RESEARCH ARTICLE

System identity and transformation in petroleum jurisdictions: A multi-method approach for the North Slope Borough, Alaska

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Abstract

Capturing the multidimensionality of a bounded social-environmental system (SES) presents a range of challenges to interdisciplinary researchers due to the need to integrate divergent scientific paradigms, scalar data, and social theories. Contemporary Arctic circumpolar SESs studied under conditions of rapid and unprecedented climatic, ecological, economic, and sociopolitical change, defy any singular established methodological approach that aims to schematize and interpret the system for decision-making purposes. As a small interdisciplinary team working within a large Arctic SES modeling effort, we have found that developing systems models to support resilience in the Arctic requires an understanding of system dynamics that is attentive to holistic indicators of change, measured both quantitatively and qualitatively. Using the Alaska North Slope Borough as a case study, we apply three convergent frameworks to capture significant dimensions of the system for improved problem definition in confronting the challenges of Arctic climate change. We describe contemporary "oil and gas" social-ecological system components and dynamics, the historical processes and transformations that fundamentally altered the system, and the scientific projections for the most likely catalysts of future change. This analysis results in a typology for defining subnational Arctic hydrocarbon SESs. We conclude that the future of oil and gas development as a policy pathway in different locations experiencing rapid climate change can be evaluated when difficult-to-quantify variables are included.

Author summary

In recent decades, Arctic research approaches have included diverse but standardized spatial and temporal scales, rarely engaging with subnational regionality (i.e., states, municipalities, territories). System identity and transformation studies have been methodologically confined within disciplinary silos, attending to fundamental biophysical dynamics, socioeconomic models, or historical developments. To provide a holistic social-environmental understanding of an Arctic region and its transformative possibilities, we present a multidimensional study of the coastal hydrocarbon-producing North Slope Borough. Building on current scholarship, climate data, government reports, and

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recent participatory scenarios work, we investigate system identity asking whether the region's financial, social, and environmental investment in hydrocarbons will persist under changing political and environmental conditions. The resulting typology demonstrates the value of multidisciplinary coupled social-environmental research for key elements in a system that may not be easy to quantify for current models, such as the role of Indigenous Peoples in resisting and adapting to colonial processes, state and local level decision making, and subnational environmental concerns. Focusing on a widespread form of Arctic resource extraction, our paper speaks to many other remote, hydrocarbon-dependent jurisdictions. It provides insight for policy-making and development under social and environmental uncertainty by highlighting the entanglement of energy regimes, power relations, cultural conflict, and climate change.

1 Introduction

Evidence indicates that the Arctic is undergoing rapid environmental changes driven by anthropogenic global warming. According to the US Global Change Research Program's 2017 Climate Change Special Report, over the past 50 years, annual average near-surface air temperatures across Alaska and the Arctic have increased at a rate more than twice as fast as the global average. This warming has precipitated other changes in Arctic systems, such as melting glaciers; diminishing sea ice, which is decreasing in age, thickness and extent; and thawing permafrost, both on land and under coastal waters. In brief, the Arctic is undergoing a transformation towards a warmer system with potentially large socio-ecological changes. The consequences of this trend include significant alterations to the seasonal and annual cycles that people rely on in Alaska. This affects cycles of hunting, harvest, and fishing, as well as mobility, storage, and safety of people and infrastructure.

The coastal zones in the Arctic are of special concern because they not only provide a dynamic interface between land and ocean, but they are where the majority of human activity takes place in the High North. How sensitive any coastal area is to changing environmental conditions (e.g., wind, waves, erosion, accretion) depends on permafrost, ice below land surface, and sea ice [1]. Because these environmental "states of being frozen" change with the pressures of warming and development, both affecting the balances of land-atmosphere energies and storm frequency and intensity, these coasts are becoming more dynamic. Such dynamism for the North Slope coasts means historical records (i.e., western scientific) are less applicable, operations in the region are riskier, and people and organizations have higher levels of uncertainty in their planning. Is the North Slope Borough heading towards a major *transformation* and what perspectives have bearing on how that transformation occurs?

Currently, public and private sector attention is fixed on the region's changes, happening at a rate twice as fast as in lower latitudes [2]. In the North American Arctic, coupled human-natural systems have been conditioned by the cryosphere for millennia to shape the present-day cultures, livelihoods, local to global relationships, ecosystem benefits, threats to stability and possibilities for regime change, or "transformation" [3,4]. But the current period is novel with no evidence from scientific data or oral histories that have planet-wide climatic, geospheric, and biospherical changes of such magnitude. The tension underlying these system dynamics between novel and continuous forms is often addressed in the language of "resilience". Resilience scholarship examines the maintenance and change of fundamental properties in systems facing perturbation [5–8]. Similar literatures that address social-environmental systems [9–11] have explored when fundamental reorganization within a system takes place. These studies mobilize different parameters to define system identity and human environmental subjectivity. Given the interest from geophysical, natural, and social sciences in the changing arctic system and how it affects individuals, peoples, communities, and locations, it is important to develop an understanding of what interdisciplinary concepts of system identity and transformation may mean and how they can support planning and management efforts on a planet whose climate regime may not permit continuation of "business as usual" [113,114]. We explore *transformation* with a detailed case study of the North Slope Borough (NSB) in Alaska in support of a defining typology for petroleum-dependent social-environmental systems at scales smaller than the national level.

This paper represents a portion of a larger research project, the Interdisciplinary Research for Arctic Coastal Environments (InteRFACE) that aims to quantify and reduce uncertainties in our fundamental understanding of the magnitude, rates, and patterns of change along Arctic coasts. In recognizing the complex co-evolution of human and natural systems in the Arctic, our paper distills key aspects of an Arctic Oil & Gas coastal Socio-Ecological System (SES) to assess the future of resource development and human activity in the Arctic. First, we aim to understand system identity and change in the North Slope Borough in order to lay the groundwork for further improvement of projections and integrated models of Arctic coastal regions. Second, we strive to define a coupled oil & gas-Arctic community SES as a distinct type, embodied paradigmatically by the NSB and reflected at various scales across the High North. Third, we synthesize the use of participatory and earth system model scenarios to describe the limitations in each approach, and suggest pathways for more convergence in futures thinking moving forward.

1.1 Social-environmental systems and typologies

It is now accepted that the interactions between the human and the non-human are so tightly linked that the "coupled social-ecological system" can be addressed as an integrated unit of analysis [7,12]. An interdisciplinary literature examining the attributes of social-ecological systems (SESs) has developed that strives to understand the feedbacks between society and ecosystems in order to inform institutional arrangements and management practices [12–14] and what the management goals for such complex systems may be [5,15]. Anderies et al. [14] define a social-ecological system (SES) as "an ecological system intricately linked with and affected by one or more social systems." In order to capture non-living features in the system such as sea ice [16] we change "ecological" to "environmental," cleaving more to the National Academy of Sciences description of the core dynamic of an SES as an interaction when "system A affects system B, and system B, in turn, affects system A as a two-way interaction" [17,18]. Both the social and environmental components of a system have self-organizing independent relationships contained within them. For example, the Porcupine Caribou Herd is a complex ecological unit, composed of numerous individuals, but operating as a unitary sub-system. This sub-system interacts with the landscape and broader environment (through consumption of vegetation and lichen, drinking of water, decomposition of bodies), with other species (e.g., as prey), with the Gwich'in people (providing cultural, spiritual, and caloric sustenance), and with the federal US and Canadian governments (through being inscribed as resources of national significance). In sum, the socio-economic and political natures of human populations are in part determined by how these populations interact with their natural surroundings. It is the historic coherence of this mutually-constituting condition of complex socio-natures in the NSB that allows us to define it as the provisional core system under analysis. As Andrachuk and Armitage [18] point out, system identity is a heuristic that allows for an examination of patterns of continuance and transformation. Identity and transformation are thus mutually-constitutive as well as mutually-limiting.

