. Company Fined Nearly $3M for 2016 Fuel Spill in B.C. First Nation's Fishing Territory.” July 16. https://www.cbc.ca/news/canada/british-columbia/nathan-e-stewart-spill-2016-heiltsuk-nation-sentencing-1.5213264.

CBC News. 2020. “Wrecked Cargo Ship Begins Leaking Oil 52 Years After It Sank in B.C.'s Nootka Sound.” December 11. https://www.cbc.ca/news/canada/british-columbia/shipwreck-discovered-in-bc-zuciarte-shannel-bligh-island-nootka-sound-1.5838352.

CBC News. 2024. “Vancouver Tanker Traffic Rises Tenfold After TMX Project.” August 27. https://www.cbc.ca/news/canada/british-columbia/tanker-traffic-trans-mountain-pipeline-expansion-1.7305702.

Canadian Coast Guard Western Region. 1989. *Nestucca Oil Spill Report*. Canadian Coast Guard.

C-CORE (Centre for Cold Ocean Resources Engineering). 1980. *An Oilspill in Pack Ice*. Arctic Marine Oilspill Program, Environmental Protection Service Contract OSS 79–0007. Ottawa: Environmental Protection Service.

Cederwall, Jeffrey, Tyler A. Black, Jules M. Blais, et al. 2020. “Life Under an Oil Slick: Response of a Freshwater Food Web to Simulated Spills of Diluted Bitumen in Field

Mesocosms." Canadian Journal of Fisheries and Aquatic Sciences 77 (5): 779–88. https://doi.org/10.1139/cjfas-2019-0224.

CER (Canada Energy Regulator). 2018. "Market Snapshot: Why Do Canadians Use So Much Oil?" January 24. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2018/market-snapshot-why-do-canadians-use-so-much-oil.html.

CER (Canada Energy Regulator). 2020. "Market Snapshot: Canadian Exports of Crude Oil to Destinations Other Than the United States Are Mainly From Newfoundland and Labrador's Offshore." April 8. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2020/market-snapshot-canadian-exports-crude-oil-destinations-other-than-united-states-are-mainly-from-newfoundland-labradors-offshore.html.

CER (Canada Energy Regulator). 2024a. "Market Snapshot: Almost All Canadian Crude Oil Exports Went to the United States in 2023." August 21. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2024/market-snapshot-almost-all-canadian-crude-oil-exports-went-to-the-united-states-in-2023.html.

CER (Canada Energy Regulator). 2024b. "Market Snapshot: Crude Oil Imports Rose Slightly in 2023, for the First Time Since 2019." June 12. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2024/market-snapshot-crude-oil-imports-rose-slightly-2023-first-time-since-2019.html.

CER (Canada Energy Regulator). 2024c. "Market Snapshot: Refined Petroleum Product Imports Decreased by 10% in 2023." June 19. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2024/market-snapshot-refined-petroleum-product-imports-decreased-by-10-percent-in-2023.html.

CER (Canada Energy Regulator). 2024d. "Market Snapshot: Zero Emission Vehicles Now Account for Over 10% of All New Vehicles in Canada." June 5. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2024/market-snapshot-zero-emission-vehicles-now-account-for-over-10-percent-of-all-new-vehicles-in-canada.html.

César, Filipa. 2018. "Meteorisations: Reading Amílcar Cabral's Agronomy of Liberation." *Third Text* 32 (2–3): 254–72. https://doi.org/10.1080/09528822.2018.1492073.

Christopher, Charles A., and Nick Vanderkooy. 1993. *Newfoundland Offshore Burn Experiment (NOBE) August 5–15, 1993*. Amoco Production Company, Research Department.

Chua, Charmaine S. 2017. "Logistical Violence, Logistical Vulnerabilities." *Historical Materialism* 25 (4): 167–82. https://doi.org/10.1163/1569206X-12341544.

Claes, Dag Harald, Andreas Goldthau, and David Livingston. 2015. "Saudi Arabia and the Shifting Geoeconomics of Oil." Carnegie Endowment for International Peace, May 21,

2015. https://carnegieendowment.org/2015/05/21/saudi-arabia-and-shifting-geoeconomics-of-oil-pub-60169.

Clark, Karin, Cory Hetherington, Chris O'Neil, and Jana Zavitz. 1997. *Breaking Ice with Finesse: Oil & Gas Exploration in the Canadian Arctic*. Arctic Institute of North America.

Clear Seas. 2020. "Research Spotlight: Dr. Kenneth Lee, Expert in Oil Spill Response Technologies." July 8. https://clearseas.org/insights/research-spotlight-dr-kenneth-lee/.

COAATF (Canadian Offshore Aerial Application Task Force). 1981. *The Suffield Field Trial of Aerially Applied Oil Spill Dispersants.* PACE Report No. 81–6. Petroleum Association for Conservation of the Canadian Environment.

COAATF (Canadian Offshore Aerial Applications Task Force). 1986. *The Effectiveness of Three Aerially Applied Dispersants in an Offshore Field Trial*. Canadian Offshore Oil Spill Research Association.

Cobanli, Susan E, Gary Wohlgeschaffen, Camilla Ryther, et al. 2022. "Microbial Community Response to Simulated Diluted Bitumen Spills in Coastal Seawater and Implications for Oil Spill Response." *FEMS Microbiology Ecology* 98 (5): 1–13. https://doi.org/10.1093/femsec/fiac033.

Coen, Ross. 2012. *Breaking Ice for Arctic Oil: The Epic Voyage of the SS Manhattan through the Northwest Passage*. UBC Press.

Collard, Rosemary-Claire, and Jessica Dempsey. 2022. "Future Eco-Perfect : Temporal Fixes of Liberal Environmentalism." *Antipode* 54 (5): 1545–65. https://doi.org/10.1111/anti.12849.

Collard, Rosemary-Claire, Jessica Dempsey, and Mollie Holmberg. 2020. "Extirpation despite Regulation? Environmental Assessment and Caribou." *Conservation Science and Practice* 2 (4): e166. https://doi.org/10.1111/csp2.166.

Collender, Guy. 2025. "Five Ways to Cut Emissions From Shipping." *Conversation*, January 22. https://theconversation.com/five-ways-to-cut-emissions-from-shipping-246829.

Colley, Sherri Borden. 2017. "Federal Government to Spend $80M on Ocean Protection." *CBC News*, December 18. https://www.cbc.ca/news/canada/nova-scotia/federal-government-to-spend-80m-on-ocean-protection-1.4454474.

Comfort, G., and W. Purves. 1982. *The Behaviour of Crude Oil Spilled Under Multi-Year Ice*. Technology Development Report EPS 4-EC-82-4. Ottawa: Environment Canada.

Corcoran, T.M. 1979. *Trenching With Explosives in Multiyear Sea Ice*. Hardy Associates Ltd.

COOSRA (Canadian Offshore Oilspill Research Association). 1985. Information Pamphlet and Catalogue of Research Reports. File 897, Box 75, Subseries 1, Series 15, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Coupal, Bernard. 1976. *Controlled Combustion Tests Carried Out Near Rimouski*. EPS-4-EC-76-2. Minister of Supply and Services Canada.

Covitt, Beth A., and Charles W. Anderson. 2022. "Untangling Trustworthiness and Uncertainty in Science: Implications for Science Education." *Science & Education* 31 (5): 1155–80. https://doi.org/10.1007/s11191-022-00322-6.

Cowen, Deborah. 2014. *The Deadly Life of Logistics: Mapping Violence in Global Trade*. University of Minnesota Press.

CPA-FD OSC (Canadian Petroleum Association Frontier Division Oil Spill Committee). 1986. Meeting Minutes for October 28, 1986. File 384, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Cret, Laurence, Hannes Gauch, Elizabeth Connelly, and Leonardo Paoli. 2025. "How the Shipping Sector Could Save on Energy Costs." International Energy Agency, March 28. https://www.iea.org/commentaries/how-the-shipping-sector-could-save-on-energy-costs.

CUPW (Canadian Union of Postal Workers). n.d. "Delivering Community Power: Our Plan." https://www.deliveringcommunitypower.ca/our_plan.

Currie, Pat. 2004. "For Bugs With the Munchies; Bacteria Set Loose to 'Eat' Oil, Grease in Cleanups." *Toronto Star*, January 3. Canadian Major Dailies.

Daggett, Cara. 2018. "Petro-Masculinity: Fossil Fuels and Authoritarian Desire." *Millennium: Journal of International Studies* 47 (1): 25–44. https://doi.org/10.1177/0305829818775817.

Dávila, Agustín Lage. 2024. *The Knowledge Economy and Socialism: Science and Society in Cuba.* Monthly Review Press.

Davis, Victoria. 2018. "Spilling Oil in the Name of Science." *Science*, July 5, 2018. https://www.science.org/content/article/spilling-oil-name-science.

De Beukelaer, Christiaan. 2023. "Wind-Powered Cargo Ships Are the Future: Debunking 4 Myths That Stand in the Way of Cutting Emissions." *Conversation*, February 13. https://theconversation.com/wind-powered-cargo-ships-are-the-future-debunking-4-myths-that-stand-in-the-way-of-cutting-emissions-199396.

DeCola, Elise. 2020. *Compensation for Ship-Source Oil Spills: Considerations for Modernizing Canada's Marine Liability Regime to Support Indigenous Communities*. WWF-Canada. https://wwf.ca/wp-content/uploads/2021/01/210113-MLA-Indigenous-report-FINAL.pdf.

Degiuli, Nastia, Ivana Martić, Andrea Farkas, and Ivan Gospić. 2021. "The Impact of Slow Steaming on Reducing CO2 Emissions in the Mediterranean Sea." *Energy Reports* 7 (November):8131–41. https://doi.org/10.1016/j.egyr.2021.02.046.

Dembicki, Geoff. 2022. *The Petroleum Papers*. Greystone Books.

Dennis, R.W., and B.L. Steelman. 1979. *Overland Aerial Application Tests of Oil Spill Dispersants Held At Abbotsford B.C., March 13–14, 1979*. Exxon Research and Engineering Company.

D. F. Dickins Associates. 1992. *Test Plan for an Offshore Oil Burning Experiment*. Newfoundland Burn Subcommittee.

D. F. Dickins Engineering. 1979. *Air Deployable Oil Spill Igniter Tests – Yellowknife May 14, 1979*. Canadian Marine Drilling Ltd.

D. F. Dickins Engineering. 1981. *Return to Balaena Bay: Long Term Effects of a Large Scale Crude Oil Spill Under Arctic Sea Ice 1975 to 1981*. Canadian Offshore Oil Spill Research Association.

DFO (Fisheries and Oceans Canada). 2022. "Projects." Multi-Partner Research Initiative, October 3. https://www.dfo-mpo.gc.ca/science/partnerships-partenariats/research-recherche/mpri-irmp/projects-projets-eng.html#projectsTable.

DFO (Fisheries and Oceans Canada). 2024. "Government of Canada and Heiltsuk Nation Reaffirm Commitment to Local Marine Emergency Response Capacity." July 4. https://www.canada.ca/en/fisheries-oceans/news/2024/07/government-of-canada-and-heiltsuk-nation-reaffirm-commitment-to-local-marine-emergency-response-capacity.html.

Dickins, David. 2022. "Oil Spill Behavior In Ice: 5 Decades of Field Research and Lessons for Future Oil In Ice Response." Oil Spill Prevention and Response, June 2, webinar, 1:30:40. https://youtu.be/GVEN7Qp8BJM?si=an_gqx5wb_wOO2jK.

Dickins, David F., Ian A. Buist, and William M. Pistruzak. 1981. "Dome's Petroleum Study of Oil and Gas Under Sea Ice." *International Oil Spill Conference Proceedings* 1981 (1): 183–189. https://doi.org/10.7901/2169-3358-1981-1-183.

Dickins, David F., David E. Thornton, and Walter J. Cretney. 1987. "Design and Operation of Oil Discharge Systems and Characteristics of Oil Used in the Baffin Island Oil Spill Project." *Arctic* 40 (5): 100–108. https://doi.org/10.14430/arctic1806.

Dickinson, A., D. Mackay, and D. McWatt. 1985. *Report on the Beaufort Sea Small Scale Oil Spill Dispersant Trial*. Environment Canada.

Dokis, Carly A. 2015. *Where the Rivers Meet: Pipelines, Participatory Resource Management, and Aboriginal-State Relations in the Northwest Territories*. UBC Press.

Dokis, Carly. 2023. "Imposing Calculations: The Visibility and Invisibility of Harm in the Mackenzie Gas Project Environmental Assessment." *Frontiers in Sociology* 7 (January):1056277. https://doi.org/10.3389/fsoc.2022.1056277.

Dotto, Lydia. 1974a. "Black Holes of Oil and Herbicide Found Under Polar Sea." *Globe and Mail*, November 12. ProQuest Historical Newspapers.

Dotto, Lydia. 1974b. "Oil Spills Locked in Ice Pose Recovery Problem, Arctic Study Finds." *Globe and Mail*, November 11. ProQuest Historical Newspapers.

Dotto, Lydia. 1974c. "Scientists Spill Oil, Test Effects on Ice." *Globe and Mail*, May 1. ProQuest Historical Newspapers.

Dome Petroleum, Esso Resources Canada, and Gulf Canada Resources. 1982. *Environmental Impact Statement for Hydrocarbon Development in the Beaufort Sea - Mackenzie Delta Region, Volume 7: Research and Monitoring*. Dome Petroleum. https://pubs.aina.ucalgary.ca/misc/9636.pdf.

Drummond, K. J. 2011. "Oil and Gas Resources, Kopanoar Play, Beaufort Sea." American Association of Petroleum Geologists, October 24. https://www.searchanddiscovery.com/documents/2011/10365drummond/ndx_drummond.pdf.

Duerden, F. Colin, and James J. Swiss. "Kurdistan—An Unusual Spill Successfully Handled." *International Oil Spill Conference Proceedings* 1981 (1): 215–19. https://doi.org/10.7901/2169-3358-1981-1-215.

