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SOCIAL CHANGE, ECOLOGY AND CLIMATE IN 20th CENTURY GREENLAND

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ABSTRACT

Two great transitions, from seal hunting to cod fishing, then from cod fishing to shrimp, affected population centers of southwest Greenland during the 20th century. These economic transitions reflected large-scale shifts in the underlying marine ecosystems, driven by interactions between climate and human resource use. The combination of climatic variation and fishing pressure, for example, proved fatal to west Greenland's cod fishery. We examine the history of these transitions, using data down to the level of individual municipalities. At this level, the uneven social consequences of environmental change show clearly: some places gained, while others lost. Developments in 20th -century Greenland resemble patterns of human-environment interactions in the medieval Norse settlements, suggesting some general propositions relevant to the human dimensions of climatic change.

INTRODUCTION

Greenlanders live between a continental ice sheet and the sea. Human presence on these marginal lands dates back more than four thousand years, punctuated by periods when climatic and other hardships emptied formerly inhabited regions. The earliest historical settlers, Viking Age Norse from Iceland, reported evidence of previous peoples but no living inhabitants at the time they first reached south Greenland around A.D. 985. A few centuries later, the Norse settlements themselves were struggling, and ultimately failing, to survive amidst worsening climate. While the Norse faltered, a more arctic-adapted culture, the Thule Eskimo, was expanding southwards. The Thule's Inuit descendants were Greenland's only inhabitants when Europeans "rediscovered" Greenland in the 18th century, and they comprise most of the population today. Like their predecessors, modern Greenlanders live primarily by marine resources. The population concentrates near ports that have been favorable for commercial fishing, along the comparatively warm and ice-free southwest coast.

Two great resource transitions—from seal hunting to cod fishing, and from cod fishing to shrimp—took place on this coast in the 20th century. Climate influenced both transitions, through interactions with ecological and social systems. Such interactions also affected the medieval Norse. We begin here by sketching the Norse story, which provides background for more recent developments: the rise and fall of cod fishing (ca. 1920–1992), and adaptation in the 1990s to a new ecological regime dominated by shrimp. Parallels between the two Greenland stories suggest some propositions about the human dimensions of future climatic change.

SOCIETY AND ENVIRONMENT IN PRE-MODERN GREENLAND

"Greenland's cultural history...is the history of many population groups who migrated to the country, lived there for a while, and then vanished." (Berglund 1986:109)

In the seas around Greenland, climatic variations—on seasonal, decadal or longer time scales; and whether in the prehistoric past, historical memory or computer models projecting the future—tend to be dramatic (e.g., Vilhjálmsson 1997; Mayewski *et al.* 1994; Ogilvie 1992; Manabe 1995). Humans have occupied Greenland during favorable periods over the past 4000 years, but their occupation has been interrupted by centuries in which large regions, or even all Greenland, lay uninhabited. Archaeological evidence suggests multiple waves of migration, including the Paleo-Eskimo Independence I culture that arrived during a warm period about 2000 B.C. Climatic change, notably a cold period that depopulated Greenland around 400 B.C., played a role in the succession of later cultures (Fitzhugh 1984). Today's Inuit descend from Thule Eskimo, who reached northwest Greenland in the early 12th century A.D. after spreading eastward across the arctic shores of Alaska and Canada during another warm period.

The same warm period also facilitated Viking Age westward expansion. Around A.D. 985, Norse pastoralists from Iceland (led by Eirik Rauða, Erik the Red, according to Icelandic sagas) began settling in southern Greenland (Jansen 1972; Jones 1986). Attracted by virgin grazing lands of the inner fjords, the Norse brought sheep, goats, cattle and other animals, and sought to reproduce in Greenland a version of their traditional herding economy (Berglund 1986; archaeological work reviewed in McGovern 1990). They established what were called the Eastern and Western Settlements in parts of south and southwest Greenland—present-day Nanortalik, Qaqortoq, Narsaq and Nuuk municipalities. These are the mildest areas of Greenland now, and were probably even milder then.