More specifically, the ecological elements of a location are "formative in the development and maintenance of human identities" through iterative interactions between humans, their environment, and the web of normative relationships created in the SES tied to markets, rule sets, cultures, technologies, and sensory cues [19,50]. Consequently, people living and working in a particular environment with a particular array of imposed rule sets and personal choices–such as those in the North Slope Borough where the communities are tied physically, economically, and existentially to both ice regimes and hydrocarbon production–will have similar experiences and engage in some similar behaviors. We argue that the social and physical construction of petroleum producing installations within Arctic political jurisdictions below the national level are a particular type of SES.

The environmental changes happening in concert with socio-economic changes across the Arctic are tied primarily to global trends of market expansion in shipping, market growth, and resource extraction industries such as mining, oil, and gas. Such exogenous factors impact the NSB both directly, through localized pollution events, and indirectly, through contributing to climate change and moving economic wealth and opportunity to different locations. The general demographic trend in the Arctic, including Arctic Alaska, is slow population growth overall, with populations growing in cities as smaller rural communities gradually depopulate [20]. Because most of rural Alaska and a majority of its Indigenous inhabitants operate in a mixed-subsistence economy in which store-bought foods, wild-harvested foods, and fuel are vital components of maintaining food security [21–24]. Forces influencing the biological productivity of the local landscape have an outsize effect on regional food security, making dependence on a limited and hazardous economic portfolio risky.

1.2 Resilience and transformation

Early theorists of resilience distinguished ecological from engineering resilience. In the former, focusing on capacity for persistence and adaptation and in the latter the capacity to "bounce back" after a disturbance, but both hinging on a mechanistic, modern concern with an equilibrium [25]. As originally formulated, resilience had no application to policy or social theory. On the heels of the sustainability discourse, however, resilience has become a key concept to define the magnitude of disturbance a system can undergo before it enters a different state with different dynamics and parameters [26]. For our purposes, we use the Arctic Resilience Report [4] definition as the "capacity to cope with stress and shocks by responding or reorganizing in ways that maintain essential identity, function, and structures, as well as the capacity to navigate and shape change, including transformational change (xvii)". Resilience can be identified across scales: system-wide resilience, indicating overall stability, or the resilience of a given component, retaining its own function and identity amidst change. A single change of sufficient magnitude, such as with climate or pollution, can push whole systems (and their composite parts) over thresholds, whereas gradual change across a sufficient number of components, can likewise trigger a change in system identity. Resilience is a measure of how easily this can occur. The Arctic Resilience Report further defines "transformation" as a "fundamental change to the coupled social-ecological system" (xvii). Transformations, as with resilient phenomena, have no inherent positive or negative tendency; they are evaluated from the diverse vantage points of people and the sectors of society located within and outside of the system. Because systems are nested, actors may perceive a transformation because of significant changes in a component or sub-system, though this may not precipitate a classifiable transformation in whatever larger system is under investigation.

In this paper, with the NSB as our geographically and jurisdictionally-bounded system, transformations will only refer to those changes that qualitatively reconfigure the whole system. Oran Young [27] provides us a concise typology of transformations that can occur in a system: inflections, cascades, and explosions. *Inflection* refers to "asymmetrical changes in key variables that alter the dynamics of complex systems in such a way that the systems experience transformative changes over time" [ibid. 72]. *Cascades* depend on a single event that triggers a positive feedback loop, with a "domino effect" progression; Young uses the example of the Great Depression and its contribution to the rise of Fascism in Germany. And *explosions*, as the name suggests, are abrupt state changes—examples include the onset of war, natural catastrophes, and radical changes in electoral politics. We will use this typology to understand the nature and long-term impacts of changes in the NSB.

2 Materials and methods

Our article has an applied component. In order to capture a multidimensional profile of the NSB, we adopt three distinct methods that augment and reinforce one another in service to well-informed decision-making. Respectively, the DAPSIWRM framework provides a contemporary schematic of all major system components and their relationships to Arctic coastal activity. Periodization provides a historic overview centered on key transformative events in system identity, and scenarios offer scientifically and socially-grounded data to use in planning and priority-setting. In their review of "socio-ecological" system identity and transformative potential, Andrachuk and Armitage use periodization to understand a system's perceived identity and reduce conceptual vagueness among managers and resource users, avoiding "confusion and communication breakdowns, false inferences about real-world problems, and subsequently, challenges for application in management" [18]. This attention to management is realized in our initial use of the DAPSIWRM framework to structure the complex problem tied to data organization for any SES, in particular dynamic locations [28]. After applying the DAPSIWRM framework to the contemporary North Slope Borough SES we take this understanding further by asking, how is the NSB of today related to its past and future? More narrowly we are asking about system resilience in one place over time in order to ultimately organize the SES elements into a typology that can be used as a variable, building block [29], or as insight into management concerns for Arctic coasts. This mutual understanding of place identity, in particular between Indigenous populations and "administrators" is crucial to collaborative adaptation, especially where change is rapid [115,116,117].

Andrachuk and Armitage [18] develop an empirical approach to understanding SES change and transformation by using community perceptions of system identity developed from fieldwork and interviews in small-scale fisheries in Vietnam. They consciously note that their goal was to ". . .build up a rich and holistic understanding of this particular case rather than make generalizations about social-ecological transformations. . ." They use an approach that emphasized "community-based research that is sensitive to local interests and cross-cultural issues, and is oriented toward embracing local knowledge and the expertise of local resource users" [ibid. 3]. While not escaping the importance of individual and community perception as sources of evidence for SES definition and transformation, we explore more deeply the nature of a SES itself using other forms of empirical evidence. First we structure our location in the present day and problematize its identity via the DAPSIWRM framework. Second, we use a historical periodization of the jurisdiction as a method of understanding shifts in system identity by creating bounded periods reflecting significant and diverse transformative events.

2.1 DAPSI(W)R(M) as a tool for structuring the problem of transformation

It can be difficult to evaluate relationships between system components within a Social-Environmental System. An increasingly used interdisciplinary [30] framework for integrated coastal and marine management is DAPSI(W)R(M) [31,32]. Our use of this decision-support tool is not to suggest decisions that should be made, but to provide the information necessary, about a SES, to consider making decisions. It helps explain how the different parts of the system relate across scales by structuring the elements of any SES. The key feature of this framework is its disentanglement of a SES's drivers, human activities, pressures on the system as a result of human activities, state changes in the environment, impacts to human well-being, and human responses labeled measures. Lovecraft and Meek [33] have adapted the DAPSI(W)R(M) framework to examine Arctic coastal systems and provide a discussion of the advantages and limitations of its use for such locations. It is important to note that the framework itself only categorizes the effects of these system elements, it does not value or prioritize them. Below we offer a diagram of the NSB system and the primary factors impacting it within the structure provided by DAPSIWRM (Fig 1).

The Drivers are represented as features of human desire in the globalized Anthropocene. They have no fixed or singular cause or institution; they are unregulable and fundamental. The primary suite of Activities that concern us are those producing changes in specifically the coastal and cryosphere features of the North Slope of Alaska. Pressures are the results of activities that create system changes for humans and environments. Cormier, Elliott, & Rice describe pressures as creating risks in society [34].