Dupuis, Alain, and Francisco Ucan-Marin. 2015. "A Literature Review on the Aquatic Toxicology of Petroleum Oil: An Overview of Oil Properties and Effects to Aquatic Biota." Canadian Science Advisory Secretariat Research Document 2015/007. Fisheries and Oceans Canada, Ecosystems and Oceans Science.

Eckhouse, Gabe. 2025. "Performing Energy: The International Energy Agency and the Conflicting Imaginaries of Capitalist Energy Transition." *New Political Economy*, ahead of print, May 8. https://doi.org/10.1080/13563467.2025.2497763.

Ecojustice. 2024. "Backtracking on Trans Mountain Expansion Project Commitments Threatens the Survival of the 74 Southern Resident Killer Whales." July 25. https://ecojustice.ca/news/backtracking-on-trans-mountain-expansion-project-commitments-threatens-the-survival-of-the-74-southern-resident-killer-whales/.

EIA (U.S. Energy Information Administration). 2022. "Oil and Petroleum Products Explained." July 1. https://www.eia.gov/energyexplained/oil-and-petroleum-products/use-of-oil.php.

Ellis, Madison, Ianina Altshuler, Lars Schreiber, et al. 2022. "Hydrocarbon Biodegradation Potential of Microbial Communities from High Arctic Beaches in Canada's Northwest Passage." *Marine Pollution Bulletin* 174: 1–13. https://doi.org/10.1016/j.marpolbul.2021.113288.

EMRC (Energy, Mines and Resources Canada). 1980. *The National Energy Program*. https://publications.gc.ca/collections/collection_2016/rncan-nrcan/M23-12-80-4-eng.pdf.

EMRC (Energy, Mines and Resources Canada). 1987. *Petroleum Incentives Administration Annual Report 1987*. Minister of Supply and Services.

Energetex Engineering. 1978. *Testing of Air-Deployable Incendiary Devices for Igniting Oil on Water.* Technology Development Report EPS 4-EC-78-11. Environment Canada. https://publications.gc.ca/collections/collection_2019/eccc/en46-4/En46-4-78-11-eng.pdf.

Energetex Engineering. 1980. *Improvement of Air-Deployable, Oil Slick Igniters*. Energetex Engineering.

Energetex Engineering. 1981a. *Arctic Field Trials of D.R.E.V. Incendiary Devices*. Energetex Engineering.

Energetex Engineering. 1981b. *Burning of Crude Oil Under Wind Herding Conditions*. Canadian Offshore Oil Spill Research Association.

Energetex Engineering. 1982. *Final Report Environmental Testing of Dome Air-Deployable Igniter*. Energetex Engineering.

English, John. 2009. *Just Watch Me: The Life of Pierre Elliott Trudeau, Volume Two: 1968–2000*. Knopf Canada.

Environment Canada, United States Minerals Management Service, Canadian Coast Guard, et al. 1993. *NOBE: Newfoundland Offshore Burn Experiment*. Environment Canada.

Environment Canada, Fisheries and Oceans Canada, and Natural Resources Canada. 2013. "Properties, Composition and Marine Spill Behaviour, Fate and Transport of Two Diluted Bitumen Products from the Canadian Oil Sands." Government of Canada, November 30. https://publications.gc.ca/collections/collection_2014/ec/En84-96-2013-eng.pdf.

EVS Consultants. 1995. *Aquatic Toxicity from In-situ Oil Burning.* Environment Canada, Environmental Technology Centre, Emergencies Science Division.

Farish, Matthew. 2006. "Frontier Engineering: From the Globe to the Body in the Cold War Arctic." *Canadian Geographies / Géographies canadiennes* 50 (2): 177–96. https://doi.org/10.1111/j.0008-3658.2006.00134.x.

Farish, Matthew, and Leah Fusco. "The Path to Panarctic: The Emergence of an Extractive Frontier in Arctic Canada, 1948–1958." *Canadian Geographies / Géographies Canadiennes* 2024: 1–16. https://doi.org/10.1111/cag.12923.

Farish, Matthew, and P. Whitney Lackenbauer. 2017. "Western Electric Turns North: Technicians and the Transformation of the Cold War Arctic." In *Ice Blink: Navigating Northern Environmental History*, edited by Stephen Bocking and Brad Martin, 261–292. University of Calgary Press.

Faxness, LivGuri, Mona Skagseth Noreng, and Svein Ramstad. 2012. *Long-Term Effects of Oil on Beaches*. SINTEF A23166. SINTEF.

Ferek, Ronald J., John L. Ross, and Peter V. Hobbs. 1997. *Airborne Sampling of Smoke Emissions*. Environment Canada.

Ferguson, Deidra K., Carmen Li, Chunqing Jiang, Anirban Chakraborty, Stephen E. Grasby, and Casey R.J. Hubert. 2020. "Natural Attenuation of Spilled Crude Oil by Cold-Adapted Soil Bacterial Communities at a Decommissioned High Arctic Oil Well Site." Science of The Total Environment 722: 1–12. https://doi.org/10.1016/j.scitotenv.2020.137258.

Fingas, Merv F. 1998. "In-Situ Burning of Oil Spills - An Overview." *Spill Technology Newsletter* 23 (1–4): 1–14. https://publications.gc.ca/collections/collection_2018/eccc/En40-52-1-23-4-eng.pdf.

Fingas, Merv. 2002. *A Review of Literature Related to Oil Spill Dispersants Especially Relevant to Alaska.* https://www.pwsrcac.org/wp-content/uploads/filebase/programs/environmental_monitoring/dispersants/review_of_alaska_related_osd_literature.pdf.

Fingas, Merv. 2011. Physical Spill Countermeasures. In *Oil Spill Science and Technology*, edited by Merv Fingas, 303–337. Gulf Professional Publishing.

Fingas, Merv. 2015. "Introduction to Oil Chemistry and Properties." In *Handbook of Oil Spill Science and Technology*, edited by Merv Fingas, 53–77. John Wiley & Sons.

Fingas, Merv. 2018. *In-Situ Burning for Oil Spill Countermeasures*. CRC Press.

Fingas, Merv, and Elise Decola. 2006. *Oil Spill Dispersant Effectiveness Testing in OHMSETT: February – March 2006.* https://www.pwsrcac.org/wp-content/uploads/osd_effectiveness_testing_in_ohmsett.pdf.

Fingas, Merv, and Patrick Lambert. 2018. "The Newfoundland Offshore Burn Experiment." In *In-Situ Burning for Oil Spill Countermeasures*, edited by Merv Fingas, 285–348. CRC Press.

Fingas, Mervin F., Wayne S. Duval, and Gail B. Stevenson. 1979. *The Basics of Oil Spill Cleanup: With Particular Reference to Southern Canada*. Minister of Supply and Services Canada.

Foght, Julia. 2006. *Potential for Biodegradation of Sub-Littoral Residual Oil by Naturally Occurring Microorganisms Following the Lake Wabamun Train Derailment*. Alberta Environment.

Forman, Lisa, Carly Jackson, and Kaitlin Fajber. 2023. "Can We Move beyond Vaccine Apartheid? Examining the Determinants of the COVID-19 Vaccine Gap." *Global Public Health* 18 (1): 2256822. https://doi.org/10.1080/17441692.2023.2256822.

Fossum, John Erik. 1997. *Oil, the State, and Federalism: The Rise and Demise of Petro-Canada as a Statist Impulse*. University of Toronto Press.

Fraser, Gail S., and Joanne Ellis. 2008. "Offshore Hydrocarbon and Synthetic Hydrocarbon Spills in Eastern Canada: The Issue of Follow-up and Experience." *Journal of Environmental Assessment Policy and Management* 10 (2): 173–87. https://doi.org/10.1142/S1464333208002993.

Fraser, Graham. 1988. "Mulroney Set to Sign $1.3 Billion Accord." *Globe and Mail*, July 16. ProQuest Historical Newspapers.

Fraser, Nancy. 2022. *Cannibal Capitalism: How our System is Devouring Democracy, Care, and the Planet – and What We Can Do About It*. Verso Books.

French, Carey. 1983. "Major Oil Tanker Disaster Seems Inevitable." *Globe and Mail*, August 20. Canadian Major Dailies.

French-McCay, Deborah P., Katherine Jayko, Zhengkai Li, et al. 2021. "Oil Fate and Mass Balance for the Deepwater Horizon Oil Spill." *Marine Pollution Bulletin* 171: 1–17. https://doi.org/10.1016/j.marpolbul.2021.112681.

Gaede, James, and James Meadowcroft. "A Question of Authenticity: Status Quo Bias and the International Energy Agency's World Energy Outlook." *Journal of Environmental Policy & Planning* 18 (5): 608–27. https://doi.org/10.1080/1523908X.2015.1116380.

Gainer, J.G. 1982. "Re: Chairman's Report: APOA/EPOA Oil Spill Committee." April 20, 1982. File 380, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Galison, Peter. 1987. *How Experiments End*. University of Chicago Press.

Garavini, Giuliano. 2019. *The Rise and Fall of OPEC in the Twentieth Century*. Oxford University Press.

Garcia-Blanco, Susana, Albert D. Venosa, Makram T. Suidan, Kenneth Lee, Susan Cobanli, and John R. Haines. 2007. "Biostimulation for the Treatment of an Oil-Contaminated Coastal Salt Marsh." *Biodegradation* 18 (1): 1–15. https://doi.org/10.1007/s10532-005-9029-3.

Gardner, Timothy, and Noah Browning. 2022. "IEA Countries to Tap 60 Mln Barrels of Oil on Top of U.S. Release." *Reuters*, April 6. https://www.reuters.com/business/energy/iea-countries-tap-60-mln-barrels-oil-top-us-release-2022-04-06/.

Georghiou, Paris E., and Patricia E. Sheppard. 1982. *A Study of the Mutagenicity of Residue Resulting from the Burning of Crude Oil*. Environment Canada.

Gervais, Nicole. 1989. "How I Lived Through the Oil Spill: A Journal," Submitted on July 15, 1989, to David Anderson, Special Advisor to the Premier on Oil Transportation and Oil Spills. File R12730-308-5-E - Volume No. 17, Subseries R12730-17-5-E, Series R12730-8-4-E, David Anderson fonds (R12730-0-X-E), Library and Archives Canada, Ottawa.

Gill, Shawn D. 1977. "Dispersant Field Trials in Canadian Waters." *International Oil Spill Conference Proceedings* 1977 (1): 391–394. https://doi.org/10.7901/2169-3358-1977-1-391.

Gill, S. D., and C. W. Ross. 1982. "1981 Dispersant Application Field Trial - St. John's Newfoundland." *Proceedings of the Arctic Marine Oil Spill Program Technical Seminar* 1982: 255–263.

Gill, Shawn D., and W. Ryan. 1979. "Assessment of the ACW-400 Oil Skimmer by the Canadian Coast Guard for Oil Spill Countermeasure Operations." *International Oil Spill Conference Proceedings* 1979 (1): 497–499. https://doi.org/10.7901/2169-3358-1979-1-497.

Gill, S. D., R. Goodman, and J. Swiss. 1985. "Halifax '83 Sea Trial of Oil Spill Dispersant Concentrates." *International Oil Spill Conference Proceedings* 1985 (1): 479–482. https://doi.org/10.7901/2169-3358-1985-1-479.

Gill, S. D., C. A. Bonke, and J. Carter. 1985. "Management of the Uniacke G-72 Incident." *International Oil Spill Conference Proceedings* 1985 (1): 311–313. https://doi.org/10.7901/2169-3358-1985-1-311.

Global Alliance for the Future of Food. 2023. *Power Shift: Why We Need to Wean Industrial Food Systems Off Fossil Fuels*. Global Alliance for the Future of Food. https://futureoffood.org/wp-content/uploads/2023/10/ga_food-energy-nexus_report.pdf.

Globe and Mail. 1969. "Lakes Hearings: Ottawa and Ontario Differ on Oil Damage." December 3. ProQuest Historical Newspapers.

Globe and Mail. 1970. "Wait for Non-Burning Booms Delays Igniting Arrow Oil: Jamieson Sees New Tanker Rules." February 10. ProQuest Historical Newspapers.

Globe and Mail. 1971. "Alyeska Condemns Canadian Protest." December 22. ProQuest Historical Newspapers.

Globe and Mail. 1972. "TAP Sounds Concert of Disagreements." May 13. ProQuest Historical Newspapers.

Globe and Mail. 1979a. "Across Canada: Oil Spill Cleanup Finished in N.S." September 11. Canadian Major Dailies.

Globe and Mail. 1979b. "Cold Facts on Oil Spills." September 18. Canadian Major Dailies.

Globe and Mail. 1979c. "Tanker, Cargo of Oil May be Sent to Bottom." March 17. Canadian Major Dailies.

Globe and Mail. 1980a. "Aquitaine Re-Enters Well." July 29. ProQuest Historical Newspapers.

Globe and Mail. 1980b. "Oil-Spill Test to be Kept Confidential." April 8. Canadian Major Dailies.

Globe and Mail. 1984. "Liability For '79 Spill Still Fought." March 22. Canadian Major Dailies.

Globe and Mail. 1987. "Wind Hampers Cleanup of Oil Spill as Equipment is Tested in Atlantic." September 26. Canadian Major Dailies.

Gomez, Michelle. 2021. "Sumas First Nation Built on Higher Ground, Unaffected by Flooding in Former Lake Bed, Says Chief." *CBC News*, November 19. https://www.cbc.ca/news/canada/british-columbia/sumas-lake-history-1.6255693.

Goodman, R. H. 1980. "Canadian Oil Spill Research by APOA/EPOA." File 379, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Goodman, R. H., and MacNeill, M. R. 1984. "The Use of Remote Sensing in the Determination of Dispersant Effectiveness." In *Oil Spill Chemical Dispersants: Research, Experience, and Recommendations*, edited by Tom E. Allen, 143-160. American Society for Testing and Materials.

Gordillo, Gastón. 2014. *Rubble: The Afterlife of Destruction.* Duke University Press.