By the late 13th century, the northern Atlantic climate was becoming less favorable. Sea ice more frequently impeded trade with Europe and Iceland, as well as the Greenlanders' own foraging and communication. In spring their livestock, kept indoors by the snow, neared the end of food harvested the year before. Unusually long winters or cold wet summers could therefore lead to crisis (McGovern 1991, 1992). In the 1350s, southwest Greenland experienced a cluster of cold seasons, including what might have been the hardest winter in 800 years (inferred from analysis of GISP2 ice-core $\delta^{18}O$ measurements on *Greenland Summit Ice Cores CD-ROM*; see Grootes and Stuiver 1997). Soil erosion, hastened by grazing and the clearing of trees and brush, reduced the productivity of marginal farmlands (Amorosi *et al*. 1997; Berglund 1986). Thule Eskimo at this time were expanding their range southwards down the west coast, along with the ice margins where they hunted ringed seals. The Thule presented a potential threat to Norse foraging activities, which were essential to the Western Settlement's economy (McGovern 1992).

In the mid-14th century, the Western Settlement was abandoned. For some farms, the final days apparently were dramatic (see Buckland *et al.* 1996, and sources cited). The larger, more southerly Eastern Settlement survived about one century longer. Exactly how things ended, or what became of the people, remain questions for scholarly debates based on incomplete and sometimes contradictory historical, archaeological and climatological evidence (e.g. see Berglund 1986, McGovern 1991, 1992 on one side; Arneborg 1991, Keller 1991 on another). Internal weaknesses and events in Europe likely contributed to the collapse, but ecological/climatic change appears to have played an important role.

Other Norse Atlantic settlements in Iceland and the Faroe Islands also experienced hardship and population declines by 1500. Summarizing lessons from research, Amorosi *et al.* (1997) identify three general patterns that characterized relationships between medieval North Atlantic societies and their environments:

Natural capital depletion. The early Norse colonists in Iceland and Greenland were entering previously unexploited ecosystems. They could prosper for a time by drawing down the "environmental

capital" of virgin woods, hunting grounds and fields. This capital initially buffered their societies from the vagaries of near-arctic climate.

Synergistic interactions. Deforestation and soil erosion caused by Norse farmers' agricultural practices reduced their lands' productivity, and increased the settlements' vulnerability. Spells of harsh weather had more serious consequences as soils became depleted.

Intensification and technological fixes. Expansion of North Atlantic trade and commercial fisheries, especially for cod, helped Iceland overcome the environmental trap of its depleted soils. Greenland has sought to do likewise. But recent fisheries crises warn that marine capital, too, can be depleted.

Feedbacks with delayed effects sometimes produce step-like transformations in human/natural systems. In the following sections, we look at two such transformations in 20th-century Greenland. The parallels suggest that Amorosi *et al.*'s patterns have broader relevance.

AN OVERVIEW OF GREENLAND TODAY

European explorers and whalers landed occasionally in Greenland during the 16th and 17th centuries, and a Danish expedition claimed Greenland for Denmark in 1605. The fate of the old Norse colonies remained unknown in Europe, however, until the arrival of a Danish-sponsored missionary, Hans Egede, in 1721. Egede had hoped to establish trade with and re-Christianize the Vikings' presumably lapsed descendants. He found the Western Settlement abandoned and in ruins. Greenland's surviving people were Inuit, hunting seals much as their Thule ancestors had.

Greenland remained under Danish control until 1979, when it was granted the limited sovereignty of Home Rule status. Population grew slowly, doubling (8,000 to 17,000, nearly all Greenland born) over the ninety years 1840–1930. After World War II, public health improvements including a successful campaign against tuberculosis, plus an influx of Danes involved with development, propelled a period of faster growth. In one twenty-year period, 1950–1970, the population doubled (24,000 to 47,000), while the proportion born in Greenland fell from 97 to 84%. As the Home Rule government assumed more responsibility, the proportion of Danes stabilized and eventually began to drop. By 1999 the total population stood at 56,000, 89% of them Greenland born. Outmigration and a falling birth rate have halted overall growth in the last few years.

Administratively, Greenland is divided into 18 municipalities, most containing one principal town with about 1,000–5,000 people, plus one or more smaller settlements—about 60 settlements in all. In 1999, 45,000 people (81%) lived in the towns, including more than 13,000 (23%) in the capital city of Nuuk. **Figure 1** maps the distribution of population by municipality, showing its concentration along the southwest coast.