State changes are not temporary, but constitute what can be identified as a change in the environmental portion of the system. Critical thresholds in sea salinity, invasive species dominance, sea ice loss, or urbanization, can be regarded as state changes, which Elliot et al. [35] describe as "a signal against a background of inherent variability ('noise') to relate to the

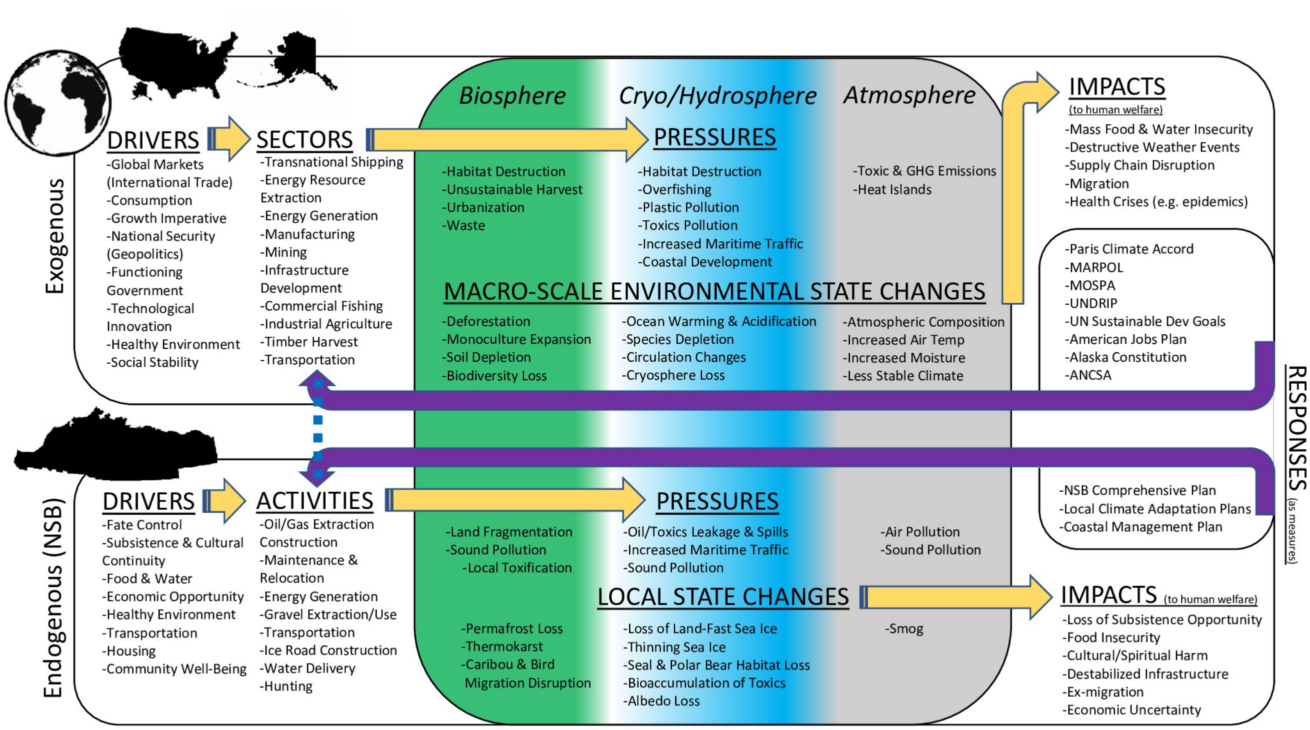

Fig 1. Application of the DAPSIWRM framework to the North Slope of Alaska.

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natural system (the ecology) due to single or multiple Pressures. This includes both the physico- chemical variables (i.e. sediment type, dissolved oxygen, organic matter, etc.) and biological health at all levels of organization—the cellular system, individuals, populations, communities and ecosystems." Lastly, we describe Impacts at broad scales (such as widespread food and water insecurity and associated concerns of health and well-being, framed from both Western and Indigenous perspectives), and local scale impacts (such as loss of subsistence opportunity). The suite of Measures (responses) can occur at local, national and international levels, but may not address all of the impacts on the North Slope SES. Due to the history of the region we have records that can directly link state changes to pressures and then up to activities which are the result of human drives for material goods, food, energy, or human identity in a specific time period. We detail this in the discussion of the historical transformations below.

2.2 Periodization as a tool for understanding the history of transformation

Above we have structured the contemporary problem of the North Slope Borough in a way that demonstrates the location as one of centuries-long steady externally-driven resource extraction Pressures, by forces not open to local input even through Alaska Statehood, that have changed the State of the region and fundamentally altered the lives of Inuit and other Alaska Natives. Measures to empower the Indigenous population or resist global market exploitation have been relatively weak feedbacks in a SES that has continued to produce products for global commerce. Why?

Periodization of changing system identity organizes historical sources of continuity and novelty in order to understand how system conditions have shaped the path of development [18,36]. The emergence and persistence of properties in social-environmental systems over the past feeds directly into how system identity and other properties may act in the future. We use the study of institutions, those sets of rules defining the nature of the North Slope Borough, to ground our periodization, rather than periods of environmental change, because the nature of the location has had a relatively stable environment through its most recent period of oil development. It is the direct and targeted push for the extraction of resources significant to the global economy that has changed the rules for the borough region for over a century. Following Lieberman, this section has evaluated the outcomes of the SES by analyzing "the joint effect of changing, noninstitutional variables," the Pressures and State changes, on the "sticky institutional factors that tend to change more slowly" ([37]; page 1013). In this manner,

> Periodization is a cornerstone of virtually all historical analysis that involves the simplification of history through the recognition of certain types of events or processes as more "important" than others. . . and that uses the dates of those events as dividing lines for a chronology. Periods are bounded by important events, changes, or turning points that can be conceptualized as markers of variation in a potentially important explanatory variable- . . .Within a mass of historical observations, only a few events define a period, whereas most other events and processes are explained as taking place during a period [ibid. 1017].

Through this method we have identified five distinct periods in the evolution of the Alaska North Slope system that are distinguished by political, economic, environmental, and intersectional thresholds, each leading to novel dynamics and trends within the total system. We use these insights to narrate the history of Alaska's North Slope as a region that has evidenced multiple system identities through gradual integration of both endogenous and exogenous forces. By establishing separate periods that define the region, we can then determine if the key variables binding the current period are destabilizing, reorganizing, or changing.

2.3 Scenarios as a tool for projecting future transformations

Having articulated the history of transformation and its processural structure, our final step in characterizing the NSB SES depends on the use of scenarios methods to identify the likeliest sources of novelty and uncertainty in the future. Scenarios work, in our experience, has two dominant strains that respectively fall into social and environmental disciplinary silos: participatory scenarios of futures and scenarios based on environmental modeling. The participatory scenarios approach has been applied on the North Slope to engage communities and decision-makers with a breadth of perspectives on North Slope futures [107,108]. In-person discussions during participatory scenarios workshops provide the opportunity for knowledge exchange and social learning that can form the basis for creative scenario narratives that do not require quantifying or constraining uncertainty. This allows wild-card events such as the occurrence of a major Arctic oil spill or influential geopolitical events to be considered in scenarios of SES transformation. In contrast, scenarios based on modeled environmental phenomena such as air temperature and sea ice change with different emission scenarios tend to focus on quantifiable, physical aspects of SES change. Both types of scenarios approaches are included in the discussion as each approach provides a unique component of future system transformation research.

2.4 Addressing scales and sources of change

Using these three methods, we can better understand the complex set of dynamic relationships that threads across transnational industries and U.S. federal and state politics to shape the well-being of individuals in the NSB. Degrading impacts on the environment and Indigenous food security create disproportionate harms to Arctic communities, both economically and medically, with likely downstream consequences for government expenditures on medical and food provisioning [118]. Likewise, individuals, movements, and biophysical resources from within the NSB have dramatically impacted the systems of which they are a part, not least in terms of enhancing both natural and economic value and supporting year-round populations. We structure our method around the problematic of cross-scalar relations in the development of a bounded system over time. But, to explain the system's identity, or "type", it is necessary to understand the development of its defining path dependencies, core elements, and social construction (modes of representation), which each have distinct spatial and temporal elements.