Goss, Heather. 2020. “Deepwater Horizon’s Legacy of Science.” *Eos*, March 25. https://eos.org/agu-news/deepwater-horizons-legacy-of-science.

Government of Canada. 2011. “Petrochemicals Industrial Profile.” November 17. https://ised-isde.canada.ca/site/canadian-chemical-industry/en/petrochemicals-industrial-profile.

Grant, Jennifer. 2012. “Relying on End Pit Lakes for Tailings ‘Reclamation’ is Reckless.” Pembina Institute, December 12. https://www.pembina.org/blog/relying-end-pit-lakes-tailings-reclamation-reckless.

Grant, Shelagh. 2010. *Polar Imperative: A History of Arctic Sovereignty in North America*. Douglas & McIntyre.

Gray, Malcolm. 1979a. “Cleanup of Kurdistan Oil Continues, Officials Say It May Equal Arrow Spill.” Globe and Mail, May 1. Canadian Major Dailies.

Gray, Malcolm. 1979b. “Decision Likely Today Over Salvaging Stern of British Oil Tanker.” Globe and Mail, March 20. ProQuest Historical Newspapers.

Green, D. R., J. Buckley, and B. Humphrey. 1982. “Fate of Chemically Dispersed Oil in the Sea: A Report on Two Field Experiments.” Technology Development Report EPS 4-EC-82-5. Ottawa: Environment Canada.

Green, Fergus, and Richard Denniss. 2018. “Cutting with Both Arms of the Scissors: The Economic and Political Case for Restrictive Supply-Side Climate Policies.” *Climatic Change* 150 (1–2): 73–87. https://doi.org/10.1007/s10584-018-2162-x.

Grenon, Stéphane, Vincent Jarry, Darcy Longpré, Kenneth Lee, and Albert D. Venosa. 2001. “Logistics for the Conduct of Controlled Oil Spill Experiment on Biorestoration of Freshwater Wetlands.” *International Oil Spill Conference Proceedings* 2001 (2): 1467–69. https://doi.org/10.7901/2169-3358-2001-2-1467.

Grimes, David Robert. 2022. “Balancing Benefits and Potential Risks of Vaccination: The Precautionary Principle and the Law of Unintended Consequences.” *BMJ Evidence-Based Medicine* 27 (6): 319–23. https://doi.org/10.1136/bmjebm-2021-111773.

Gros, Jonas, Deedar Nabi, Birgit Würz, et al. 2014. “First Day of an Oil Spill on the Open Sea: Early Mass Transfers of Hydrocarbons to Air and Water.” *Environmental Science & Technology* 48 (16): 9400–9411. https://doi.org/10.1021/es502437e.

Gross, Samantha. 2023. “Reducing Us Oil Demand, Not Production, is the Way Forward for the Climate.” Brookings Institute, September. https://www.brookings.edu/articles/reducing-us-oil-demand-not-production-is-the-way-forward-for-the-climate/.

Guénette, Chantal C., Gary A. Sergy, Edward H. Owens, Roger C. Prince, and Kenneth Lee. 2003. "Experimental Design of the Svalbard Shoreline Field Trials." *Spill Science & Technology Bulletin* 8 (3): 245–56. https://doi.org/10.1016/S1353-2561(03)00038-0.

Guo, Weijun, Xinggang Wang, Sihong Liu, Xiangpeng Kong, Pengcheng Wang, and Tiaojian Xu. 2022. "Long-Term Petroleum Hydrocarbons Pollution after a Coastal Oil Spill." *Journal of Marine Science and Engineering* 10 (1380): 1–13. https://doi.org/10.3390/jmse10101380.

Gutstein, Donald. 2018. *The Big Stall: How Big Oil and Think Tanks Are Blocking Action on Climate Change in Canada*. Lorimer.

Hack, Kevin. 2024. "Crude Oil Imports From Canada Reached a Record After Pipeline Expansion." U.S. Energy Information Administration, October 30. https://www.eia.gov/todayinenergy/detail.php?id=63564.

Hanieh, Adam. 2021. "Petrochemical Empire." *New Left Review* 130: 25–51. https://newleftreview.org/issues/ii130/articles/petrochemical-empire.

Hanieh, Adam. 2024. *Crude Capitalism: Oil, Corporate Power, and the Making of the World Market*. Verso Books.

Hansen, Bue Rübner. 2021. "The Kaleidoscope of Catastrophe - On the Clarities and Blind Spots of Andreas Malm." *Viewpoint*, April 14. https://viewpointmag.com/2021/04/14/the-kaleidoscope-of-catastrophe-on-the-clarities-and-blind-spots-of-andreas-malm/.

Hans J. A. Neu. 1981. *Sea State During the Breakup of the Oil Tanker Kurdistan.* Report Series BI-R-81-11. Dartmouth: Bedford Institute of Oceanography.

Haraway, Donna. 1988. "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective." *Feminist Studies* 14 (3): 575-599. https://doi.org/10.2307/3178066.

Haraway, Donna. 1991. *Simians, Cyborgs and Women: The Reinvention of Nature*. Routledge.

Hart, Gordon L. S. 1971. *Report of the Royal Commission Pollution of Canadian Waters by Oil and Formal Investigation into Grounding of Steam Tanker "Arrow."* Information Canada.

Harvey, David. 1990. *The Condition of Postmodernity*. Wiley-Blackwell.

Harvey, David. 2006. "Space as a Keyword." In *David Harvey: A Critical Reader*, edited by Noel Castree and Derek Gregory, 270–293. John Wiley & Sons.

Harvey, David. 2007. *The Limits to Capital*. Verso Books.

Healy, Ciarán, Rebecca McKimm, and Ivo Walinga. 2025. “Oil Demand for Fuels in China Has Reached a Plateau.” International Energy Agency, March 11. https://www.iea.org/commentaries/oil-demand-for-fuels-in-china-has-reached-a-plateau.

Heinrich, Michael. 2012. *An Introduction to the Three Volumes of Karl Marx's Capital*. Monthly Review Press.

Hemens, Aaron. 2024. “Sentencing of Tiny House Warriors Involved in TMX Confrontation Adjourned to 2025.” *IndigiNews*, November 5. https://indiginews.com/news/tiny-house-warriors-sentencing-over-tmx-confrontation-adjourned-to-2025.

Henderson, Ross. 1990. “Microbes Enlisted to Eat Oil Spill.” *Edmonton Journal*, July 14. Canadian Major Dailies.

Hess, David. 1970. “Debate Swirls Over Lake Erie Oil Drilling: League Opposes Drilling.” *Christian Science Monitor*, January 7. ProQuest Historical Newspapers.

Hibernia Management and Development Company. 2025. “Hibernia Development Milestones.” https://www.hibernia.ca/about-hibernia/milestones/.

Hoogeveen, Dawn. 2016. “Fish-Hood: Environmental Assessment, Critical Indigenous Studies, and Posthumanism at Fish Lake (Teztan Biny), Tsilhqot’in Territory.” *Environment and Planning D: Society and Space* 34 (2): 355–70. https://doi.org/10.1177/0263775815615123.

Heiltsuk Tribal Council. 2017. *Investigation Report: The 48 Hours After the Grounding of the Nathan E. Stewart and Its Oil Spill*. Heiltsuk Tribal Council.

Heiltsuk Tribal Council. 2018. *Dáduqvḷá1 Qṇtxv Ǧvi’Ḷásax̌ to Look at Our Traditional Laws Decision of the Heiltsuk (Haíɫzaqv) Dáduqvḷá Committee Regarding the October 13, 2016 Nathan E. Stewart Spill*. Heiltsuk Tribal Council.

Heiltsuk Tribal Council. 2021. “Return to Gale Creek: Commemorating the Anniversary of the Nathan E. Stewart Oil Spill.” October 13. https://heiltsuknation.ca/statement-by-heiltsuk-nation-on-5th-anniversary-of-nathan-e-stewart-oil-spill/

Heiltsuk Tribal Council. 2022. “Return to Gale Creek: Commemorating the Anniversary of the Nathan E. Stewart Oil Spill.” October 13. https://heiltsuknation.ca/return-to-gale-creek-commemorating-the-anniversary-of-the-nathan-e-stewart-oil-spill/.

Heiltsuk Tribal Council. 2024. “Heiltsuk Nation Calls Upon United Nations Agency to Ensure Laws Address Indigenous Cultural Losses From Marine Oil Spills.” March 20. https://www.heiltsuknation.ca/_files/ugd/2b9783_97907cc072264330bf9e01cadaad6d71.pdf.

Hickel, Jason. 2021. *Less is More: How Degrowth Will Save the World*. Penguin Random House.

Hickel, Jason, and Dylan Sullivan. 2024. "How Much Growth Is Required to Achieve Good Lives for All? Insights from Needs-Based Analysis." *World Development Perspectives* 35 (September):100612. https://doi.org/10.1016/j.wdp.2024.100612.

Huber, Matthew T. 2013. *Lifeblood: Oil, Freedom, and the Forces of Capital*. University of Minnesota Press.

Hughes, David. 2016. *Can Canada Expand Oil and Gas Production, Build Pipelines and Keep Its Climate Change Commitments?* Parkland Institute, June 2. https://www.parklandinstitute.ca/can_canada_expand.

Hume, H. R., I. Buist, D. Betts, and R. Goodman. 1983. "Arctic Marine Oil Spill Research." *Cold Regions Science and Technology* 7: 313–41. https://doi.org/10.1016/0165-232X(83)90078-2.

Humphrey, B., P. D. Boehm, M. C. Hamilton, and R. J. Norstrom. 1987. "The Fate of Chemically Dispersed and Untreated Crude Oil in Arctic Benthic Biota." *Arctic* 40 (5): 149–61. https://doi.org/10.14430/arctic1810.

Humphrey, B., E. H. Owens, and Gary A. Sergy. 1992. *The Fate and Persistence of Stranded Crude Oil: A Nine-Year Overview from the BIOS Project, Baffin Island, NWT, Canada*. Environment Canada.

Hunnie, Blake E., Lars Schreiber, Charles W. Greer, and Gary A. Stern. 2023. "The Recalcitrance and Potential Toxicity of Polycyclic Aromatic Hydrocarbons within Crude Oil Residues in Beach Sediments at the BIOS Site, Nearly Forty Years Later." *Environmental Research* 222 (April):115329. https://doi.org/10.1016/j.envres.2023.115329.

Hunter, Justine. 2018. "Trans Mountain Pipeline Delay Means Gaps in Oil Spill Response Remain." *Globe and Mail*, September 14. https://www.theglobeandmail.com/canada/british-columbia/article-trans-mountain-pipeline-delay-means-gaps-in-oil-spill-response-remain/.

Hussain, Yadullah. 2014. "New Emissions From Canada's Oil Sands 'Extremely Low,' Says IEA's Chief Economist." *Financial Post*, November 27. https://financialpost.com/commodities/energy/new-emissions-from-canadas-oil-sands-extremely-low-says-ieas-chief-economist?__lsa=5627-8d96.

IEA (International Energy Agency). 2022. *Canada 2022: Energy Policy Review*. International Energy Agency.

IEA (International Energy Agency). 2024. *World Energy Outlook 2024*. International Energy Agency.

Impact Assessment Agency of Canada. 2021. *Bay du Nord Development Project: Environmental Assessment Report*. August 9. https://iaac-aeic.gc.ca/050/documents/p80154/138155E.pdf.

Jessop, Bob. 2016. *The State: Past, Present, Future*. Polity.

Jones, Gordon. 1980. Notes on Government–Industry Meeting Regarding Oilspill Research Funding. February 28. File 374, Box 31, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Jones, Gordon. 1981. "The Role of Research Associations In Frontier Exploration Arctic Petroleum Operators'' Association (APOA) And Eastcoast Petroleum Operators'' Association (EPOA)." *Journal of Canadian Petroleum Technology* 20 (4): 116–119. https://doi.org/10.2118/81-04-10.

Jones, Gordon. n.d. Letter Re: Canadian Offshore Oil Spill Research Association (COOSRA). File 903, Box 75, Subseries 1, Series 15, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Jones, Lindsay. 2018. "How Do You Remove 462,000 Litres of Oil From a Sunken Ship?" *Maclean's*, October 25, 2018. https://macleans.ca/news/canada/how-do-you-remove-462000-litres-of-oil-from-a-sunken-ship/.

Karasiuk, D. J., and P. N. Boothroyd. 1982. *Preliminary Environment Assessment of Proposed Harbour Sites and McKinley Bay and Baillie Islands, Northwest Territories, Volume 1: Migratory Bird Habitat and Bird Use, 1980*. Ottawa: Canadian Wildlife Service.

Keating, Michael. 1982. "Oil Spilled as Part of Pollution War." *Globe and Mail,* February 12. Canadian Major Dailies.

Kerslake, Danny. 2016. "Spills Happening at a Rate of About 2 Per Day in Saskatchewan: Researcher." *CBC News*, July 27. https://www.cbc.ca/news/canada/saskatoon/spills-happen-rate-two-per-day-saskatchewan-researcher-1.3696261.

Khalili, Laleh. 2020. *Sinews of War and Trade: Shipping and Capitalism in the Arabian Peninsula*. Verso Books.

Kharey, Gurpreet S., Vince Palace, Lyle Whyte, and Charles W. Greer. 2024. "Native Freshwater Lake Microbial Community Response to an in Situ Experimental Dilbit Spill." *FEMS Microbiology Ecology* 100 (5): fiae055. https://doi.org/10.1093/femsec/fiae055.

Kharrat, Abdel M., Jose Zacharia, V. John Cherian, and Allwell Anyatonwu. 2007. "Issues with Comparing SARA Methodologies." *Energy & Fuels* 21: 3618–3621. https://doi.org/10.1021/ef700393a.

Kheraj, Sean. 2020. “A History of Oil Spills on Long-Distance Pipelines in Canada.” *Canadian Historical Review* 101 (2): 161–91. https://doi.org/10.3138/chr.2019-0005.

Kimes, Nikole E., Amy V. Callaghan, Joseph M. Suflita, and Pamela J. Morris. 2014. “Microbial Transformation of the Deepwater Horizon Oil Spills—Past, Present, and Future Perspectives.” *Frontiers in Microbiology* 5 (603): 1–11. https://doi.org/10.3389/fmicb.2014.00603.