Climate and geography constrain many activities, from farming to trade, that support modern economies elsewhere. Greenland's present economy depends largely on commercial fisheries and block grants from Denmark. This economy coexists, however, with subsistence hunting and fishing activities that provide significant food sources as well as cultural identity. Hunting receives some subsidies from the state, which serve indirectly to support rural life and communities. An overview of Greenland's economic development since 1953 appears in Lyck and Taagholt (1987). Caulfield (1997) describes how economic transformation has reshaped Greenland's traditional hunting culture; Lyster (1997) estimates the cash value of subsistence catches, which vary substantially from one municipality to the next. Lauritzen (1989) chronicles the transition from Danish to Home Rule government. Rasmussen and Hamilton (1999) outline the development of fisheries. Paldam (1997) offers a critical appraisal of Greenland's economy. Poppel (1997) reviews how economic changes have affected the population during the Home Rule period. Full independence from Denmark remains a goal for many Greenlanders,

but it does not presently appear practical because export earnings provide only about half of Greenland's hard currency needs. These export earnings have come primarily from cod and shrimp.

THE RISE AND FALL OF COD FISHING

In 1774 Denmark established a trade monopoly, the Royal Greenland Trade Department (Den kongelige grønlandiske Handel, or KGH). During the 1800s, KGH evolved as an instrument of the state, having goals broader than just profitable trade with the Greenlanders— which in any event proved not always possible. To some degree KGH also sought to support Greenlandic settlements (and Danish colonial authority) by providing essential goods, if necessary at stable and below-market prices. Greenlanders were meant to be protected from outside influence, and their traditional way of life preserved. The population grew from around 8,000 in 1840 to 11,600 in 1901, but it remained heavily dependent upon hunting. Sealskins, blubber and liver made up 85% of the exports in 1901 (Mattox 1973). Dependence upon hunting became less tenable, however, as both seal populations and the market for seal products contracted. Seals had been reduced partly by hunting, including predation by the now rifle-armed Greenlanders as well as massive overkills by others on the Newfoundland–Labrador and Jan Mayen breeding grounds during the 19th century. The seals also were affected by a changing climate.

West Greenland had begun gradually warming during the middle and late 1800s, part of a general Arctic trend. Temperature increases were marked after 1920, peaking around 1930 (**Figure 2**). As the warm Irminger Current reached farther north up Greenland's west coast, the southern limits of pack ice—prime seal hunting grounds—retreated northwards as well. Beset by climatic change, falling prices and resource depletion, hunting could not support the growing Inuit population. In southwest Greenland the mean catch fell steadily, from 6.3 seals per inhabitant in 1900–1910 down to 2.7 in 1933–34 (Mattox 1973).

This trend was apparent to hunters and planners. The Danish Commission of 1906 recommended that Greenlanders, and government policy, look to other activities besides sealing as the basis for their economy. Fish had long been a component of Greenlanders' diets, although in general fishing was less prestigious, and supplied a narrower range of needs, than hunting. Now that would change: to Danish planners, fishing appeared to offer the best, indeed the only, hope for developing an urgently-needed modern economy.

For centuries, Atlantic cod (*Gadus morhua*) had sustained fishing cultures on both sides of the northern Atlantic. Such cod only occasionally occurred in any great numbers near Greenland—for example around 1820, and in the late 1840s, both times coinciding with brief warming spells (Schmidt 1989). A more protracted 20th-century warm period brought cod from the Irminger Sea to Greenland's west coast, reaching Nuuk Fjord by 1920, and northwards past Disko Bay after 1927 (Vilhjálmsson 1997). Warmer waters made possible an independently spawning west Greenland cod population. Greenland's nascent fishing industry, struggling to find commercially viable products, started exploiting this new resource in earnest after 1925.

At about the same time, Faroese, Icelandic, Norwegian, French and other fishermen began taking cod from the international waters offshore. Total cod catches off west Greenland exceeded 100,000 tons several times in the 1930s, with Greenlandic fishermen—limited by their small boats and lack of processing capacity—accounting for only a minor fraction (**Figure 3**). This fraction loomed large relative to Greenland's population and economy, however. By 1930, fishing had replaced seal hunting as Greenlanders' most important economic pursuit (Mattox 1973).

Fishing by Europeans paused during World War II, while Greenlandic catches continued to rise. After the war, international fishing intensified throughout the North Atlantic. The fleet taking cod from the Davis Strait included ships from twelve nations led by Portugal, the Faroe Islands and West Germany. Cod catches from west Greenland waters peaked peak above 400,000 tons in the early 1960s.

This proved unsustainable: stocks declined 75% between 1956 and 1966 (Arnason and Friis 1995), and within a few years catches fell below 100,000 tons.