It is important to recognize that what is "manageable" (Endogenous) and not manageable (Exogenous) in a SES can be a fuzzy line. Measures are often endogenous rules, laws, and practices that target activities in response to the impacts on human well-being. Between the NSB coastal communities and the largely exogenous Pressure of climate change there are some effects that can be managed even though management of them in no way can change the nature of the Pressure. There is a strong disconnect between the causes of what is changing our cryosphere–global Drivers and Activities–and the possible Measures that could be taken at a local level. Naturally, as one scales up in governance more possibilities arise to mitigate the impacts of emissions and development. In sum, DAPSI(W)R(M) demonstrates a way to create a defined set of variables that make up a system for analysis. It provides a structure to the key relationships across the system that let one analyze the flows of people and their environment. From this we can inquire about the historical nature of the NSB SES identity and whether climate change will push this place into transition and transformation.

3 Results

3.1 Overview the NSB region and bounded periods of identity

Over more than two-hundred-years, from initial contacts to the present Great Acceleration [38], the ecology and society of the North Slope was irrevocably diminished by exogenous markets. Disease, violence, and other products of settler colonialism reduced the Alaska Native population, estimated at nearly 140,000 prior to contact, to 28,300 by 1900 [39], paving the way for the expropriation of native lands and wealth and imposition of settler structures [40]. The gold rush of the 1890s doubled Alaska's non-native population, altering the landscape with mining operations and permanent settlements and instigating new instruments of governance. By 1950, Euro-American settlers, concentrated largely in the south, comprised approximately 72% of Alaska's total population. Soon, prospects for state control of resource wealth, civil institutions, and commerce would serve to destabilize, then push the "frontier" system into a new regime, firmly embedded in US federalism and subject to a wider range of local and national interests. The initial breach in "isolation" in 1744 constituted a tipping point—an *explosion* transformation [27]—as imperial projects of expansion realized Alaska's colonial potential, driving commercial and state interests alike to enclose and exploit the region. By 1959, at the time of statehood, the North Slope Iñupiat found themselves disenfranchised subjects, whose region had national scientific interest but few modern economic opportunities. They were increasingly cognizant of impending changes to land tenure rules. At the millennium the science of climate change was coming into focus around the globe. Shortly after it was discovered that the Earth's poles are warming at rates twice as fast as the rest of the planet and this strongly disrupts Arctic coastal social-environmental systems.

3.1.1 Colonization: 1744–1959. The core elements of the North Slope Borough system have existed since time immemorial: the biophysical system and the Iñupiat people, whose culture nurtured reciprocal and sustainable relations with the natural world, left few permanent structures, but whose kin networks extended across Arctic North America and Eurasia. The historical "golden spike" separating pre-contact core actor-networks within the system from settlers constitutes a Euro-historical baseline of system identity that has since inherited and assimilated extreme, expropriative, and exogenous sources of novelty. Russian colonization in the mid-18th century marked the monumental and genocidal first encounter between Europeans and Indigenous People of the Alaska region, destroying the sustainable system of human-nature reciprocity with its rapacious mercantile orientation towards the harvest of fur-bearing animals [41]. This colonial relationship, whereby the resources of Alaska were extracted to enrich an imperial center, would become the defining trend henceforward. Though Russians did not physically reach the North Slope, operating predominantly in the Aleutians and Southeast, the devastation of local species, especially fur seal and otter, and the spread of disease could be felt as far as the North Slope.

Direct changes to the region can be traced to the northwestward expansion of whaling in the mid-19th century. After the Alaska purchase by the U.S. Johnson Administration in 1867, American whalers descended on the North Pacific and the Arctic to provide oil and baleen to booming industries. The exogenous pressure of the U.S. market also generated, and subsequently met, some endogenous needs as Iñupiat began to frequent trading posts and settlements at Point Barrow and Point Lay. There, Iñupiat were rapidly drawn into the seasonal wage employment of commercial whaling, their labor purchased with goods such as rifles, kettles, and alcohol. Iñupiat traditions and social structures survived these agents of change, albeit indelibly altered. But whalers and territorial administrators exploited this economic adaptability for commercial gain, resulting in material dependencies, intergenerational division, and, after the collapse of the whaling trade in the early 1900s, intermittent poverty [42]. Extractive logics drove oil exploration beginning in the 1920s while military construction projects during and after WWII provided work and indicated strengthening state institutional presence on the North Slope.

3.1.2 Growth of institutions and infrastructure: 1959–1976. With the establishment of Alaskan statehood in 1959, the North Slope underwent extreme transformation, with a series of *cascading events* involving the mass reorganization of land ownership and rights [43], the creation of novel state institutions and municipal bodies [44], and a sea change in the regional economy. Marking a shift in municipal responsibilities, budgetary mandates, and political possibilities, statehood represents a second threshold in the system's evolution. Statehood brought with it political hierarchy, requiring the application of technical legal procedures and redistricting and distribution of land. As Native land claims remained to be settled while the state began selecting its own lands, and as new state and federal agencies began to encroach upon traditional hunting and fishing rights, Alaska Native communities started politically mobilizing [45,46]. Longstanding power imbalances shifted as Native capacities and competencies in the use of US courts, the creation of organizations, including the Alaska Federation of Natives (AFN), and access to financial resources improved [47]. Playing a central role in these processes of institution-building, Alaska Natives saw the resolution of long-postponed land claims through the 1971 Alaska Native Claims Settlement Act (ANCSA), that created the twelve corporations, including the Arctic Slope Regional Corporation (ASRC), and endowed them with a relatively small amount of private land, but funds near a billion dollars [48]. These events, comprising the first half of this period, can be understood as the intensive integration, rather than imposition, of colonial structures into Iñupiat society.

Statehood also drove development, including plans for an Arctic deep-water port, the Rampart Canyon dam, and of course, oil exploration [49]. The discovery in 1968 of the Prudhoe Bay oil field altered the identity of the region. Hastened by fears arising from the 1973 Arab oil embargo, the development of the North Slope oil complex was driven nearly exclusively by exogenous colonial economic imperatives. Amid the unresolved controversies about land selection, North Slope leaders realized the significance of the find and, taking advantage of provisions in Alaska's Borough Act, formed a home rule borough with expansive taxation rights between 1972–3 [45]. Despite years of opposition from both oil companies and the state, including significant lawsuits, the Borough's incorporation succeeded and the NSB began to collect on oil property revenues in 1972 [50,51]. While Prudhoe Bay development disturbed thousands of acres of land, Borough revenues grew at an annual average rate of 50% between 1974 and 1978, allowing the leadership to undertake ambitious capital improvement programs and radically improve the region's material well-being with jobs and infrastructure [45,52,53]. Vital Iñupiat traditions like whaling persisted, and subsistence and cultural practices strengthened with access to money [52], but stable wage labor, purchasing power, and the influx of American culture marked a threshold of new demands, expectations, and forms of agency among the North Slope's residents [54]. With the completion of the Trans-Alaska Pipeline (TAPS) in 1977, permitting the "on-streaming" of Prudhoe Bay oil, all the components that would define the NSB as an oil and gas SES (OGSES), a nested "petro-state" type of jurisdiction, were riveted together.