Kingham, Jim. 1981. Section of Review of Papers Presented at 1981 Oil Spill Conference. April 22, 1981. File 379, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators’ Association and Eastcoast Petroleum Operators’ Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Kirsch, Scott. 2011. “Laboratory/Observatory.” In *The SAGE Handbook of Geographical Knowledge*, edited by John A. Agnew and David N. Livingstone, 76–87. SAGE Publications.

Klein, Naomi. 2007. *The Shock Doctrine: The Rise of Disaster Capitalism.* Knopf Canada.

Knox, Jack. 2018. “Six New Spill-Response Bases Put on Hold, a Consequence of Pipeline-Project Halt.” *Times-Colonist*, April 14. https://www.timescolonist.com/local-news/jack-knox-spill-response-bases-put-on-hold-a-consequence-of-pipeline-project-halt-4661190.

Kohler, Robert E. 2002. *Landscapes & Labscapes: Exploring the Lab-Field Border in Biology*. University of Chicago Press.

Kommenda, Niko. 2019. “How Your Flight Emits as Much CO2 as Many People Do in a Year.” *Guardian*, July 19. https://www.theguardian.com/environment/ng-interactive/2019/jul/19/carbon-calculator-how-taking-one-flight-emits-as-much-as-many-people-do-in-a-year.

Kroepsch, Adrianne C., and Katherine R. Clifford. 2022. “On Environments of Not Knowing: How Some Environmental Spaces and Circulations Are Made Inscrutable.” *Geoforum* 132 (June): 171–81. https://doi.org/10.1016/j.geoforum.2021.05.009.

Kujawinski, Elizabeth B., Christopher M. Reddy, Ryan P. Rodgers, J. Cameron Thrash, David L. Valentine, and Helen K. White. 2020. “The First Decade of Scientific Insights from the Deepwater Horizon Oil Release.” *Nature Reviews Earth & Environment* 1 (5): 237–50. https://doi.org/10.1038/s43017-020-0046-x.

Labban, Mazen. 2008. *Space, Oil and Capital*. Routledge.

Labban, Mazen. 2010. Oil in Parallax: Scarcity, Markets, and the Financialization of Accumulation. *Geoforum* 41 (4): 541–552. https://doi.org/10.1016/j.geoforum.2009.12.002.

Lalonde, Marc. 1990. “Riding the Storm: Energy Policy, 1968–1984.” In *Towards a Just Society: The Trudeau Years*, edited by Thomas S. Axworthy and Pierre Elliott Trudeau, 49–77. Viking.

Lamb, Mike. 1990. “Oil Spill Fighters Find Safe Prairie Harbor.” *Calgary Herald*, October 12. Canadian Major Dailies.

Lane, Patricia A., Michael J. Crowell, David G. Patriquin, and Ian Buist. 1987. *The Use of Chemical Dispersant in Salt Marshes*. Environmental Studies Research Funds Report No. 70. Environmental Studies Research Funds. https://publications.gc.ca/collections/collection_2016/one-neb/NE22-4-070-eng.pdf.

Lassalle, Guillaume, Rebecca Del’Papa Moreira Scafutto, Rafael Andre Lourenço, Paulo Mazzafera, and Carlos Roberto De Souza Filho. 2023. “Remote Sensing Reveals Unprecedented Sublethal Impacts of a 40-Year-Old Oil Spill on Mangroves.” *Environmental Pollution* 331: 1–12. https://doi.org/10.1016/j.envpol.2023.121859.

Latour, Bruno. 1987. *Science in Action: How to Follow Scientists and Engineers Through Society*. Harvard University Press.

Latour, Bruno, and Steve Woolgar. 1986. *Laboratory Life: The Social Construction of Scientific Facts*. Princeton University Press.

Laxer, James. 1983. *Oil and Gas: Ottawa, the Provinces, and the Petroleum Industry*. Lorimer.

Leedham, Emily. 2022. “Canada’s “Freedom Convoy” Is a Front for a Right-Wing, Anti-Worker Agenda.” *Jacobin*, February 5. https://jacobin.com/2022/02/canada-freedom-convoy-conservative-right-wing-anti-worker-anti-vaccine.

Lee, Marc. 2024. “The Trans Mountain Pipeline Expansion Was an Expensive Mistake.” Canadian Centre for Policy Alternatives, September 25. https://www.policyalternatives.ca/news-research/the-trans-mountain-pipeline-expansion-was-an-expensive-mistake/.

Lee, Kenneth. 2020. “Oil Spill Science and Alternative Response Measures with Dr. Kenneth Lee.” Fisheries and Oceans Canada, June 2, lecture, 30:36. https://youtu.be/cIwReiRA3GM?si=gP3g7vwdpj4nhdLN.

Lee, Kenneth, and Eric M. Levy. 1987. “Enhanced Biodegradation of a Light Crude Oil in Sandy Beaches.” *International Oil Spill Conference Proceedings* 1987 (1): 411–416. https://doi.org/10.7901/2169-3358-1987-1-411.

Lee, Kenneth, and Eric M. Levy. 1989. “Enhancement of the Natural Biodegradation of Condensate and Crude Oil on Beaches of Atlantic Canada.” *International Oil Spill*

Conference Proceedings 1989 (1): 479–86. https://doi.org/10.7901/2169-3358-1989-1-479.

Lee, Kenneth, Kenneth G. Doe, Lucila E. J. Lee, Makram T. Suidan, and Albert D. Venosa. 2001. "Remediation of an Oil-Contaminated Experimental Freshwater Wetland: II. Habitat Recovery and Toxicity Reduction." *International Oil Spill Conference Proceedings* 2001 (1): 323–28. https://doi.org/10.7901/2169-3358-2001-1-323.

Lee, Kenneth, Patricia Stoffyn-Egli, Gilles H. Tremblay, et al. 2003. "Oil–Mineral Aggregate Formation on Oiled Beaches: Natural Attenuation and Sediment Relocation." *Spill Science & Technology Bulletin* 8 (3): 285–96. https://doi.org/10.1016/S1353-2561(03)00042-2.

Lee, Kenneth, Zhengkai Li, Brian Robinson, and Paul E. Kepkay. 2011. "Field Trials of In-Situ Oil Spill Countermeasures in Ice-Infested Waters." *International Oil Spill Conference Proceedings* 2011 (1): 1–16. https://doi.org/10.0.30.221/2169-3358-2011-1-160.

Lee, Kenneth, Michel Boufadel, Bing Chen, et al. 2015. *The Royal Society of Canada Expert Panel: The Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments*. Royal Society of Canada. https://rsc-src.ca/sites/default/files/OIW%20Report_1.pdf.

Levin, Julia. 2024. *Canada's Fossil Fuel Funding in 2023*. Environmental Defence. https://environmentaldefence.ca/wp-content/uploads/2024/03/Canadas-Fossil-Fuel-Subsidies.pdf.

Lewis, C. A. 1980. Letter to W. F. Bernard of Canmar About Recommendations. July 9, 1980. File 376, Box 31, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Lewis, Sophie, and Ailie Gallant. 2013. "Lost in Translation: Confidence and Certainty in Climate Science." *Conversation*, August 22. https://theconversation.com/lost-in-translation-confidence-and-certainty-in-climate-science-17181.

Li, Fabiana. 2015. *Unearthing Conflict: Corporate Mining, Activism, and Expertise in Peru*. Duke University Press.

Li, Fabiana. 2018. "Moving Glaciers: Remaking Nature and Mineral Extraction in Chile." *Latin American Perspectives* 45 (5): 102–19. https://doi.org/10.1177/0094582X17713757.

Li, Ken, Eric Dainty, Mervin F. Fingas, Jacqueline M. R. Bélanger, and J. R. Jocelyn Paré. 1995. "Remote Controlled Helicopters: A Tool for Air Sampling in Difficult Situations." *Journal of Hazardous Materials* 43 (1–2): 117–27. https://doi.org/10.1016/0304-3894(95)00032-P.

Li, Tania. 2007. *The Will to Improve: Governmentality, Development, and the Practice of Politics*. Duke University Press.

Liberal Party of Canada. 2019. “Justin Trudeau on the Trans Mountain Expansion Project.” June 20. https://liberal.ca/justin-trudeau-on-the-trans-mountain-expansion-project/.

Liboiron, Max. 2021. *Pollution is Colonialism*. Duke University Press.

Lindblom, Gordon P., Bruce D. Emery, and Miguel A. Garcia Lara. 1981. “Aerial Application of Dispersants at the Ixtoc I Spill.” International Oil Spill Conference Proceedings 1981 (1): 259–62. https://doi.org/10.7901/2169-3358-1981-1-259.

Lin, Yatang, Yu Qin, Jing Wu, and Mandi Xu. 2021. “Impact of High-Speed Rail on Road Traffic and Greenhouse Gas Emissions.” *Nature Climate Change* 11 (11): 952–57. https://doi.org/10.1038/s41558-021-01190-8.

Livingstone, David N. 2003. *Putting Science in Its Place: Geographies of Scientific Knowledge*. University of Chicago Press.

LTLC Consulting, and Salmo Consulting. 2012. *Oil and Gas Exploration & Development Activity Forecast Canadian Beaufort Sea 2012 – 2027*. Beaufort Regional Environmental Assessment Aboriginal Affairs and Northern Development Canada. https://beaufortrea.ca/wp-content/uploads/2012/04/Beaufort-Sea-OG-activity-forecast-2012-2017.pdf.

Lunel, Tim, and Jenifer M. Baker. 1999. “Quantification of Net Environmental Benefit for Future Oil Spills.” *International Oil Spill Conference Proceedings* 1999 (1): 619–27. https://doi.org/10.7901/2169-3358-1999-1-619.

Mackay, Donald. 1984. “Oil-Spill Research in Canada’s Arctic in a Dangerous Skid?” *Globe and Mail*, February 7. ProQuest Historical Newspapers.

Mackay, D., M. E. Charles, and C. R. Phillips. 1974. *The Physical Aspects of Crude Oil Spills on Northern Terrain*. Environmental-Social Committee Northern Pipelines, Task Force on Northern Oil Development, Report No. 73–42. Information Canada.

MacKinnon, D. S., and P. A. Lane. 1993. *Saltmarsh Revisited - The Long-Term Effects of Oil and Dispersant on Saltmarsh Vegetation*. Environmental Studies Research Funds Report No. 122. Environmental Studies Research Funds.

MacNeill, M. R., R. H. Goodman, J. B. Bodeux, K. E. Corry, and B. A. Paddison. 1985. “Dispersant Tests in a Wave Basin.” *International Oil Spill Conference Proceedings* 1985 (1): 463–69. https://doi.org/10.7901/2169-3358-1985-1-463.

Markusoff, Jason. 2017. “Does Spilled Pipeline Bitumen Sink or Float?” *Maclean’s*, January 7. https://macleans.ca/society/does-spilled-pipeline-bitumen-sink-or-float/.

Marotte, Bertrand. 1993. "Ottawa Takes 8.5-per-cent Stake in Hibernia; Share in Oil Megaproject Will Be Sold When Time is Right: Energy Minister." *Gazette*, January 16. Canadian Major Dailies.

Marx, Karl. 1971. *Grundrisse*. Translated by David McLellan. New York: Harper & Row.

McClenachan, Giovanna, and R. Eugene Turner. 2023. "Disturbance Legacies and Shifting Trajectories: Marsh Soil Strength and Shoreline Erosion a Decade after the Deepwater Horizon Oil Spill." *Environmental Pollution* 322: 1–8. https://doi.org/10.1016/j.envpol.2023.121151.

McClintock, Anne. 2010. "Slow Violence and the BP Coverups." *CounterPunch*, August 23. https://www.counterpunch.org/2010/08/23/slow-violence-and-the-bp-coverups/.

McDonald, Kira. 2024. *From Margins to Growth: The Economic Case for a Public Rail System.* Climate & Community Institute. https://climateandcommunity.org/research/from-margins-to-growth/.

McGlade, Christophe, and Paul Ekins. 2015. "The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2 °C." *Nature* 517 (7533): 187–90. https://doi.org/10.1038/nature14016.

McGrattan, Kevin B., William D. Walton, Anthony D. Putorti, William H. Twilley, Jay McElroy, and David D. Evans. 1995. *Smoke Plume Trajectory From In Situ Burning of Crude Oil in Alaska: Field Experiments*. NISTIR 5764. Alaska Department of Environmental Conservation, Division of Spill Prevention and Response.

McKenzie-Sutter, Holly. 2018. "Newfoundland's Largest-Ever Oil Spill is Now Impossible to Clean Up." *Canadian Press*, November 20. https://financialpost.com/commodities/energy/n-l-s-largest-ever-oil-spill-is-now-impossible-to-clean-up-regulatory-board.

McNeil Jr., Donald G. 1979. "Tanker Splits Off Nova Scotia Coast." New York Times, March 16. ProQuest Historical Newspapers.

McRae, Robert N. 1982. "A Major Shift in Canada's Energy Policy: Impact of the National Energy Program." *Journal of Energy and Development* 7 (2): 173–198.

McSheffrey, Elizabeth. 2018. "Scientists Are Planning an Oily Bitumen Spill in This Ontario Lake." *Canada's National Observer*, May 22. https://www.nationalobserver.com/2018/05/22/news/scientists-are-planning-oily-bitumen-spill-ontario-lake.

McSheffrey, Elizabeth. 2021. “Sumas First Nation Chief Reflects on ‘Disaster’ B.C. Flooding Where Lake Used to Be.” *Global News*, November 18. https://globalnews.ca/news/8385289/sumas-lake-reflection-first-nations/.

Merlin, Francois, Zhiwen Zhu, Min Yang, et al. 2021. “Dispersants as Marine Oil Spill Treating Agents: A Review on Mesoscale Tests and Field Trials.” *Environmental Systems Research* 10 (1):1–19. https://doi.org/10.1186/s40068-021-00241-5.