Denmark and Greenland asserted control of a 200-mile economic exclusion zone around Greenland in 1977. With new limitations on foreign trawlers, Greenland's own catches grew, but the total catch remained far below its earlier size. Greenland's pre-war fishery had been hampered not only by a lack of fishing equipment and boats, but also by labor shortages in the small, scattered settlements. Traditional settlement patterns proved uneconomic for landing, processing and transporting the fish. Following recommendations from the Commission of 1948 (published in 1950), the Danish government began a lengthy, capital-intensive effort to rationalize the fishing industry. Doing so required not only reorganizing and expanding Greenland's fish catching and processing capacity, but also constructing a modern social infrastructure (including housing, transportation, power, education, training and health services) around it.

Government and KGH policies encouraged internal migration by concentrating development in the towns, creating more jobs, housing and other attractions there than in smaller settlements. The "urbanization" drive engendered some resistance as its cultural and practical disadvantages became apparent (Petersen 1986), and after 1979 Greenland's Home Rule government set the new goal of maintaining the viability of small settlements too. Nevertheless, the fraction of the Greenland-born population living in towns, which had grown from 20% in 1901 to 56% in 1960, reached 81% by 1999. Most of the concentration took place along the southwest coast, from Qaqortoq to Aasiaat, and especially in the "open water district" (Paamiut to Kangaatsiaq) where conditions favored commercial fishing. Between 1960 and 1970, new fish freezing plants— drawing new workers, housing and infrastructure—were built at Narsaq, Paamiut, Nuuk, Manitsoq and Sisimiut. In north and east Greenland, on the other hand, commercial fishing was less practical, so partly-subsidized versions of the old hunting economy still dominated.[1]

Resettlement and investment decisions thus created structural adaptations to a cod-rich ecosystem. Communities grew in the vicinity of good fishing grounds. Some planners recognized the hazards inherent in depending too much on a single species, and since 1950 had encouraged diversification. Cod nevertheless continued to be the main staple, accounting for 86% of the total landed value of fish in 1951, and still 61% in 1961 (Mattox 1973). During the 1960s, however, as cod-economy construction was in full swing, it became clear that conditions were changing. West Greenland waters were cooling; cod began appearing later each year, and not as far north. Catches by the offshore fleet in the Davis Strait fell steeply despite high levels of effort. As inshore catches declined near Narsaq, the processing plant there was forced to bring fish in from farther away. Even so, insufficient supplies kept this and other plants working below their designed capacities.

In 1979, Denmark conferred Home Rule status upon Greenland. This gave Greenlanders authority to govern their internal affairs, while reserving police and external authority (for example regarding defense, passports and currency) to Denmark. Greenland remained under the Danish constitution, and was to be compensated for the costs of self-government by block grants from Denmark. These block grants, plus other transfers from Denmark, amounted to 71% of Greenland's gross national income in 1981, and 44% in 1995.

The desire of both Danes and Greenlanders to make Greenland less dependent focused further attention on fishing. By the mid-1980s the Home Rule government had taken over much administrative responsibility, and initiated new construction centered around the fishing industry. The timing was unfortunate. Two unusually severe "ice winters" in 1982–84 (see lower right in Figure 2) froze vessels into their harbors. Fishing effort soon recovered, but the fish themselves did not. Cold water slowed cod growth and reduced their replacement through migration and reproduction; biomass fell 70% (Rätz 1991, 1992; **Figure 4**). Over the next few years, warmer water and lower catches allowed biomass to rebuild,

which encouraged fisheries expansion. Reflecting this expansion, cod catches peaked again over 1988–90. But temperatures had been cooling again since 1986, and biomass decreasing since 1987. The intensified fishing effort thus fell upon a declining fish population. Cod biomass plummeted more than 99% between 1988 and 1991, and has since shown no signs of recovery despite warming waters. Plants, communities and people that had adapted to cod fishing were left behind by this large-scale change.

Investment had targeted both cod and shrimp. Both fisheries were economically important in the 1980s, but not in the same places. Many communities had locations or processing facilities suitable for one but not the other. While cod catches followed their erratic, downward course, shrimp catches rose to new peaks (**Figure 5**). After the cod fishery collapsed in the early 1990s, shrimp stood almost alone as a source of export earnings.