3.1.3 Steady flow: 1977–1988. With TAPS completed, the period of Steady Flow was the stabilization of interrelationships between the major policy subsystems, institutions, and infrastructures of the NSB as Prudhoe Bay oil flowed at a rate of more than a million barrels a day. State and Borough tax revenues rapidly enriched communities and government accounts, allowing for a host of programs and policies, including the Permanent Fund. The state of Alaska removed its personal income tax and pinned its future on oil revenue in 1980 [55]. The phenomenal volume of oil produced with the "On Streaming" of Prudhoe Bay, which in 1981 constituted ~17.7% of total US production, would peak in 1988, with additional volume from the Kuparuk River (1981), Milne Point (1985), and Endicott (1987) fields, at ~24.9%. Wage labor and subsistence became coupled in the Borough's new economy, with the ability to go on the land contingent on adequate equipment, ammunition, fuel, and ultimately access to money [56–58]. The literature refers to what emerged as a "mixed economy", which saw both men and women across the villages working more months overall, but also getting more food from subsistence [58,59]. Increased wealth and education also initiated a process of out-migration for both work and school [44,60,61]. Thus, while certain relationships and opportunities were fortified by oil, the newfound financial wealth destabilized cultural and demographic elements. Cultural changes within the NSB stemmed not just from economic development, but from the permanent hires of non-Natives from outside the community, including consultants, managers, construction workers, and teachers [53,58]. In 1980, 802 non-Natives lived in the NSB, whereas in 1990, the number was 1613 [53]. Communication with settler professionals encouraged the spread of English as the dominant language, resulting in a loss of Inupiaq fluency [62]; already in 1980, only 5000 of the NSB's 12000 people spoke Inupiaq [63].

Between 1977 and 1988, the total number of NSB drill sites increased from 22 to 95, the number of exploration sites from 63 to 104, and the miles of roads from 138 to 357 [62]. Property tax revenues provided capital for the NSB government to invest in its communities, resulting in the full employment of the population throughout the 1980's, and a large increase in the Borough's assessed value [57]. The Borough accrued $30 million in revenues in 1977, spending only four million that year, whereas at the end of this period in 1987, they earned $347 million and spent $197 million on both operations and capital improvements *[ibid.]*. A unilateral restriction on whaling by the IWC in the same year demonstrated an emerging and controversial environmental ethic, prompting the establishment of the Alaska Eskimo Whaling Commission (AEWC) to advance a more collaborative management strategy (ibid.). Driven by both Indigenous interests and environmentalists, academic studies and NSB policy statements of this period began to signal concerns over environmental health in mixed tones of enthusiasm and resignation to the inevitability of oil development [45,57]. Atmospheric warming also became apparent, as reduced sea ice allowed whales to migrate farther from shore, creating challenges for hunters [64]. But by and large, subsistence species actually increased in numbers during this period [65]. Beliefs that oil development and environmental protection could coexist solidified as Iñupiat culture experienced a resurgence through the opportunities of the Native Corporations and oil wealth.

3.1.4 Diminishing returns: 1989–2006. Peak oil production from Prudhoe Bay marks the threshold of this period, though the 1989 Exxon Valdez spill serves as a parallel and connected event. The spill's catastrophic impacts on the marine environment and Alaska's economy provided incentive for the adoption of stringent environmental regulations on oil, politically foreclosed prospective development in ANWR, and may be understood as the first major impetus for full-fledged environmentalist movements in Alaska [66]. Significant reductions in sea ice [67], including a large calving event in 1997 outside of Barrow [68], and shifting caribou migration heightened concerns in the NSB over this period. At the same time, oil production began to decline from its 1988 peak, over 2 million bpd, to approximately 800 thousand bpd in 2006 [69]. Over a decade of steady revenue suddenly faltered due to the inherent finitude of Prudhoe Bay oil. The decline in production corresponded to diminishing Borough revenues beginning in the early 1990's [70], a symptom of resource dependency that Knapp & Morehouse [57] identify as the most important check on North Slope governance. Even while the government managed to preserve financial solvency and adjust operational and improvement expenditures, this period saw an increase in unemployment, which peaked at 22.9% in 2003/4 [71]. The number of Iñupiat households who depend on local subsistence resources for half or more of the food they consume also increased between 1998 and 2003. But despite the economic hardships and environmental harms of this period, 1988 was also inaugurated with the first Iñupiat "Messenger Feast" celebration to be held in 70 years [72]. Along with an increased number of households speaking Inupiaq [73] and the rise in subsistence engagement, the celebration indicates a growing vitality in cultural identity and community ties. But community dependence on oil property revenues remained high, even as the vulnerability of the oil complex, to both the market and public opinion, was becoming more apparent.

3.1.5 Climate change and infrastructure development at odds: 2006 –Present. In 2006, the North Slope experienced its first major oil spill, which drenched the tundra between Gathering Centers 1 and 2 with one million liters of oil. The following year, Arctic sea ice first reached a summer low that was more than 2 standard deviations away of the mean sea ice extent from the satellite record. These events mark the threshold of an ongoing phase defined by the intersection of climate change and social justice thinking, linking in the Arctic the issues of Indigenous rights, environmental health, neoliberal capitalism, and energy use. In recent years, North Slope residents have become more divided on questions of oil development, especially offshore, with the community of Nuiqsut, hemmed in by active oil fields, split over health and economic concerns [74]. Evincing the tight, but controversial coupling of the North Slope Iñupiat and oil, in 2019, the Arctic Slope Regional Corporation resigned from the Alaska Federation of Natives over climate politics.

On the North Slope, fossil fuel exploration and development has continued unabated, with two new units online since 2006 and hundreds of untouched acres disturbed annually by new roads, gravel pads, and infrastructure, demonstrating a path dependency begun in 1972. Permafrost degradation, however, now threatens Arctic infrastructure and may soon put North Slope assets at risk [75]. Symptoms of declining ecosystem health are abundant. Through increased scientific engagement with traditional knowledge holders during this period abnormal environmental events have been documented, including mass walrus and seal mortality events, observations of ice seals with unusual diseases/ hair loss, mass seabird strandings and death, and increasing observations of harmful algal blooms. Coastal erosion has intensified [73,76,77] and seasonal changes threaten ice roads and cellars. Subsistence use and resource sharing have remained at high levels [77,78], but the myriad of environmental consequences of warmer air and waters on species health and availability are not yet fully understood. Future tipping points may be driven by a climatic or biophysical transformation or a political one, initiated locally by Iñupiat leadership, nationally, or even globally.

3.2 Discussion of a subnational "Petro State"

This periodization demonstrates how institutional formation, clusters of Measures, in response to Pressures from Activities, has altered the State of the environment and society differently over time creating distinct periods of organization in the North Slope Borough. Since the exploitation of the Prudhoe Bay field, the regional social system, despite being highly dependent on a healthy environment, has accepted and become almost inextricably intertwined with the extractive regime. Yet, it was primed for this "post-colonial identity" based on over a century of externally-driven natural resource extraction and, at best, general disregard for Indigenous peoples [119]. We do not use this phrase "post-colonial" given that the appropriate term should represent a context that is working against the legacies of colonialism. But the social, material, and power flows of Alaska's Arctic boroughs demonstrates ongoing, though not totalizing, re-inscription of the various powers of colonialism [119].

Considering the low levels of direct local employment in the oil fields (locals predominantly work in Alaska Native Corporation-owned contracting companies) and the "cost of doing business" with the North Slope Iñupiat, it is difficult to say that the industry has the same dependence on the regional system. The obligation of any oil company to the NSB is secured only by the Alaska Constitution and the Borough Act through the right of taxation, limited operations on Alaska Native Corporation-owned lands, and more recent contractual agreements with locally-owned companies. Industry must comply with these strictures in order to maintain legitimate access to the subsoil resources.