Merriam, Sharan B., and Elizabeth J. Tisdell. 2016. *Qualitative Research: A Guide to Design and Implementation*, 4th ed. Jossey-Bass.

Mertl, Steve. 1989. “Expert Says Oil Spills Don't Hurt Beaches as Much as Believed.” *Ottawa Citizen*, January 28. Canadian Major Dailies.

Metz, Robert. 1979. “Market Place: Newfoundland Oil Prospects.” *New York Times*, September 12. ProQuest Historical Newspapers.

Meyer, Carl. 2018. “COOGER Town: Inside the Federal Lab That’s Testing How Oil Spills Affect the Ocean.” *National Observer*, September 26. https://www.nationalobserver.com/2018/09/26/news/cooger-town-inside-federal-lab-thats-testing-how-oil-spills-affect-ocean.

Michaels, David, and Celeste Monforton. 2005. “Manufacturing Uncertainty: Contested Science and the Protection of the Public’s Health and Environment.” *American Journal of Public Health* 95 (S1): S39–48. https://doi.org/10.2105/AJPH.2004.043059.

Miller, Robert, Eliot Whittington, Samuel Gabra, et al. 2024. *Five Years to Chart a New Future for Aviation.* Aviation Impact Accelerator. https://report.aiazero.org/.

Milne, Allen. 2010. *Oil, Ice and Climate Change.* RESTCo. https://www.restco.ca/BSP_Climate.shtml.

Milne, A. R., R. H. Herlinveaux, and G. Wilton. 1977. *A Field Study of the Permeability of Multiyear Ice to Sea Water with Implications on Its Permeability to Oil*. Technology Development Report EPS-4-EC-77-11. Fisheries and Environment Canada.

Mitchell, Timothy. 2011. *Carbon Democracy: Political Power in the Age of Oil.* Verso Books.

Ministry of Transport. 1970. *Report of the Task Force - Operation Oil (Clean-up of the Arrow Oil Spill in Chedabucto Bay), Volume 1*. Information Canada.

Moore, Jason W. 2017. “Metabolic Rift or Metabolic Shift? Dialectics, Nature, and the World-Historical Method.” *Theory and Society* 46 (4): 285–318. https://doi.org/10.1007/s11186-017-9290-6.

Moreau, Jennifer. 2015. “Kinder Morgan's Relationship to Western Canada Marine Response Corporation.” *Burnaby Now*, April 16. https://www.burnabynow.com/opinion/kinder-morgans-relationship-to-western-canada-marine-response-corporation-3026778.

Morgan, Hani. “Conducting a Qualitative Document Analysis.” *The Qualitative Report* 27, no. 1 (2022): 64–77. https://doi.org/10.46743/2160-3715/2022.5044.

Muttitt, Greg, Adam Scott, and Tim Buckley. 2018. *Off Track: How the International Energy Agency Guides Energy Decisions Towards Fossil Fuel Dependence and Climate Change*. Oil Change International and Institute for Energy Economics and Financial Analysis. https://www.oilchange.org/wp-content/uploads/2018/04/Off-Track-IEA-climate-change1.pdf.

Nagel, Jeff. 2013. “One-Hour Oil Spill Response Urged for Burrard Inlet.” *Langley Advance Times*, December 20. https://www.langleyadvancetimes.com/news/one-hour-oil-spill-response-urged-for-burrard-inlet-2462127.

NASEM (National Academies of Sciences, Engineering, and Medicine). 2019. *Reproducibility and Replicability in Science*. National Academies Press. https://nap.nationalacademies.org/catalog/25303/reproducibility-and-replicability-in-science.

NASEM (National Academies of Sciences, Engineering, and Medicine). 2020. *The Use of Dispersants in Marine Oil Spill Response*. National Academies Press. https://doi.org/10.17226/25161.

Nature Climate Change. 2019. “Scientific Uncertainty.” 9 (11): 797–797. https://doi.org/10.1038/s41558-019-0627-1.

Nature. 2022. “Use Hydrogen Wisely, Not Indiscriminately.” 611: 426. https://doi.org/10.1038/d41586-022-03693-6.

NEB (National Energy Board). 1984. *Canadian Energy Supply and Demand 1983–2005 Summary Report*. Minister of Supply and Services Canada.

Nelson, Joshua. 2020. “Petro-masculinity and Climate Change Denial among White, Politically Conservative American Males.” *International Journal of Applied Psychoanalytic Studies* 17 (4): 282–95. https://doi.org/10.1002/aps.1638.

New York Times. 1973. “Canada to Increase Tax on Oil Shipped To U.S. by 375%.” November 2. https://www.nytimes.com/1973/11/02/archives/canada-to-increase-tax-on-oil-shipped-to-us-by-375.html.

New York Times. 1985. “Petro-Canada Write-Down Set.” August 21. https://www.nytimes.com/1985/08/21/business/petro-canada-write-down-set.html.

Nikiforuk, Andrew. 2016. "The Oil Spill Cleanup Illusion." *Hakai Magazine*, July 12. https://hakaimagazine.com/features/oil-spill-cleanup-illusion/.

Nikiforuk, Andrew. n.d. *The Arctic Is Not A Casino: The Beaufort Sea Project and the Enduring Hazards of Arctic Offshore Drilling*. Greenpeace Canada. https://www.restco.ca/The%20Arctic%20Is%20Not%20A%20Casino.pdf.

NIST (National Institute of Standards and Technology). 1994. *In Situ Burning Oil Spill Workshop Proceedings, Orlando, Florida, January 26-28, 1994*. NIST Special Publication 867. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication867.pdf.

Nixon, Rob. 2011. *Slow Violence and the Environmentalism of the Poor*. Harvard University Press.

NOAA (National Oceanic and Atmospheric Administration). 2012. "In Situ Burn (ISB) Emissions Comparisons." February 9. https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/in-situ-burn-emissions-comparisons.html.

Noonan, Larry. 2015. "Stories from Rouge Park." *Toronto.com*, December 3. https://www.toronto.com/news/stories-from-rouge-park-the-beare-road-landfill-started-as-a-sand-and-gravel-pit/article_aba81db6-6ecf-56b9-a920-42826c1468ad.html?.

NORCOR Engineering and Research Limited. 1975. *The Interaction of Crude Oil with Arctic Sea Ice*. Beaufort Sea Technical Report No. 27. Beaufort Sea Project.

NORCOR Engineering and Research Limited. 1977. *Probable Behaviour and Fate Of a Winter Oil Spill in the Beaufort Sea*. Technology Development Report EPS-4-EC-77-5. Ottawa: Environment Canada.

"Notes From Meeting Held in Calgary - April 15, 1977, Between Permit Holders in Baffin Bay-Davis Strait Area and DINA Officials." April 15, 1977. File 360, Box 30, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Nuccitelli, Dana. 2024. "How Oil Sands Undermine Canada's Climate Goals." *Yale Climate Connections*, February 20. https://yaleclimateconnections.org/2024/02/how-oil-sands-undermine-canadas-climate-goals/.

O'Connor, James. 1998. *Natural Causes: Essays in Ecological Marxism*. Guilford Press.

Odenweller, Adrian, Falko Ueckerdt, Gregory F. Nemet, Miha Jensterle, and Gunnar Luderer. 2022. "Probabilistic Feasibility Space of Scaling up Green Hydrogen Supply." *Nature Energy* 7 (9): 854–65. https://doi.org/10.1038/s41560-022-01097-4.

Ogden, Lesley Evans. 2018. "How a Deliberate Oil Spill Will Help Protect the Environment." *BBC News*, June 25. https://www.bbc.com/future/article/20180625-the-oil-spill-experiment-in-a-canada-lake.

Oil & Gas Journal. 1993. "Oil Spill Burn Test Slated Off E. Canada." July 26: 28–30. ABI/INFORM Collection.

O'Malley, Martin. 1974. "Missing Value Caused 502,000-gallon Labrador Spill: Tanker Pumped Oil Into Atlantic for 33 Hours Before One-foot Gap in Pipeline Noticed." *Globe and Mail*, September 23. ProQuest Historical Newspapers.

Oreskes, Naomi, and Erik M. Conway. 2010. *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*. Bloomsbury Press.

Orihel, Diane. 2019. "Why We Spilled Oil For Science." *Canadian Geographic*, June 17. https://canadiangeographic.ca/articles/why-we-spilled-oil-for-science/.

Overton, Edward B., Puspa L. Adhikari, Jagoš R. Radović, and Uta Passow. 2022. "Fates of Petroleum during the Deepwater Horizon Oil Spill: A Chemistry Perspective." *Frontiers in Marine Science* 9: 1–25.. https://doi.org/10.3389/fmars.2022.928576.

Owens, E. H. 1971. *The Restoration of Beaches Contaminated by Oil in Chedabucto Bay, Nova Scotia*. Manuscript Report Series No. 19. Information Canada.

Owens, Ed. 1993. "Are We Ready for the `Big One?'; Experiment Off Newfoundland Encouraging, but Coping With Oil Spills Still Burning Question." *Ottawa Citizen*, August 16. Canadian Major Dailies.

Owens, Ed. 2022. "The BIOS and ITOSS Oiled Shoreline Field Experiments." Oil Spill Prevention and Response, September 6, webinar, 1:13:46. https://youtu.be/dtNjsQAG5mM?si=_r8NHkQ4J-h4MpPl.

Owens, Edward H., Wishart Robson, and Carl R. Foget. 1987a. "A Field Evaluation of Selected Beach-Cleaning Techniques." *Arctic* 40 (5): 244–57. https://doi.org/10.14430/arctic1818.

Owens, Edward H., John R. Harper, Wishart Robson, and Paul D. Boehm. 1987b. "Fate and Persistence of Crude Oil Stranded on a Sheltered Beach." *Arctic* 40 (5): 109–23. https://doi.org/10.14430/arctic1807.

Owens, Edward H., A. Mark Sienkiewicz, and Gary A. Sergy. 1999. "Evaluation of Shoreline Cleaning Versus Natural Recovery: The Metula Spill and the Komi Operations." *International Oil Spill Conference* Proceedings 1999 (1): 503–9. https://doi.org/10.7901/2169-3358-1999-1-503.

Owens, Edward H, Gary A. Sergy, Chantal C. Guénette, Roger C. Prince, and Kenneth Lee. 2003. "The Reduction of Stranded Oil by In Situ Shoreline Treatment Options." *Spill Science & Technology Bulletin* 8 (3): 257–72. https://doi.org/10.1016/S1353-2561(03)00041-0.

Owens, Edward H., Gary A. Sergy, Roger C. Prince, and Kenneth Lee. 2024. "Shoreline Response: Lessons from the BIOS and ITOSS Field Experiments and Long-Term Spill Studies." *International Oil Spill Conference Proceedings* 2024 (1): 1–20. https://doi.org/10.7901/2169-3358-2024.1.114.

Palace, Vince P., Lisa Peters, Nancy Berard-Brown, et al. 2021. "The Freshwater Oil Spill Remediation Study (FOReSt): 2018 Pilot Study at the Experimental Lakes Area, Canada." *International Oil Spill Conference Proceedings* 2021 (1): 667537.

Pawson, Chad. 2016. "Bella Bella Diesel Spill Response Questioned by Heiltsuk First Nation Chief After Booms Fail." *CBC News*, October 22. https://www.cbc.ca/news/canada/british-columbia/community-in-state-of-shock-after-diesel-spill-booms-fail-1.3817560.

Perelman, Michael. 1978. "Karl Marx's Theory of Science." *Journal of Economic Issues* 12 (4): 859–70.

Peyton, Jonathan. 2017. *Unbuilt Environments: Tracing Postwar Development in Northwest British Columbia*. UBC Press.

Pickering, Andrew. 1995. *The Mangle of Practice: Time, Agency, and Science*. University of Chicago Press.

Pirani, Simon. 2018. *Burning Up: A Global History of Fossil Fuel Consumption*. Pluto Press.

Plummer, Eric. 2022. "Sonar Scan Planned This Spring, as Shipping Containers Remain Missing." *Ha-Shilth-Sa*, March 15. https://hashilthsa.com/news/2022-03-15/sonar-scan-planned-spring-shipping-containers-remain-missing.

Potter, Stephen, Ian Buist, Ken Trudel, David Dickins, and Ed Owens. 2012. *Spill Response in the Arctic Offshore*. February 2. American Petroleum Institute and the Joint Industry Programme on Oil Spill Recovery in Ice. https://www.api.org/~/media/files/ehs/clean_water/oil_spill_prevention/spill-response-in-the-arctic-offshore.ashx.

Powell, Kristen. 2024. "Decreasing Speed Cuts Emissions, Wildlife Collisions and Costs." WWF-Canada. https://www.arcticwwf.org/the-circle/stories/decreasing-speed-cuts-emissions-wildlife-collisions-and-costs/.

Powell, Richard C. 2017. *Studying Arctic Fields Cultures, Practices, and Environmental Sciences*. McGill-Queen's University Press.

Prado, Glaucia H. C., Yuan Rao, and Arno de Klerk. 2017. “Nitrogen Removal from Oil: A Review.” *Energy & Fuels* 31 (1): 14–36. https://doi.org/10.1021/acs.energyfuels.6b02779.

Pratt, Larry. 1982. “Energy: The Roots of National Policy.” *Studies in Political Economy* 7 (1): 27–59. https://doi.org/10.1080/19187033.1982.11675694.

Pratt, Larry. 1985. “Energy, Regionalism and Canadian Nationalism.” *Newfoundland Studies* 1 (2): 175–199. https://id.erudit.org/iderudit/nflds1_2art04.

Prime Minister of Canada. 2016. “The Prime Minister of Canada Announces the National Oceans Protection Plan.” November 7. https://www.pm.gc.ca/en/news/news-releases/2016/11/07/prime-minister-canada-announces-national-oceans-protection-plan.

Professional Mariner. 2018. “TSB Urges Action on Crew Fatigue After Nathan E. Stewart Grounding.” August 31. https://professionalmariner.com/tsb-urges-action-on-crew-fatigue-after-nathan-e-stewart-grounding/.