ADAPTING TO SHRIMP

West Greenland's shrimp fishery had begun on a small scale near Qasigiannguit on Disko Bay, and Narsaq in south Greenland, during the 1950s. It expanded during the 1960s. During the 1970s Greenland developed a deepwater shrimp fishery in the Davis Strait and off the east coast, that eventually surpassed cod landings both in tonnage and value. The same environmental pressures—cooling waters and overfishing—that doomed the cod also made shrimp more abundant. These shrimp belong to a temperature-robust species (*Pandalus borealis*), able to thrive in colder water. Cod had been among their predators. Shrimp catches rose from under 20,000 tons in the 1970s to more than 80,000 tons in 1995, at which time they comprised 73% of Greenland's total exports.

By shifting from cod to shrimp, Greenland followed a pattern seen elsewhere in fisheries around the world: redirecting efforts towards smaller, shorter-lived species closer to primary production, after larger predators have been depleted (Pauly *et al.* 1998). Cod crises occurred throughout the Atlantic during the late 1980s and early 1990s. Responding to markets as well as ecological changes, new invertebrate fisheries often emerged in compensation (Hamilton *et al*. 1998). Greenland's shrimp, exported to Japan, provided a high-value economic alternative to cod.

The cod-to-shrimp transition appears a roughly even exchange at the national level. Its local consequences, however, were not even at all. Although large and mid-sized trawlers could be refitted for shrimping, shrimp provided no substitute for small-scale inshore fishing. And many settlements built for cod fishing found themselves in places where the fish no longer came.

Figure 6 depicts cod landings in 13 west Greenland municipalities over 1988–98. The small graphs are in south-to-north order, starting with the southernmost municipality, Nanortalik. The government center, Nuuk, is omitted from Figures 6–12 because it depends less upon local resources. Historically Julianehåb (which included present-day Nanortalik, Qaqortoq and Narsaq municipalities), Frederikshåb (Paamiut), Godthåb (Nuuk), Sukkertoppen (Manitsoq) and Holsteinborg (Sisimiut) had been the main cod districts. Cod were gone earlier from the north, so during the terminal 1988–91 boom, the southwestern municipalities of Narsaq, Paamiut and Maniitsoq were primary participants. The southernmost municipalities, Nanortalik and Qaqortoq, and two mid-coast places, Sisimiut and Kangaatsiaq, also landed a few thousands of tons each. By 1992, however, cod landings everywhere fell to insignificant levels.[2]

Figure 7 plots trends in shrimp landings. The Disko Bay (northern) municipalities Aasiaat, Qasigiannguit and Ilulissat took no part in the cod boom, but maintained their production of shrimp. Two mid-coastal places, Maniitsoq and Sisimiut, lost cod but made offsetting gains in shrimp. Most of the southern municipalities, on the other hand, lost cod and did not gain shrimp. Paamiut, a cod-fishing specialist, experienced the greatest fall.

Greenland halibut (*Reinhardtius hippoglossoides*) emerged during this period as the second most valuable resource (**Figure 8**). While shrimp comprised 78% of the fish products exported in 1995,

Greenland halibut made up another 15%. Halibut favor colder waters around Disko Bay and points north. They supplemented the shrimp fishery in Ilulissat, and provided a main livelihood in Uummannaq and Upernavik. The rise of halibut fishing brought little benefit to the former cod fishing municipalities of south Greenland, however.

Changes in the number of Greenland-born inhabitants are graphed in **Figure 9**. Because human populations change more slowly than fish, a longer time frame (1970–98) is shown in Figure 9. During these years the native population of Greenland as a whole increased 26%, from roughly 39,000 to 49,000 people. This overall increase contrasts with the negative or low growth occurring throughout south Greenland, including Nanortalik (–6%), Narsaq (3%) and Paamiut (–5%). Qaqortoq (16%), although also below average, grew more than its neighbors due to government investments that made it the services and training center for south Greenland. In contrast, the Greenlandic populations of Sisimiut (shrimp) and Ilulissat (shrimp and halibut) both grew more than 50%. (Even steeper growth took place in Greenland's metropolis, Nuuk: 84%, not shown in these graphs.) Two Disko Bay municipalities with steady or declining shrimp landings, and no halibut, lost population: Aasiaat (–2%) and Qaasigainnguit (–11%). Farther north Upernavik, which has expanded halibut fishing to supplement its traditional hunting, grew by 52%.

Figures 6–9 show differences between municipalities, but not the further differences between towns and smaller settlements within each municipality. Inshore cod fishing was once possible from many small settlements, often being a main reason for their existence (Rasmussen and Hamilton 1999). Shrimp fishing, in contrast, is primarily a deepwater activity. Small trawlers deliver their catch to processing plants ashore. Large factory trawlers can process and pack their catch onboard. In either case the most direct benefits accrue to a limited number of towns, bypassing most settlements. Thus, environmental change added to the economic and social pressures favoring urbanization. The absolute numbers of Greenland-born people living in settlements declined from 1970 to 1998 in all but three municipalities, two of which (Ilulissat and Upernavik) have substantial halibut landings.