As a municipality with an Indigenous majority, Indigenous corporate structures, and extensive taxation powers, NSB's structure of socioeconomic and enviro-infrastructural relations is unique in the Arctic, but also embodies dynamics that can be found elsewhere. This type of imbalanced and extractive interdependency is mirrored in numerous distinct forms across the Arctic [e.g. 79–82], constituting what we consider a distinct *type* of Arctic system: O&G SES. In other contexts, the coupling of extraction and community livelihoods may be characterized by Impact-Benefit Agreements, Environmental Impact Assessments, Private-Public Partnerships, or Corporate Social Responsibility initiatives. Especially in northern mixed economies, access to regular payouts and other forms of material support from industry become critical to community planning when considering subsistence access and food security, mobility, and safety. It is this coupling between northern community and industry, which in many cases drives path dependency, that defines an Arctic O&G SES and presents an opportunity to develop a functional typology.

An Arctic O&G SES can be considered a smaller scale variation on what is often referred to as a "petrostate." Petrostates are frequently identified with the "resource curse" [83], which entails significant political shifts towards smaller government, reduced democratic accountability, and indices of corruption under the influence of sudden massive surges of natural resource-derived capital. As their original theorist, Karl, describes, petro-states "rely on an unsustainable development trajectory fueled by an exhaustible resource–and the very rents produced by this resource form an implacable barrier to change. . . Petro-states are not like other states. . .the economies and politics of countries dependent on oil are rapidly and relentlessly shaped by the influx of petrodollars. . .Oil wealth molds institutions more dramatically" [84,30–31]. While some scholars have used the term "oil state" and its path dependency to describe the state of Alaska [e.g. 85–88], Lee Huskey [89] has argued that the NSB has itself avoided many of the pitfalls of the resource curse by redistributing wealth through government employment, investing in public infrastructure, allocating it to environmental protection, and putting a substantial amount into savings. Yet these actions have only been made possible via hydrocarbon production. The political and geographic scale at which the NSB is able to operate is significant and contrasts sharply from the scales at which, for example, reindeer herders in the Nenets Autonomous Okrug, Russia, or Cree, Dene, and Metis peoples in Alberta are able to take advantage of local oil development [90,91]. Interdependencies in both financial and environmental terms are functionally, if not structurally, equivalent.

This raises the potential to develop a typology of such coupled systems across the Arctic, with shared and divergent indicators that can inform approaches to economic transitions, social justice issues, and resource management. In Table 1, we offer seven possible variables by which an O&G SES might be defined: Size of Dominant Companies, Financial Value of Resource Deposit, Year for Beginning of Exploitation, State Policy Mechanism, Indigenous Demographic, Quality of Industry-Community Relationship, Presence of Ecologically Important Species/Landforms. Together, these indicators can paint a baseline picture of the stakes, power dynamics, and historicity of each O&G SES and facilitate the development of criteria for transition away from hydrocarbon extraction in the circumpolar north. Key to this typological development is considering the nested nature of a petroleum dependent jurisdiction—these are not nations and thus cannot behave as such in global affairs. Other traits shared by

Table 1. Preliminary OGSES Typology Chart.

Arctic/ Subarctic Oil and Gas Regions	Dominant Companies (Current)	O&G Statistics/ Financial Value of Resource (publicly available)	Start of Commercial Production	Relevant State Policy Mechanisms (Currently Active)	Community Demographics	Relationship between Companies and Community	Ecologically Important Species and Landforms
North Slope Borough (NSB), Alaska	BP, Hilcorp, ConocoPhillips	>95% Borough Tax Revenue 18 billion barrels produced in total	1977	Alaska Constitution (1959), ANCSA (1971), ANILCA (1980)	Pop. 9,832 (2019) 63% Inupiat	Tension over subsistence impacts, Native Corporation contractors have O&G related employment, borough taxation capacity	**Coastal Tundra**, Continuous permafrost, Three wild caribou herds, bowhead whale hunting
Northern Alberta, Canada	Suncor Energy, Syncrude Canada, Shell	47.9% non-renewable resource revenue for Alberta 97% of Canada's proven oil reserves	1967	Treaties 6, 8, 10, Responsible Energy Development Act (2012), Oil Sands Consultations Multistakeholder Committee, Guidelines on Consultation (2014)	Fort McMurray Pop. 66,573 (2016) Fort McMurray First Nation Pop. 870, Cree and Chippewa	Traditional land use studies and Environmental Impact Assessments, which Baker and Westman (2018) describe as extractive, duty to consult, bilateral benefit sharing agreements	**Interior Plains**, Discontinuous permafrost, Tar sands (open pit mining and *in situ* extraction), muskeg, wood bison, enormous water use by industry
Mackenzie River Valley, NWT	Imperial Oil, TransCanada Corp.	3% of NWT GDP 226 million barrels produced in total	1920	Sahtu Dene and Metis Comprehensive Land Claim Agreement (1993)	Norman Wells Pop. 809 (2017) Inuvialuit Settlement Region Inuvialuit- pop. 3,115 (2006) Sahtu- pop. 1,600 (2016) Gwich'in- pop. 2,400	Strong community opposition to development and participation in consultation (Dana et al. 2009), Berger Inquiry (1970s) halted pipeline construction	**Interior Boreal Forest**, Continuous permafrost, longest river system in Canada, Great Slave Lake, caribou
Nenets Autonomous Okrug (NAO)	Lukoil, Total, Rosneft, Surgutneftegaz	95% of regional tax revenues 1.4 billion tons of proven O&G reserves	1970	Federal Law: On Subsoil Resources (1992), Guarantees of the Rights of Indigenous Small-Numbered Peoples of the North (1999), Land Code (2001)	Pop. 44,389 (2021) Nenets- 17.83% Komi- 8.61%	Partnership agreements with okrug and district governments, companies fund construction and repair of village infrastructure, undisclosed compensation agreements with reindeer herding co-ops (Tulaeva & Tysiachniouk 2017)	**Coastal Tundra**, Discontinuous permafrost, White Sea, reindeer herding (70% of territory classified as reindeer pasture)
Khanty-Mansisk Autonomous Okrug (KMAO)	Rosneft, Surgutneftegaz, Lukoil, Slavneft, Gazprom Neft	81.1% of total industrial economic activity 7.8 million tons of oil produced in total	1953	Federal Law: On Subsoil Resources (1992), Guarantees of the Rights of Indigenous Small-Numbered Peoples of the North (1999), Land Code (2001), On Territories of Traditional Nature Use (2001)	Pop. 1,532,243 Khanty- 1.3% Mansi- .8%	Partnership agreements with okrug and district governments, companies fund construction and repair of village infrastructure, standardized compensation agreements with reindeer herding co-ops (Tulaeva & Tysiachniouk 2017)	**Interior Plains**, Limited permafrost, reindeer herding, Ob and Irtysh Rivers

(*Continued*)

Table 1. (Continued)

Arctic/ Subarctic Oil and Gas Regions	Dominant Companies (Current)	O&G Statistics/ Financial Value of Resource (publicly available)	Start of Commercial Production	Relevant State Policy Mechanisms (Currently Active)	Community Demographics	Relationship between Companies and Community	Ecologically Important Species and Landforms
Yamalo-Nenets Autonomous Okrug (YNAO)	Gazprom, Novatek, Total	50% of regional GDP 81% of Russian gas production, 17 trillion m3 of proven gas reserves	1962	Federal Law: On Subsoil Resources (1992), Guarantees of the Rights of Indigenous Small-Numbered Peoples of the North (1999), Land Code (2001)	Pop. 522,904 (2010) Nenets- 5.9% Khanty-1.9% Komi- 1.0%	Companies support Indigenous NGOs, range of formal and informal benefit sharing agreements, low levels of compensation for land destruction (Tulaeva et al. 2019)	**Coastal Tundra**, Continuous permafrost, Yamal Peninsula
Norway	Equinor (Statoil), Petoro	20% of GDP 2–3% of employed in country 5.14 billion barrels of proven oil reserves	1971	Finnmark Act (2005), Mineral Act (2009), Sovereign Wealth Fund,	Pop. 5,385,300 (2020) Sami- .7%	Limited consultation of Sami Parliament in resource development applications for areas within Finnmark, absence of consultation in traditional lands that fall outside of Finnmark, minimal opportunities for communities to financially benefit (Carstens 2016)	**Coastal/Offshore**, No permafrost