Purves, F. 1978. *The Interaction of Crude Oil and Natural Gas with Laboratory-grown Saline Ice*. Technology Development Report EPS 4-EC-78-9. Environment Canada.

Reimer, E. M. 1980. “The Visual Identification of Bunker-C Oil in Dynamic Pack Ice.” In *Scientific Studies During the Kurdistan Tanker Incident: Proceedings of a Workshop*, edited by J. H. Vandermeulen, 74–85. Bedford Institute of Oceanography.

Renwick, Melissa. 2021. “Coastal Communities ‘Raise the Alarm’ Around Marine Debris.” *Ha-Shilth-Sa*, December 18. https://hashilthsa.com/news/2021-12-18/coastal-communities-raise-alarm-around-marine-debris.

Rieppel, Lukas, Eugenia Lean, and William Deringer. 2018. “Introduction: The Entangled Histories of Science and Capitalism.” *OSIRIS* 33 (1): 1–24. https://doi.org/10.7916/d8-cfjh-f461.

Riofrancos, Thea, Alissa Kendall, Kristi K. Dayemo, et al. 2023. *Achieving Zero Emissions with More Mobility and Less Mining*. Climate & Community Institute. https://climateandcommunity.org/research/more-mobility-less-mining/.

Robertson, Morgan M. 2006. “The Nature That Capital Can See: Science, State, and Market in the Commodification of Ecosystem Services.” *Environment and Planning D: Society and Space* 24 (3): 367–87. https://doi.org/10.1068/d3304.

Robson, Wishart. 1983. APOA/EPOA Oil Spill Committee Minutes. January 17, 1983. File 381, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators’ Association and Eastcoast Petroleum Operators’ Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Rodney, Walter. 1981. *How Europe Underdeveloped Africa*. Howard University Press.

Rodriguez-Gil, Jose Luis, Sawyer Stoyanovich, Mark L. Hanson, et al. 2021. "Simulating Diluted Bitumen Spills in Boreal Lake Limnocorrals - Part 1: Experimental Design and Responses of Hydrocarbons, Metals, and Water Quality Parameters." *Science of The Total Environment* 790 (October):148537. https://doi.org/10.1016/j.scitotenv.2021.148537.

Rose, Hilary, and Steven Rose, eds. 1976. *The Political Economy of Science*. Macmillan Press.

Ross, John L., Ronald J. Ferek, and Peter V. Hobbs. 1996. "Particle and Gas Emissions from an In Situ Burn of Crude Oil on the Ocean." *Journal of the Air & Waste Management Association* 46 (3): 251–59. https://doi.org/10.1080/10473289.1996.10467459.

Rowland, Robin. 1981. "Wrangle Near End in Tanker Mishap." *Globe and Mail*, August 13. Canadian Major Dailies.

Rudy, Alan P. 2019. "On Misunderstanding the Second Contradiction Thesis." *Capitalism Nature Socialism* 30 (4): 17–35. https://doi.org/10.1080/10455752.2019.1652663.

Rutgers, Julia-Simone. 2024. "Millions of Litres of Oil Spilled, Zero Provincial Fines or Penalties." *Winnipeg Free Press*, June 29. Canadian Major Dailies.

Sandlos, John, and Arn Keeling. 2016. "Toxic Legacies, Slow Violence, and Environmental Injustice at Giant Mine, Northwest Territories." *Northern Review* 43 (1): 7–21. https://thenorthernreview.ca/index.php/nr/article/view/566.

Sanger, Clyde. 1970. "Nova Scotia MPs Give Minister Rough Time Over Arrow Cleanup. *Globe and Mail*, February 25. ProQuest Historical Newspapers.

Saraiva, Tiago. 2022. "Black Science: Amílcar Cabral's Agricultural Survey and the Seeds of African Decolonization." *Isis* 113 (3): 597–609. https://doi.org/10.1086/721072.

Schindler, D. W. 2009. "A Personal History of the Experimental Lakes Project." *Canadian Journal of Fisheries and Aquatic Sciences* 66 (11): 1837–47. https://doi.org/10.1139/F09-134.

Schlenker, Lela, John Stieglitz, Justin Greer, et al. 2022. "Brief Oil Exposure Reduces Fitness in Wild Gulf of Mexico Mahi-Mahi (Coryphaena Hippurus)." *Environmental Science & Technology* 56: 13019–28. https://doi.org/10.1021/acs.est.2c01783.

Schmelzer, Matthias, Aaron Vansintjan and Andrea Vetter. 2022. *The Future is Degrowth: A Guide to a World Beyond Capitalism*. Verso Books.

Schreiber, Lars, Nathalie Fortin, Julien Tremblay, et al. 2019. "Potential for Microbially Mediated Natural Attenuation of Diluted Bitumen on the Coast of British Columbia

(Canada).” *Applied and Environmental Microbiology* 85 (10): 1–19. https://doi.org/10.1128/AEM.00086-19.

Schreiber, Lars, Nathalie Fortin, Alberto Mazza, et al. 2023. “An Experimental Oil Spill at a Tidal Freshwater Wetland along the St. Lawrence River Re-Visited after 21 Years.” *Environmental Research* 216 (January):114456. https://doi.org/10.1016/j.envres.2022.114456.

Schulze, Robert. 1998. *Oil Spill Response Performance Review of Skimmers.* American Society for Testing and Materials.

Scott, Brian F., and Robi M. Chatterjee. 1975. *Behaviour of Oil under Canadian Climatic Conditions: Part 1. Oil on Water under Ice-Forming Conditions.* Scientific Series #50. Ottawa: Environment Canada.

Seakem Oceanography. 1990. *Field Test of Two Spill Treating Agents*. Environment Canada.

Semeniuk, Ivan. 2019. “Slick Science: How Researchers Are Preparing for Canada’s Next Major Oil Spill.” *Globe and Mail*, July 30. https://www.theglobeandmail.com/canada/article-slick-science-how-researchers-are-preparing-for-canadas-next-major/.

Semeniuk, Ivan. 2024. “Long-Awaited Research Lab Opens in Churchill to Study Oil Spills and More.” *Globe and Mail*, August 27. https://www.theglobeandmail.com/canada/article-long-awaited-research-lab-opens-in-churchill-to-study-oil-spills-and/.

Senanayake, Nari, and Brian King. 2021. “Geographies of Uncertainty.” *Geoforum* 123 (July): 129–35. https://doi.org/10.1016/j.geoforum.2020.07.016.

Sergy, Gary A. 1985. “The Baffin Island Oil Spill (BIOS) Project: A Summary.” *International Oil Spill Conference Proceedings* 1985 (1): 571–75. https://doi.org/10.7901/2169-3358-1985-1-571.

Sergy, Gary A. 1986. *The Baffin Island Oil Spill Project*. Environment Canada and the Canadian Petroleum Association.

Sergy, Gary A., and Peter J. Blackall. 1987. “Design and Conclusions of the Baffin Island Oil Spill Project.” *Arctic* 40 (Supp. 1): 1–9. https://doi.org/10.14430/arctic1797.

Sergy, G. A., C. C. Guenette, E. H. Owens, R. C. Prince, K. Lee. 1998. “The Svalbard Experimental Oilspill Field Trials.” *Proceedings of the Twenty-First Arctic Marine Oilspill Program Technical Seminar*: 75–89. https://www.bsee.gov/sites/bsee.gov/files/osrr-oil-spill-response-research/295-ac.pdf.

Shaikh, Anwar. 2016. *Capitalism: Competition, Conflict, Crises.* Oxford University Press.

Shapin, Steven, and Simon Schaffer. 2011. *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*. Princeton University Press.

Sheppard, Robert. 1980. "Arctic Oil-Spill Experiment Approved." *Globe and Mail*, June 20. Canadian Major Dailies.

Shiskova, Ivelina, Dicho Stratiev, Sotir Sotirov, et al. 2024. "Predicting Petroleum SARA Composition from Density, Sulfur Content, Flash Point, and Simulated Distillation Data Using Regression and Artificial Neural Network Techniques" *Processes* 12 (8): 1755. https://doi.org/10.3390/pr12081755.

Simpson, Michael. 2019. "The Annihilation of Time by Space: Pluri-Temporal Strategies of Capitalist Circulation." *Environment and Planning E: Nature and Space* 2 (1): 110–28. https://doi.org/10.1177/2514848618817726.

S. L. Ross Environmental Research. 1987. *Offshore Testing of Booms and Skimmers*. Environment Canada and US Minerals Management Service. https://www.bsee.gov/sites/bsee.gov/files/osrr-oil-spill-response-research//113ac.pdf.

S. L. Ross Environmental Research, and D. F. Dickins Associates. 1987. *Field Research Spills to Investigate the Physical and Chemical Fate of Oil in Pack Ice*. Report No. 62. Environmental Studies Revolving Funds Report.

Smedley, J. Bruce. 1981. "Assessment of Aerial Application of Oil Spill Dispersants." *International Oil Spill Conference Proceedings*: 253–257. https://doi.org/10.7901/2169-3358-1981-1-253.

Smit, Berend, Ah-Hyung Alissa Park, and Greeshma Gadikota. 2014. "The Grand Challenges in Carbon Capture, Utilization, and Storage." *Frontiers in Energy Research* 2 (55). https://doi.org/10.3389/fenrg.2014.00055.

Smith, Neil. 2007. "Nature as Accumulation Strategy." *Socialist Register* 43 (1): 16–36. https://socialistregister.com/index.php/srv/article/view/5856/2752.

Smith, Neil. 2008. *Uneven Development: Nature, Capital, and the Production of Space*. 3rd ed. University of Georgia Press.

Smith, Neil, and Phil O'Keefe. 1980. "Geography, Marx and the Concept of Nature." *Antipode* 12 (2): 30–39. https://doi.org/10.1111/j.1467-8330.1980.tb00647.x.

Smith, Susan L. 2017. "The Voice of Women Against Chemical Weapons." *Active History*, January 25. https://activehistory.ca/blog/2017/01/25/the-voice-of-women-against-chemical-weapons/.

Snow, N. B., and D. M. Rosenberg. 1975a. *Experimental Oil Spills on Mackenzie Delta Lakes I. Effect of Norman Wells Crude Oil on Lake 4*. Technical Report No. 548. Environment Canada, Fisheries and Marine Service.

Snow, N. B., and D. M. Rosenberg. 1975b. *Experimental Oil Spills on Mackenzie Delta Lakes II. Effect of Two Types of Crude Oil on Lakes 4C and 8.* Technical Report No. 549. Environment Canada, Fisheries and Marine Service.

Snow, N. B., and B. F. Scott. 1975. "The Effect and Fate of Crude Oil Spilt on Two Arctic Lakes." *International Oil Spill Conference Proceedings* 1975 (1): 527–534. https://doi.org/10.7901/2169-3358-1975-1-527.

Snow, N. B., D. M. Rosenberg, and J. Moenig. 1975. *The Effects of Norman Wells Crude Oil on the Zoobenthos of a Northern Yukon Stream One Year After an Experimental Spill*. Technical Report No. 550. Environment Canada, Fisheries and Marine Service.

Snyder, Jesse. 2018. "A Closer Look at the Oceans Protection Plan, the Liberals' $1.5B Bid to Bolster the Trans Mountain Pipeline." *National Post*, September 24. https://nationalpost.com/news/a-closer-look-at-the-oceans-protection-plan-the-liberals-1-5b-bid-to-bolster-the-trans-mountain-pipeline.

Solsberg, L. B., C. W. Ross, W. J. Logan, and M. F. Fingas. 1976. *Field Evaluation of Seven Oil Spill Recovery Devices*. Technology Development Report Number EPS 4-EC-76-3. Environment Canada.

Solsberg, L. B., W. G. Wallace, and M. A. Dunne. 1977. *Field Evaluation of Oil Spill Recovery Devices: Phase Two*. Technology Development Report EPS–4–EC–77–14. Environment Canada.

Song, Sang-Keun, Zang-Ho Shon, Yoo-Keun Kim, Yoon-Hee Kang, and Ki-Hyun Kim. 2011. "An Oil Spill Accident and Its Impact on Ozone Levels in the Surrounding Coastal Regions." *Atmospheric Environment* 45 (6): 1312–22. https://doi.org/10.1016/j.atmosenv.2010.11.055.

Sorstrom, Stein Erik, Per Johan Brandvik, Ian Buist, et al. 2010. *Joint Industry Program on Oil Spill Contingency for Arctic and Ice-covered Waters: Summary Report*. Report No. 32. SINTEF. https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2992987/jip-rep-no-32-summary-report.pdf?sequence=1&isAllowed=y.

Spears, Tom. 1990. "Tanker Spill a 'Close Call' for Canada." *Ottawa Citizen*, November 23, 1990. Canadian Major Dailies.

Speight, J. G. 2004. "Petroleum Asphaltenes - Part 1: Asphaltenes, Resins and the Structure of Petroleum." *Oil & Gas Science and Technology* 59 (5): 467–77. https://doi.org/10.2516/ogst:2004032.

Stafford, Stephen. 2024. "How Wind Power Could Be Future of Cargo Shipping." *BBC*, October 22. https://www.bbc.com/news/articles/c98y8dj542ro.

Stantec. 2012. "Summary of Clean Up and Effects of the 2007 Spill of Oil From Trans Mountain Pipeline to Burrard Inlet, Part 1: Marine Environment." https://docs.transmountain.com/2012-Summary-2007-Spill-Clean-Up-Effects-REV2.pdf.

Statistics Canada. 2024. "Record High Crude Oil Production Largely Driven by Oil Sands: Crude Oil Year in Review 2023." March 7. https://www.statcan.gc.ca/o1/en/plus/5781-record-high-crude-oil-production-largely-driven-oil-sands-crude-oil-year-review-2023.

Stay Grounded. n.d. "Setting Limits on Flights." https://stay-grounded.org/setting-limits-on-flights/.

Stephenson, Amanda. 2024. "Six Months On, What Has the Trans Mountain Pipeline Project Achieved and What's Next?" *Canadian Press*, October 21. https://www.cbc.ca/news/canada/calgary/trans-mountain-pipeline-cost-overruns-1.7357954.