Both birth rates and migration affect population change. Upernavik's high growth coincides with the highest birth rate, and also the highest per capita subsistence catch value, among west Greenland municipalities (Lyster 1997). The second-highest birth rate and subsistence catch both belong to Kangaatsiaq. As **Figure 10** shows, these subsistence catch and birth rates have a positive correlation (Pearson $r = .58$; robust regression line shown). Too far north to take part in the commercial cod or shrimp fisheries, Upernavik remained more focused on seal and whale hunting. Although hunting has recently been supplemented by a substantial Greenland halibut fishery, Upernavik could be considered west Greenland's most traditional municipality.

SOCIAL INDICATORS

The preceding section illustrated the uneven social consequences of an environmental change. To some degree, human populations followed their resources, in modern Greenland as they did prehistorically. The "location" of resources nowadays depends partly on human artifacts such as transportation, markets, and political decisions about where to support fish processing plants; but even these artifacts are constrained by biophysical realities. Non-fisheries variables also affect population—notably government programs (e.g., developing Qaqortoq as an administrative and training center) and high birth rates of the least commercialized municipalities (e.g., Upernavik and Kangaatsiaq). Fisheries clearly been important, however. **Figure 11** graphs the relative change in Greenland-born population against the change in commercial landings value (adjusted for inflation), over 1988–94. Municipalities with rising landings all gained population. Most municipalities with declining landings experienced low or negative population growth ($r = .53$).

Crime rates are one social indicator often viewed as a measure of community well-being. **Figure 12** shows the number of criminal court cases per 1000 people, graphed against changes in fisheries landings, among west Greenland municipalities. Places where the landings declined, such as Paamiut, Aasiaat, Qaqortoq and Nanortalik, were more likely to experience above-average crime rates ($r = -.65$). Those where landings increased (Uumannaq, Narsaq, Qeqertarsuaq and especially Upernavik) all had below-average crime rates.

The regression analysis of Figure 12 does not establish a causal connection between marine ecology and crime rates. It does, however, serve to highlight the possibilities for more systematically examining social indicators in the context of environmental change.

DISCUSSION

Summarizing lessons from archaeological and historical research, Amorosi *et al.* (1997) identified three general patterns—natural capital depletion, synergistic interactions and technological intensification—that had characterized relationships between medieval North Atlantic societies and their environments. Similar patterns are visible in 20th century Greenland:

Natural capital depletion. Earlier in this century, overhunting reduced seal populations that had been the staple of traditional Inuit society. The warm currents that brought cod after 1920 in effect supplied new environmental capital, which helped to build modern Greenland. Overfishing eventually depleted this resource too. Shrimp became more abundant as cod declined, and presently support a large part of Greenland's economy.

Synergistic interactions. Falling sea temperatures after 1960, and the particularly cold winters of 1982–84, could have produced codfish declines even without overfishing. But the interaction between climate and fishing proved deadly. Cold waters slowed cod reproduction and growth, and fewer fish reached west Greenland from Icelandic waters, at the same time that the stock came under heavy pressure from an industrializing fishery. The result was a total collapse; in Amorosi *et al.*'s terms, a step-like transformation.

Intensification and technological fixes. Since the 1920s, Greenland's commercial fisheries gradually intensified from small-boat inshore activities, to mid-sized coastal boats and eventually to domination by offshore trawlers. As the cod population declined, it was pursued by more efficient technologies and greater investments. The codfish collapse was "fixed," at some cost, by redirecting effort towards shrimp and other species. Although technology continues to improve, catch levels in the shrimp and Greenland halibut fisheries appear already above their own sustainable limits. Future growth must draw upon other capital. The government views mineral/energy resources and tourism as two main possibilities.

The parallels between medieval and modern Greenland suggest that we are seeing more general patterns, applicable to other societies facing future climatic change. Natural capital depletion is a virtually ubiquitous trait of civilization. The "synergistic interactions" idea might be re-expressed as a proposition: *Climatic change affects human activities through dynamic interactions with resource use.* Thus natural-capital depletion can magnify climatic effects, or vice versa. At the same time, an unwanted outcome such as fisheries collapse or crop failure will have multiple causes, weakening the identification of an appropriate policy response. Finally, we have seen that intensification and technological fixes are common responses to environmental change, but they are not equally available to all people and places. *Benefits and costs of climatic change are distributed unevenly; on large or small scales, change creates winners and losers.* Geographical advantages, human resources and government decisions can influence how different people and places fare when their environmental regime shifts. The roles of these and other influences, in mediating the human impacts of climatic change, comprise a field for future research.