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Arctic specific O&G SES include the presence of organized intermediaries between industry and Indigenous peoples, societal rifts caused by equivocal industrial activity, and, critically, the subjection of the relationship between oil and people to formal legal regulation. For example, the Nenets organization Yasavey has long had the right to oversee land transfers and compensation between herders and oil companies [92] while the Alaska Eskimo Whaling Commission engages with offshore oil and gas companies in a collaborative annual process to avoid adverse impacts to whale migration and hunting [93]. Rosemary Ahtuangaruak [94] denounces ANCSA's role in disempowering tribal government in relation to Native Corporations, and Marjorie Balzer [95] cites cases of Khanty energy company employees pressuring community members to sign land exploration waivers. In light of these similarities, we have organized the table above, which depicts key variables across a suggested typology of Arctic O&G SES. But how long can this particular SES identity last given that oil and gas are non-renewable resources and public commitment to decarbonize is growing in North America and around the world?

3.3 Scenarios of transformation potential in the North Slope Borough

As discussed in the previous section, the North Slope SES has not previously experienced *environmental* change at a magnitude that caused a transformation in system identity. Rather, its system identity has been defined and redefined by exogenous pressures of extraction, such as global marketplace prices for oil or the thickening of the State of Alaska's budgetary and legal mechanisms in support of oil exploration and production. The question of whether or not the current oil and gas identity can withstand an environmental disruption is open to inquiry. Huntington et al. [96] describe political-economic tipping points in the Arctic where rapid environmental change coupled with rising costs for responding to climate change impacts can endanger the future of remote Arctic communities. These costs have already created patterns of outmigration that could foreshadow a transformation that the current inflationary period could exacerbate.

Strategic futures research can help actors at all levels grapple with the uncertainty of future change. "Scenarios provide a flexible but informed perspective on a range of plausible socio-economic and environmental outcomes. . .Although inherently forward-looking, scenarios are not explicit models of the future. . .using scenarios is often a process of asking *what if*?" ([120]; page 217). Below we briefly review how key environmental trends directly affecting the North Slope Borough are considered from a modeled futures perspective. A comparison between climate model scenarios and a synthesis of recent participatory scenarios for Northern Alaska also places the climate modeled scenarios of regional change in the broader context of other socio-economic features that influence transformation on the North Slope.

3.3.1 Climate model-produced scenarios—the environmental future. Computer modeling lets us peek ahead in time by projecting current trends; with accuracy declining as one moves further into the future. When considering the magnitude of change required to transform the identity of the North Slope one is primarily considering impacts to oil and gas infrastructure (industrial costs, which may be shared with communities) simultaneous with changes in subsistence species (those animals and plants depended upon for Alaska Native caloric intake and identity). Both can be addressed by modeling cryospheric features of the region. Climate models frequently use RCP emissions scenarios to look at future air temperatures. Here we consider a temperature threshold of 0˚ C during the month of February to illustrate how winter warming may affect communities on the North Slope. GFDL-CM3 models from the Scenarios Network for Alaska and the Arctic (SNAP) indicate no more than 2 above freezing events that occurred during February between 1975 and 2007 for Nuiqsut, and no more than 1 such event per month occurring in Wainwright, Utqiagvik and Kaktovik. However, future projections from an RCP 8.5 scenario through 2100 show a marked increase in the number of above freezing temperature events occurring in February, with greater consistency in above freezing temperatures beyond the year 2050. Downscaled climate models also predict increasing rain on snow events between the months of November through March for the period 2006 to 2100, with more pronounced rain on snow events occurring along the western coast of the North Slope, from Utqiaġvik through south of Point Hope [97]. Amplifying winter freeze-thaw events can create problematic conditions for people and ecosystems. For instance, rain followed by freezing temperatures can create thick layers of ice that make it challenging for transportation by snow machine. Winter rain on snow events can also make it difficult for caribou to access winter forage under thick layers of ice [98], affecting caribou mortality and thus regional food security.

Another seasonality-focused example is the trends in spring subsistence harvests that are closely related to sea ice conditions. The thickness of sea ice over whaling trails varies between years, and hunters need to assess the safety of whaling camps while traveling on the sea ice [99]. However, climate models infrequently model landfast ice conditions making it difficult to predict future food security impacts from sea ice change during the spring.

Fall whaling activity on the North Slope can be affected by wind patterns. Specifically, easterly winds can support prey aggregations of krill and euphausiids, which attract whales, relatively close to shore in Utqiagvik [100]. But unusually low fall harvest numbers have occurred recently. Only a single bowhead whale was harvested in Utqiagvik on November 16, 2019 which is the latest date for a fall bowhead strike since 1974 [101]. In 2019, aerial surveys also revealed an absence of bowhead whales migrating along the coast [102]. There has been no singular explanation for the lack of bowhead whales seen that fall, but it could be linked to changing patterns of prey distributions. Trends for RCP 6.0 scenarios in two models (IPSL-CM5A, and GFDL-CM3) showed no marked decrease in predominant easterly winds during September from 2007–2100. However, in the RCP 8.5 scenario there was a decline in strong easterly winds that is more pronounced in the GFDL-CM3 model. Under such conditions, we could expect a decrease in the optimal prey-accumulating conditions needed to support a near-shore bowhead whale hunt.

Other major cryosphere changes for the region include deepening of permafrost active layer depths [103], and increasing ground temperatures. Increasing air temperatures, and secondarily decreasing the thickness and duration of winter snow cover is also known to increase rates of permafrost thaw, which is detrimental to infrastructure built over permafrost, and can negatively impact the stability of permafrost ice cellars used by Indigenous communities. Projections of infrastructure damage from permafrost thaw through 2099 could be as high as $5.5. billion in the Arctic North Slope [104].

Projections of storm surge flooding are variable across the coastal North Slope. For instance, Lantz et al. [105] found that infrastructure in Utqiagvik was more vulnerable to storm surge flooding compared to neighboring communities of Kaktovik and Wainwright. However, understanding scenarios for sea level rise over the Alaska coast is largely under-studied compared to coastal areas across the mainland U.S. [106]. Incidents of flooding, in particular, are tied to the very lifeblood of the state. In late summer 2019 the Sagavanirktok River near the Brooks Range flooded and rapidly eroded the land within 30 feet of a buried segment of the Trans-Alaska Pipeline (TAPS). Two months later the Alyeska Pipeline Service syndicate operating TAPS had to seek state authorization to manage the river's banks and protect the pipeline. Climate changes were never figured into the pipeline's design.

Given these facts, is the NSB in a transition for an inflection or a cascade transformation? In short, yes, either are now within the realm of possibility in the next half century. The latter represents a focusing event on a large scale such as a significant well blowout or other disaster that could be related to the changing coastlines of northern Alaska, and may change public opinion in relation to policy [121,122,123].

3.3.2. Participatory scenarios—the societal view of the future. Modeling physical environmental conditions based on emission scenarios in an effort to find the next system transformation, fails to account for socio-political conditions that reinforce the system identity. On the cusp of the most recent oil crash spanning 2014–2015, three significant scenarios research projects focused on Arctic Alaska and the hydrocarbon economy. The first project was a scenarios process led by the North Slope Science Initiative (NSSI) focused on exploring the future of energy development on the North Slope and adjacent seas through 2040 [107]. This participatory scenarios process engaged State and Federal agencies involved in resource management and permitting, academics, NGO's, oil and gas industry representatives, and a few residents from North Slope communities. While market forces and the regulatory environment were considered key drivers of change for the North Slope in the past and present, the role of climate change, and sea ice extent were considered more important drivers for affecting development after 2040.