Stoler, Ann Laura, ed. 2013. *Imperial Debris: On Ruins and Ruination*. Duke University Press.

Stout, Scott A., and James R. Payne. 2016. "Chemical Composition of Floating and Sunken In-Situ Burn Residues from the Deepwater Horizon Oil Spill." *Marine Pollution Bulletin* 108 (1–2): 186–202. https://doi.org/10.1016/j.marpolbul.2016.04.031.

Stoyanovich, Sawyer S., Zeyu Yang, Mark Hanson, et al. 2019. "Simulating a Spill of Diluted Bitumen: Environmental Weathering and Submergence in a Model Freshwater System." *Environmental Toxicology and Chemistry* 38 (12): 2621–28. https://doi.org/10.1002/etc.4600.

Stuhl, Andrew. 2016. *Unfreezing the Arctic: Science, Colonialism, and the Transformation of Inuit Lands*. University of Chicago Press.

Stuhl, Andrew. 2024. "Ignorance and Environmental History: The Opening of an Arctic Offshore Oil Frontier, 1968–1976." *Environment and History* 30 (4): 665–694. https://doi.org/10.3828/whp.eh.63830915903590.

Sutterlin, Natalie, and Norman Snow. 1982. "Introduction to the Eastern Arctic Marine Environmental Studies Program." *Arctic* 35 (1): iii–iv. https://doi.org/10.14430/arctic2302.

Swiss, Jim. 1986. Letter to C.B. Virtue About Oil Spill Committee Projects. October 2, 1986. File 384, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Swiss, James J., and Nick Vanderkooy. 1988. *Beaufort Sea Dispersant Trial*. Environmental Studies Revolving Fund Report No. 100. Dome Petroleum Limited.

Tannert, Christof, Horst-Dietrich Elvers, and Burkhard Jandrig. 2007. "The Ethics of Uncertainty: In the Light of Possible Dangers, Research Becomes a Moral Duty." *EMBO Reports* 8 (10): 892–96. https://doi.org/10.1038/sj.embor.7401072.

Telford, A. S. 1978. Letter to W. F. Bernard About Oil Spill Committee Report. March 6, 1978. File 387, Box 32, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

Tennyson, E. J., and H. Whittaker. 1989. "The 1987 Newfoundland Oil Spill Experiment." *International Oil Spill Proceedings* 1989 (1): 101–103. https://doi.org/10.7901/2169-3358-1989-1-101.

Thompson, E. P. 1967. "Work-Discipline, and Industrial Capitalism." *Past & Present* 38: 56–97.

Thornton, D. E., M. F. Fingas, H. Whittaker, and G. Sergy. 1992. "AMOP - The Arctic and Marine Oilspill Program." *Spill Technology Newsletter* 17 (2): 1–9. https://publications.gc.ca/collections/collection_2018/eccc/En40-52-1-17-2-eng.pdf.

Thurton, David. 2022. "Finance Canada Defends $10 Billion Loan Guarantee for Trans Mountain." *CBC News*, May 11. https://www.cbc.ca/news/politics/trans-mountain-pipeline-loan-guarantee-1.6449824.

Tidmarsh, G. D., and L. B. Solsberg. 1977. *Field Evaluation of Oil Mop and Preheat Unit*. Technology Development Report EPS-4-EC-77-12. Fisheries and Environment Canada.

Timco, G. W., and R. Frederking. 2009. *Overview of Historical Canadian Beaufort Sea Information*. Technical Report CHC-TR-057. Ottawa: NRC Canadian Hydralics Centre.

Timlick, Lauren, Jamie Dearnley, Jules M. Blais, et al. 2022. "Responses of Wild Finescale Dace (Phoxinus Neogaeus) to Experimental Spills of Cold Lake Blend Diluted Bitumen at the International Institute for Sustainable Development-Experimental Lakes Area, Northwestern Ontario." *Environmental Toxicology and Chemistry* 41 (11): 2745–57. https://doi:10.1002/etc.5457.

Timoney, Kevin. 2021. *Hidden Scourge: Exposing the Truth about Fossil Fuel Industry Spills*. McGill-Queen's University Press.

Torres, Josh, and Jenny Mandel. 2023. "Riding the Rails: Can Intermodal Transport Help Decarbonize Freight?" Environmental Defence Fund, October 19. https://business.edf.org/insights/riding-the-rails-can-intermodal-transport-help-decarbonize-freight/.

Trans Mountain. 2015. “Answering Some of Your Most Common Questions of 2014.” January 7. https://www.transmountain.com/news/2015/answering-some-of-your-most-common-questions-of-2014.

Trans Mountain. 2016. “Trans Mountain Receives Final Federal Approval of Expansion: Company Advancing Project for the Benefit of Canadians.” November 29. https://www.transmountain.com/news/2016/trans-mountain-receives-final-federal-approval-of-expansion-company-advancing-project-for-the-benefit-of-canadians.

Transport Canada. 2019. “National Oil Spill Preparedness and Response Regime.” https://tc.canada.ca/en/marine-transportation/marine-safety/national-oil-spill-preparedness-response-regime-0.

Transport Canada. 2022. *Canada’s Aviation Climate Action Plan: 2022–2030.* Government of Canada. https://tc.canada.ca/sites/default/files/2022-11/canada-aviation-climate-action-plan-2022-2030.pdf.

Transport Canada. 2023. “Oil Spill Prevention and Response in Canada: Preventing an Oil Spill.” October 5. https://tc.canada.ca/en/campaigns/oil-spill-prevention-response-canada/marine-oil-tankers-canada/preventing-oil-spill.

Transport Canada. 2024. “Minister of Transport Announces a Domestic Ban on the Use and Carriage of Heavy Fuel Oil in the Arctic.” June 28. https://www.canada.ca/en/transport-canada/news/2024/06/minister-of-transport-announces-a-domestic-ban-on-the-use-and-carriage-of-heavy-fuel-oil-in-the-arctic.html.

Transportation Safety Board of Canada. 2018. “Marine Investigation Report M16P0378: Grounding and Subsequent Sinking, Articulated Tug-barge, Tug *Nathan E. Stewart* and Tank Barge *DBL 55*, Seaforth Channel, 10 nm West of Bella Bella, British Columbia, 13 October 2016.” https://www.tsb.gc.ca/eng/enquetes-investigations/marine/2016/M16P0378/M16P0378.html.

Trites, R. W. 1985. “Preliminary Observations on Oil/Ice Interaction from CSS Hudson.” In *The Kurdistan Oil Spill of March 16–17, 1979: Activities and Observations of the Bedford Institute of Oceanography Response Team*, edited by J. H. Vandermeulen and D. E. Buckley, 39–47. Canadian Technical Report of Hydrography and Ocean Sciences No. 35. Fisheries and Oceans.

Trites, R. W., J. H. Vandermeulen, and D. Lawrence. 1980. “Kurdistan Spill Movement.” In *Scientific Studies During the Kurdistan Tanker Incident: Proceedings of a Workshop*, edited by J. H. Vandermeulen, 33–57. Bedford Institute of Oceanography.

Technical Services Branch. 1984. *A Winter Evaluation of Oil Skimmers and Booms*. Technology Development Report EPS-4-EP-84-1. Environment Canada.

Tucker, Amy. 2022. "Fuel Spill Into Hudson Bay Near Rankin Inlet Was Never Cleaned Up, Says Environment Canada." *CBC News*, April 30. https://www.cbc.ca/news/canada/north/fuel-spill-rankin-inlet-hudson-bay-nunavut-1.6436485.

UNCTAD (United Nations Conference on Trade and Development). 2024. *Review of Maritime Transport 2024: Navigating Maritime Chokepoints*. United Nations. https://unctad.org/publication/review-maritime-transport-2024.

Vandermeulen, J. H. 1985. "Oil-In-Ice and Oil-Stranding Characteristics." In *The Kurdistan Oil Spill of March 16–17, 1979: Activities and Observations of the Bedford Institute of Oceanography Response Team*, edited by J. H. Vandermeulen and D. E. Buckley, 49–64. Canadian Technical Report of Hydrography and Ocean Sciences No. 35. Fisheries and Oceans.

Vandermeulen, J. H., and D. E. Buckley, eds. 1985. *The Kurdistan Oil Spill of March 16–17, 1979: Activities and Observations of the Bedford Institute of Oceanography Response Team.* Canadian Technical Report of Hydrography and Ocean Sciences No. 35. Fisheries and Oceans. https://publications.gc.ca/collections/collection_2015/mpo-dfo/Fs97-18-35-eng.pdf.

Vandermeulen, J. H., B. Amero, and T. P. Ahern. 1980. "Physical Weathering of Kurdistan Oil: Droplet Formation and Effect on Shore-Ice Melting." In *Scientific Studies During the Kurdistan Tanker Incident: Proceedings of a Workshop*, edited by J. H. Vandermeulen, 105–119. Bedford Institute of Oceanography.

Velis, Costas. 2024. "A Global Plastic Treaty Will Only Work if It Caps Production, Modelling Shows." *Conversation,* May 3. https://theconversation.com/a-global-plastic-treaty-will-only-work-if-it-caps-production-modelling-shows-229218.

Venosa, Albert D., Kenneth Lee, Makram T. Suidan, et al. 2002. "Bioremediation and Biorestoration of a Crude Oil-Contaminated Freshwater Wetland on the St. Lawrence River." *Bioremediation Journal* 6 (3): 261–81. https://doi.org/10.1080/10889860290777602.

Vergeynst, Leendert, Jan H. Christensen, Kasper Urup Kjeldsen, et al. 2019. "In Situ Biodegradation, Photooxidation and Dissolution of Petroleum Compounds in Arctic Seawater and Sea Ice." *Water Research* 148:459–68. https://doi.org/10.1016/j.watres.2018.10.066.

Wall Street Journal. 1984. "Gulf Canada Unit Says Tests Indicate Oil Find In Canadian Beaufort." September 25. ABI/INFORM Collection.

Ward, Collin P., and Edward B. Overton. 2020. "How the 2010 Deepwater Horizon Spill Reshaped Our Understanding of Crude Oil Photochemical Weathering at Sea: A Past, Present, and Future Perspective." *Environmental Science: Processes & Impacts* 22 (5): 1125–38. https://doi.org/10.1039/D0EM00027B.

Warde, Paul. 2018. "Constructing Arctic Energy Resources: The Case of the Canadian North, 1921–1980." In *Competing Arctic Futures*, edited by Nina Wormbs, 19–46. Springer International Publishing. https://doi.org/10.1007/978-3-319-91617-0_2.

Waring, Gerald. 1970. "Canada Tests Remedies for Cold-Water Oil Spill." *Washington Post*, March 17. ProQuest Historical Newspapers.

Watkins, Lyndon. 1971. "Sea Birds Still Die: The Black Tide of Wrath in Chedabucto Bay." *Globe and Mail*, February 4. ProQuest Historical Newspapers.

Watts, Michael. 1983. "On the Poverty of Theory: Natural Hazards Research in Context." In *Interpretations of Calamity: From the Viewpoint of Human Ecology*, edited by K. Hewitt, 231–62. Allen & Unwin.

Watts, Michael, and Anna Zalik. 2020. "Consistently Unreliable: Oil Spill Data and Transparency Discourse." *Extractive Industries and Society* 7 (3): 790–95. https://doi.org/10.1016/j.exis.2020.04.009.

WCMRC (Western Canada Marine Response Corporation). 2018. "Can Spill Response Organizers Clean Up Diluted Bitumen?" May 25. https://wcmrc.com/can-spill-response-organizations-clean-diluted-bitumen/.

Weiss, Charles. 2003. "Expressing Scientific Uncertainty." *Law, Probability and Risk* 2 (1): 25–46. https://doi.org/10.1093/lpr/2.1.25.

Whittaker, Harry. 1987. "Laser Ignition of Oil Spills." *International Oil Spill Conference Proceedings* 1987 (1): 389–394. https://doi.org/10.7901/2169-3358-1987-1-389.

Whyte, Kyle. 2018. "Settler Colonialism, Ecology, and Environmental Injustice." *Environment and Society* 9 (1): 125–44. https://doi.org/10.3167/ares.2018.090109.

Wiens, John A. 2013. "Introduction and Background." In *Oil in the Environment: Legacies and Lessons of the Exxon Valdez Oil Spill*, edited by John A. Wiens, 3–36. Cambridge University Press.

Wilhelm, Sabrina I., Gregory J. Robertson, Pierre C. Ryan, and David C. Schneider. 2006. "An Assessment of the Number of Seabirds at Risk During the November 2004 Terra Nova FPSO Oil Spill on the Grand Banks." Canadian Wildlife Service, Technical Report Series No. 461. Environment Canada. https://publications.gc.ca/collections/Collection/CW69-5-461E.pdf.

Williams, Chloe. 2019. "Meet the Scientists Who Pollute Lakes on Purpose." *Atlas Obscura*, July 30. https://www.atlasobscura.com/articles/oil-spill-experiment-lakes-ontario.

Williams, Raymond. 1980. *Problems in Materialism and Culture*: *Selected Essays*. New York: Verso Books.

Wilt, James. 2020. "The Ice Can Be Conquered": Scientific Knowledge and Mobilizing Arctic Gas." Unpublished master's thesis, University of Manitoba. https://mspace.lib.umanitoba.ca/server/api/core/bitstreams/5f6bf42f-4bd4-4956-a1fc-3c06acd5d360/content.

Wilson, Nicole J., and Jody Inkster. 2018. "Respecting Water: Indigenous Water Governance, Ontologies, and the Politics of Kinship on the Ground." *Environment and Planning E: Nature and Space* 1 (4): 516–538. https://doi.org/10.1177/2514848618789378.

Wilt, James. 2020. *Do Androids Dream of Electric Cars?: Public Transit in the Age of Google, Uber, and Elon Musk*. Between the Lines Books.