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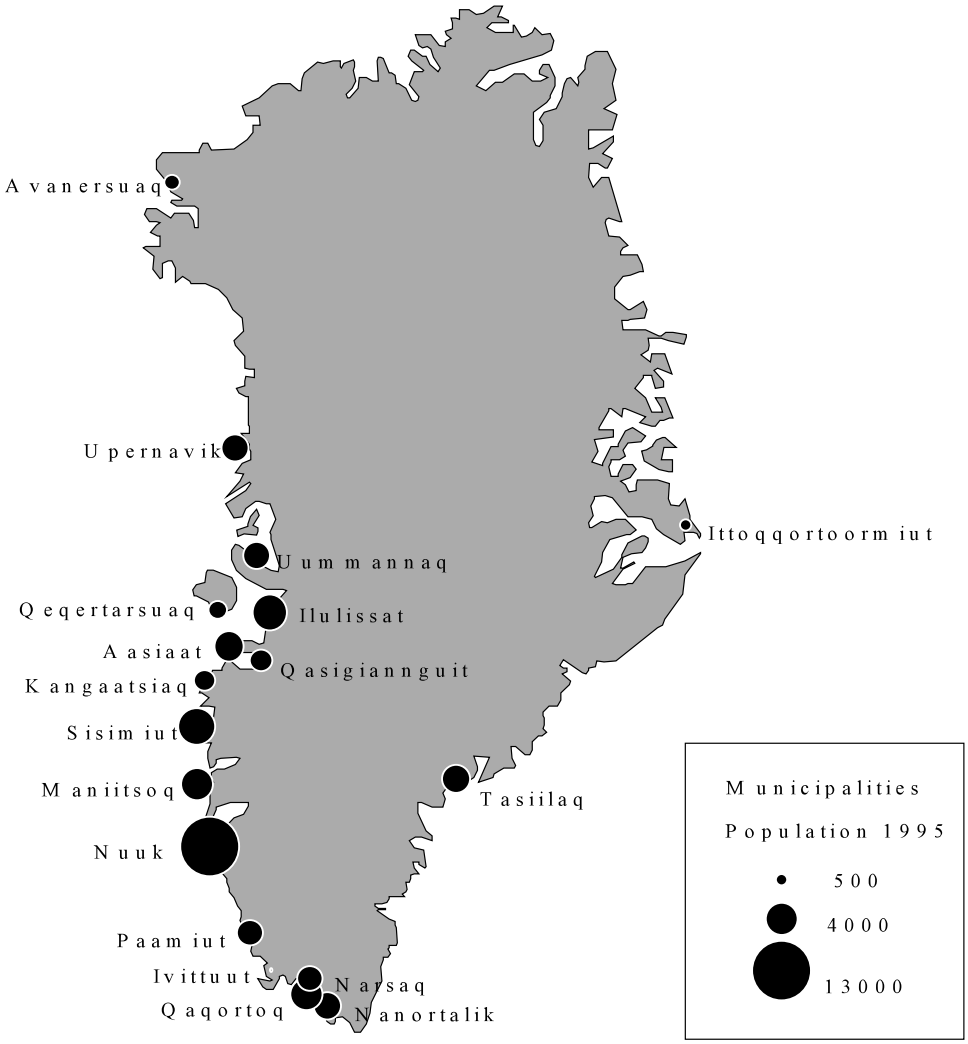

Figure 1: Greenland's 18 municipalities (circle areas proportional to 1995 population). Data source: Statistics Greenland.