The Northern Alaska Scenarios Project (NASP) engaged residents of the North Slope and Northwest Arctic Boroughs [108]. The project's focal question asked "What is required for healthy and sustainable communities in Northern Alaska by 2040?" The resulting list of twenty-one Key Factors, was narrowed down from more than 100 key factors that participants felt would drive the nature of community resilience. The factors considered were extensive, and included climate change and other key factors that would be affected by it (e.g., land management, access to markets, transmission and recognition of Indigenous Knowledge, access to and affordability of housing) Using the same method as NASP, a third participatory scenarios project by the Study of Environmental Arctic Change (SEARCH) engaged Northern Alaska resident, and non-resident, experts in 2018 to address the question of information needed to respond to changes in Arctic environments by 2050 [109]. Sixteen key factors were produced, and four of them directly addressed climate change. The experts considered the nature of Arctic systems based on future projections at RCP levels 2.5, 4, 6, and 8.5.

In both the NASP and SEARCH scenarios outcomes the participants' discussions in relation to environmental facts, such as those in section 5.1 repeatedly emphasized how the environmental change disrupted key social and cultural processes [124,125,126]. Futhermore, the NASP project also examined perceptions of risks to the future of the North Slope region, with residents from both North Slope (NSB) and Northwest Arctic (NAB) Boroughs. The results were compelling [127].

"The most frequently mentioned risk, ineffective decision making, was the same in both boroughs. The second most frequent were health and health care issues. In third place were industrial activities tied with environmental changes in the NSB group, while cost of living and health and health care issues came in second and third (respectively) in the NAB group. This analysis of observed drivers of change proved significant in providing a generalizable picture of workshop participants' perceptions about a complex and rapidly changing northern Alaska social–ecological system." (page 8)

This demonstrates that residents of Alaska's O&G SES are not only cognizant of climate change but the nature of human decision-making in relation to reducing risk in a system. The balancing of human well-being with industrial activities by NSB participants is indicative of a system that is acknowledged as "transitioning"—but into what? Our paper cannot provide this answer. But participatory scenarios demonstrate what residents, scientists, government, and industry representatives think about when they consider the North Slope Borough in a future time period. Perhaps more importantly these scenarios demonstrate the residents linking together complex chains of causality from a diminishing cryosphere to their own sources of fate control and fear of poor decision-making. In short, if the North Slope identity begins shifting from one tied to oil and gas, this will not happen unnoticed by its inhabitants and in fact they may make conscious decisions in the future to transform the region. It is difficult to change a petrostate as the social and environmental pathways created by this industry are significant and resilient. Aside from conscious multi-scalar decisions by governments to transition the SES itself, climate change remains the most likely disruptor able to cut across multiple components of a person's lived reality in the North Slope where oil production is already in steady decline.

4 Discussion

Our approach included four main components: 1) understanding and disentangling the components of a complex SES with the DAPSIWRM method, (2) explaining system identity and change using periodization, 3) defining the North Slope as an oil and gas SES in comparison with other regional O&G SESs to devise a typology, and 4) considering different scenarios for the possibility of another transformation, one that might change identity and typology. The North Slope is presented as a case example of an Arctic typology, the OGSES. But our approach can be adapted through futures methods as noted above to evaluate OGSESs globally. When will climate change impacts become costly enough to prompt coordinated efforts to decommission O&G infrastructure and remediate and restore damaged ecosystems? Global pressures to transition to renewable energy sources leave many unanswered questions about the regions and people most affected, but understanding the intersectional trends at the root of present climatic and environmental crises can support just and equitable solutions. Used alone, scenarios of climate change that rely on global emission predictions and earth system models that take a "god's eye view" of climate change are unable to capture local and regional impacts or the sociopolitical structures supporting or stymieing change. Our paper reveals a pattern to the type of subnational jurisdictions reliant on oil and gas by focusing strongly on qualitative indicators. A quantitative modeling approach that focuses only on a few aspects of environmental or economic changes (i.e., easily quantified variables, or numericized social trends) provides scenarios of limited scope that are unable to account for political will. For example, the heavy military presence in Alaska may dictate using North Slope petroleum even if it is cost-ineffective for world markets [110,111]. Such a seemingly "irrational" maintenance of hydrocarbon production is entirely rational from a U.S. national security perspective and not easily modeled given electoral cycles and changes at the highest levels of national governance.

The process of developing historic "periods" for an SES shows how a bounded but system-wide narrative approach can convey complexity in ways that neither social nor natural science can do alone. By identifying critical thresholds when key system elements rapidly transformed, researchers can better pinpoint what sector of activity has historically contributed the most to present system identity and factor that into resilience and mitigation strategies. Periodization also allows a tracing of cause and effect that offers evidence for various types of anthropogenic impacts. It is important to emphasize that the delimitation of "anthropogenic" changes in the system to those caused by modern atmospheric pollution obscures a deeper history of colonialism and extraction, whose structures and consequences persist and influence problem structures to this day. Since first contact between Alaska Natives and Euro-Western explorers, the natural wealth of the Alaskan *periphery* has been systematically appropriated and channeled to enrich people and interests in southerly urban *centers*. Each major transformation in the NSB system has fortified both the interdependence of the community and industry and the capitalization of Alaskan resources within liberal market economics modes of valuation. Likewise, the failure of housing and infrastructure in the Arctic is not attributable fundamentally to climate change, but to the forced sedentarization of Native peoples and the imposition of fixed, non-nomadic settlement strategies, while climate change further diminishes the viability of nomadic and subsistence lifestyles.

The primary contribution of our study is the initial postulation of Arctic OGSES as a subnational typology for O&G jurisdictions. The diverse cases of OGSES indicate a strong possibility for the creation of a formal typology based on several of the variables described in the table above as well as additional ones to be gathered and analyzed in our project's next phase. At present, OGSES are not spatially bounded according to a single standard logic. Areas and scales of extraction relate differently to political, legal, and cultural geographies, such that an entire country, Norway, and a small, resource rich watershed, the Mackenzie River Valley, are appropriate, if divergent, spatial objects of analysis. Variables such as population density, economic equity, and energy policy will be necessary alongside demographics, ecoregional type, and extractive methods/technologies to adequately define a full typology. Our periodization demonstrates that, as with the NSB, each OGSES will evince a unique genealogy of how extractive logics became integrated jointly into the human and ecological systems. Cognitive structures, cultural imperatives, and historical narratives should thus be understood as intangible system components. To ensure that the historicity of each case isn't lost in the formation of a typology, it becomes necessary to parameterize and control for, among other things, the political cultures (authoritarian, socialist, democratic, et al.) within which extractive systems are situated. By doing so, an Arctic OGSES typology can account for both biophysical variables and theories of human behavior.

Goldthau and Westphal [112] note that just because a global energy transition from hydrocarbons is occurring, this does not mean the "petro-state", or petro-jusrisdiction, will wither.

A low carbon transition may benefit some of the most carbon-intensive economies, as oil and gas supplies (and their affiliated refineries and petrochemicals) dwindle globally; authoritarian states being least likely to promote change [*ibid*]. We argue that the North Slope Borough's SES identity is changing slowly; it is in transition but given the industrial life cycle of oil fields and an energy intensive world economy, it will likely take another decade or two for the climate realities (i.e., costs) to significantly affect decisions on oil production. In light of this we insist on the need for co-produced studies of what community members and experts from the region think of the future, which can guide some of the research into how rightsholders and stakeholders perceive places called home, the changes in it, and what different futures may bring.

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