Witt O'Brien's, Polaris Applied Sciences, and Western Canada Marine Response Corporation. 2013. "A Study of Fate and Behavior of Diluted Bitumen Oils on Marine Waters." November 22. https://docs2.cer-rec.gc.ca/ll-eng/llisapi.dll/fetch/2000/90464/90552/548311/956726/2392873/2451003/2393359/B21%2D5_%2D_V8C_TR_8C_12_TR_S7_01_OF_03_FATE_DILUT_BITUMEN_MAR_WATER_%2D_A3S5G2.pdf?nodeid=2393796&vernum=-2.

Wong, C.S., F.A. Whitney, W.J. Cretney, K. Lee, F. McLaughlin, Jinping Wu Tianbao Fu, and Dongfa Zhuang. 1984. "An Experimental Marine Ecosystem Response to Crude Oil and Corexit 9527: Part 1—Fate of Chemically Dispersed Crude Oil." *Marine Environmental Research* 13 (4): 247–63. https://doi.org/10.1016/0141-1136(84)90032-1.

Wood, Steph Kwetásel'wet. 2024. "Frustrated With Canada's Spill Response, Heiltsuk Leaders Take Their Fight International." *Narwhal*, March 20. https://thenarwhal.ca/heiltsuk-nation-international-marine-organization/.

Woodside, John. 2024. "Canada Backs Call for Plastic Production Limits at International Summit." *Canada's National Observer*, November 29. https://www.nationalobserver.com/2024/11/29/news/canada-plastic-production-limits-international-summit.

Wright, D. D. 1972. Letter to All APOA Members Concerning Oil Spill Contingency Plans. June 30, 1972. File 358, Box 30, Subseries 5, Series 1, Arctic Petroleum Operators' Association and Eastcoast Petroleum Operators' Association Fonds (3066), Glenbow Archives, University of Calgary Archives & Special Collections.

WWF Canada. 2017. "Remote Arctic Communities Defenseless Against Oil Spills, Reports Conclude." May 24. https://wwf.ca/stories/remote-arctic-communities-defenseless-oil-spills-reports-conclude/.

Xu, Xingjian, Wenming Liu, Shuhua Tian, et al.. 2018. “Petroleum Hydrocarbon-Degrading Bacteria for the Remediation of Oil Pollution Under Aerobic Conditions: A Perspective Analysis.” *Frontiers in Microbiology* 9 (2885): 1–11. https://doi.org/10.3389/fmicb.2018.02885.

Yaffe, Barbara. 1985. “Fishermen Want Protection From Hibernia Oil Spills.” *Globe and Mail*, October 26. Canadian Major Dailies.

Yaffe, Helen. 2020. *We Are Cuba! How a Revolutionary People Have Survived in a Post-Soviet World*. Yale University Press.

Yuan, Zhi-Ming, Xinshu Zhang, Chun-Yan Ji, Laibing Jia, Huaming Wang, and Atilla Incecik. 2018. “Side Wall Effects on Ship Model Testing in a Towing Tank.” *Ocean Engineering* 147 (January):447–57. https://doi.org/10.1016/j.oceaneng.2017.10.042.

Zalik, Anna. 2009. “Zones of Exclusion: Offshore Extraction, the Contestation of Space and Physical Displacement in the Nigerian Delta and the Mexican Gulf.” *Antipode* 41 (3): 557–582. https://doi.org/10.1111/j.1467-8330.2009.00687.x.

Zehr, Leonard. 1979. “Discovery of Natural Gas Off Nova Scotia Stirs Hopes of Commercially Viable Field.” *Wall Street Journal*, July 3. ProQuest Historical Newspapers.

Zhong, Xiaomei, Haibo Niu, Pu Li, Yongsheng Wu, and Lei Liu. 2022. “An Overview of Oil-Mineral-Aggregate Formation, Settling, and Transport Processes in Marine Oil Spill Models.” *Journal of Marine Science and Engineering* 10 (5): 610. https://doi.org/10.3390/jmse10050610.

Appendix A: Experimental Spills in Canada

Date of spills	Site	Volume (type)	Study focus
Aug. 16, 1972	Tributary of Caribou Bar Creek in Northern YT	250 litres (Norman Wells crude)	Biological
Sept. 5, 1972	Small floodplain lake in Mackenzie Delta, NT	409 litres (Norman Wells crude)	Biological
Mar. 7–9, 1973	Small bay on the St. Lawrence River, near Rimouski, QC	460 litres (Ceuta crude and Bunker C)	Burning
Aug. 6–7, 1973	Two small lakes in Mackenzie Delta, NT	240 litres (Pembina and Norman Wells crudes)	Biological
July–Dec. 1973	Burlington Canal in Hamilton Harbour, ON	At least 727 litres (No. 2 fuel oil and Alberta crude)	Skimmers
Apr. 30, 1974	Near Resolute Bay, NT	455 litres (Unknown)	Ice/biological
Oct. 24, 1974–May 21, 1975	Small bay 20 km SW of Cape Parry, NT	56,000 litres (Norman Wells and Swan Hills crudes)	Ice/burning
June 25–July 11, 1975	Port Moody arm of Burrard Inlet, Vancouver, BC	Up to 2,385 litres (Western crude)	Skimmers
Aug. 1975–Mar. 1976	Bedford Basin, Halifax Harbour, NS	Unknown (Light Arabian crude)	Skimmers
May 7–14, 1976	Offshore of Esquimalt, BC	2,028 litres (Western crude, diesel, heavy bunker fuel)	Skimmers
Sept. 23–Oct. 23, 1976	St. Lawrence River at Canadian Coast Guard base in Quebec City, QC	7,139 litres (Light Arabian crude and diesel)	Skimmers
Apr. 19–26, 1977	Canadian Coast Guard base in Sorel, QC	At least 1,485 litres (Western crude and Bunker C)	Skimmers
May 19–20, 1977	St. Lawrence River at Canadian Coast Guard base in Quebec City, QC	866 litres (Light Arabian crude and diesel)	Skimmers
Aug. 12–25, 1977	Near and in Esquimalt Harbour, BC	760 litres (Alberta crude, diesel, Bunker C)	Skimmers
Sept. 26, 1977	Saanich Inlet, BC	6 litres (Prudhoe Bay crude)	Dispersants
Sept. 27–Oct.6, 1977	In Quebec City Harbour, QC	Unknown (Heavy Iranian crude and diesel)	Skimmers
Early 1978	Settling pond of Holyrood refinery, NL	Unknown (Persian Gulf crude)	Skimmers

June 1978	Outer reaches of Conception Bay, NL	2,045 litres (Persian Gulf crude)	Skimmers
June 1, 1978	Griper Bay in Melville Island, NT	1,800 litres (Norman Wells crude)	Ice
Oct. 11–13, 1978	Near Esquimalt Harbour, BC	800 litres (North Slope crude)	Dispersants
Mar. 13–14, 1979	Sumas Prairie near Abbotsford, BC	No oil (aerial dispersant test)	Dispersants
May 14, 1979	Ice surface of lake on Giant Mine property near Yellowknife, NT	173 litres (Nektoralik crude)	Burning
Dec. 17, 1979–May 2, 1980	In ice near McKinley Bay, NT	19,600 litres (Prudhoe Bay crude)	Burning/ice
Feb. 29–Mar. 8, 1980	Settling pond of Holyrood refinery, NL	Unknown (Venezuelan crude and Bunker C)	Skimmers
Apr. 9, 1980	St. John's Harbour, NL	Unknown (likely Venezuelan crude and Bunker C)	Skimmers
June 10–July 6, 1980	In ice near McKinley Bay, NT	No oil (aerial igniters using already spilled oil)	Burning
Sept. 16–18. 1980	Canadian Forces Base Suffield, AB	No oil (aerial dispersant test)	Dispersants
Aug. 20, 1980–Aug. 12, 1982	Cape Hatt on Northern Baffin Island, NU	45,000 litres (Lagomedio crude)	Dispersants/ biological/ shoreline
Oct. 21, 1981	About 50 km offshore of St. John's, NL	3,180 litres (Lagomedio crude)	Dispersants
Mar. 20–22, 1982	In ice near McKinley Bay, NT	348 litres (Kopanoar crude)	Ice/burning
July 17, 1983	Saanich Inlet, BC	250 millilitres (Prudhoe Bay crude)	Dispersants
Sept. 12–17, 1983	About 45 km offshore of Halifax, NS	15,000 litres (ASMB crude)	Dispersants
Sept. 4, 1984	Near Shingle Point in Mackenize Bay, YT	48 litres (Tarsuit crude)	Dispersants
Sept. 19, 1984–July 19, 1986	Sheltered cove about 60 km east of Halifax, NS	Unknown - 200 millilitres of oil per enclosure (Scotian Shelf condensate and Hibernia crude)	Shoreline
Aug. 11–14, 1986	40 km offshore of Tuktoyaktuk, NT	15,000 litres (ASMB crude)	Dispersants
Mar. 9–10, 1986	140 km offshore of Chedabucto Bay, NS	3,000 litres (ASMB crude)	Ice

July 7, 1986	Saltmarsh on Petpeswick Inlet, NS	41 litres (ASMB crude)	Shoreline/ dispersants
Sept. 24, 1987	About 45 km offshore of St. John's, NL	68,100 litres (Brent crude with slack wax addition)	Skimmers/spill-treating agents
Sept. 9–10, 1987	About halfway between Halifax and Sable Island, NS	8,000 litres (ASMB crude and Bunker A)	Spill-treating agents
Aug. 12, 1993	About 40 km offshore of St John's, NL	77,000 litres (ASMB crude)	Burning
July 29–Aug. 2, 1997	Three beaches in Svalbard, Norway	5,500 litres (intermediate fuel oil)	Shoreline
June 10, 1999	Freshwater wetland along St. Lawrence River near village of Sainte-Croix, QC	192 litres (Mesa crude)	Shoreline
June 6–8, 2000	Coastal salt marsh near mouth of Petpeswick Inlet, NS	72 litres (Mesa crude)	Shoreline
Jan. 30–Feb. 1, 2008	St. Lawrence River off the coast of Matane, QC	600 litres (Heidrun crude)	Spill-treating agents
Spring 2018	Shoreline of Lake 260 of Experimental Lakes Area, ON	2.5 litres (Conventional heavy crude and diluted bitumen)	Shoreline/ biological
June 20, 2018	Lake 260 of Experimental Lakes Area, ON	332 litres (diluted bitumen)	Biological
Summer 2019	Shoreline of Lake 260 of Experimental Lakes Area, ON	10 litres (diluted bitumen)	Shoreline/ biological
Summer 2021	Shoreline of Lake 260 of Experimental Lakes Area, ON	4 litres (Conventional heavy crude)	Shoreline/ biological

Appendix B: Largest Marine/Aquatic Spills in Canada

Date	Site	Volume (type)	Source
Feb. 1970	Chedabucto Bay, NS	9.5 million litres (Bunker C)	Tanker (*Arrow*)
June 1970	Deception Bay, Northern Nunavik, QC	1.6 million litres (Diesel and gasoline)	Storage tank (Asbestos Corp.)
Sept. 1970	60 km offshore of PEI	1.3 million litres (Bunker C)	Barge (*Irving Whale*)
Apr. 1974	St. Lawrence River, off Montreal Island, QC	660,000 litres (Crude)	Tanker (*Imperial Sarnia*)
Aug. 1974	Saglek, NL	1.9 million litres (Diesel)	Storage tank (NORAD base)
Dec. 1974	House River, AB	1.9 million litres (Crude)	Pipeline (Great Canadian Oil Sands)
May 1976	Strait of Canso, Point Tupper, NS	700,000 litres (Diesel)	Refinery (Gulf Canada)
Mar. 1979	Cabot Strait, near Cape Breton, NS	7.2 million litres (Bunker)	Tanker (*Kurdistan*)
Dec. 1980	Valleyview, AB	6.5 million litres	Pipeline (Pembina Pipelines)
Sept. 1981	Port of Quebec, QC	1 million litres (Bunker)	Cargo ship (*Armonia*)
Sept. 1985	Beaufort Sea offshore	388,000 litres (Diesel)	Offshore drilling (Esso's Minuk I-53)
May 1988	Ultramar docks, St. Lawrence River, Levis, QC	750,000 litres (Crude)	Tanker (*Czantoria*)
June 1990	Large area of muskeg near Rocky Mountain House, AB	1.6 million litres (crude)	Pipeline (Amoco)
June 1992	House River, AB	1.2 million (Diesel and naphtha)	Pipeline (Suncor)
Aug. 2000	Pine River, near Chetwynd, BC	1 million litres (Crude)	Pipeline (Pembina Pipelines)
Aug. 2005	Wabamun Lake, AB	700,000 litres (Bunker)	Rail (CN Rail)
July 2011	Near Little Buffalo, AB	4.5 million litres (crude)	Pipeline (Plains Midstream)
June 2012	Large area of muskeg in northwest AB	800,000 litres (crude)	Pipeline (Pace Oil & Gas)
Mar. 2015	Gogama area, near Sudbury, ON	1 million litres (crude)	Rail (CN Rail)
Nov. 2018	Offshore of St. John's, NL	250,000 litres (crude)	Offshore drilling (Husky's SeaRose)

Appendix C: Largest Marine/Aquatic Spills Outside but Connected to Canada

Date	**Site**	**Volume (type)**	**Source**	**Connection to Canada**
Nov. 1988	1,300 km off coast of NS	160 million litres (Brent crude)	Tanker (*Odyssey*)	Bound for Come by Chance, NL refinery
Jan. 1989	Grays Harbor, Washington State, US	875,000 litres (Bunker C)	Barge (*Nestucca*)	Significant volumes of oil hit BC
Nov. 1990	600 km off coast of NS	Between 15 and 25 million litres (Arabian crude)	Tanker (*Berge Broker*)	Bound for Saint John. NB refinery
Jan. 1993	Shetland, Scotland	100 million litres (Gulfaks crude)	Tanker (*Braer*)	Bound for St. Romouauld, QC refinery
July 2010	Kalamazoo River, Michigan, US	3.2 million litres (dilbit)	Pipeline (Enbridge Line 6B)	Carrying Alberta dilbit through US to Ontario