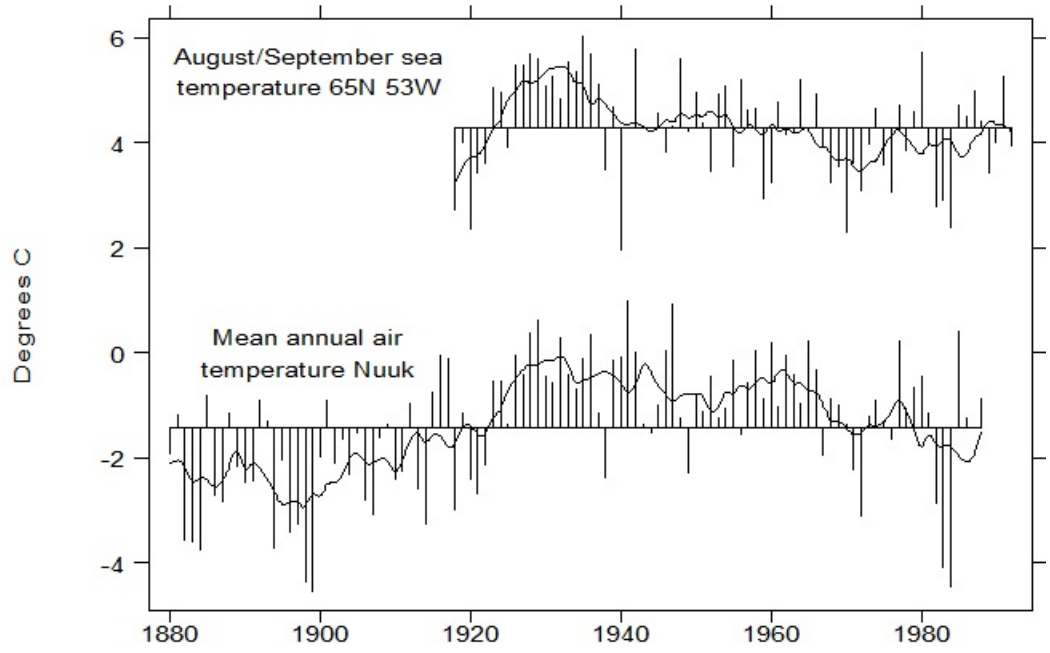

Figure 2: Mean August/September sea surface temperatures (top) and mean annual air temperatures (bottom) near Nuuk/Godthåb, 1880–1992. Graph shows monthly or annual values (bars), long-term means (horizontal lines), and lowess smoothed curves with approximately decadal bandwidths. Data sources: COADS, NHCDC.

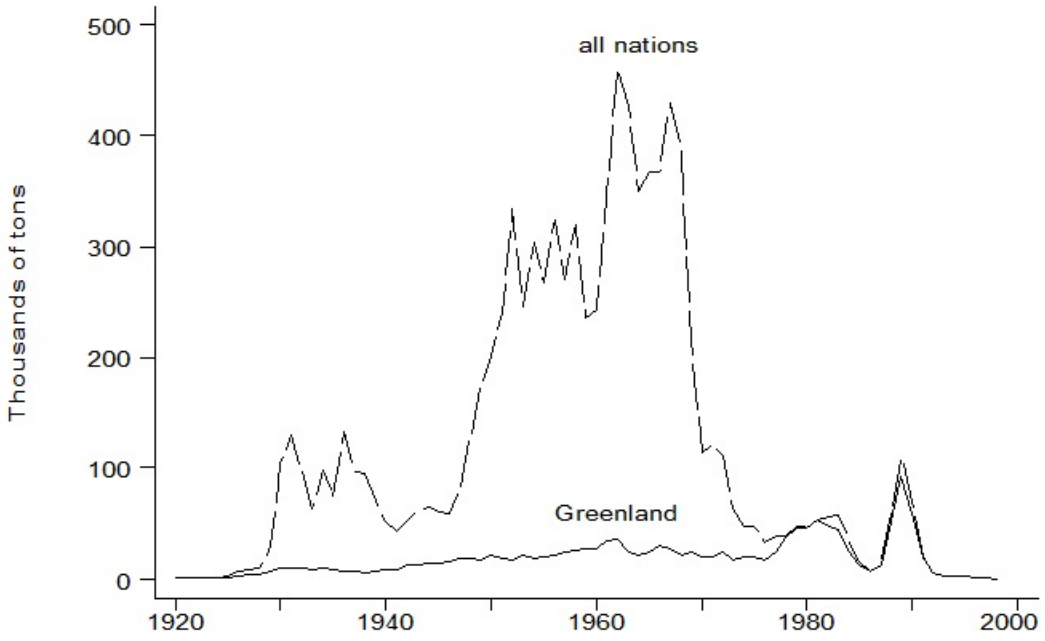

Figure 3: Rise and fall of cod fishing off west Greenland, 1920–1998. Data sources: Horsted (1994); Statistics Greenland.

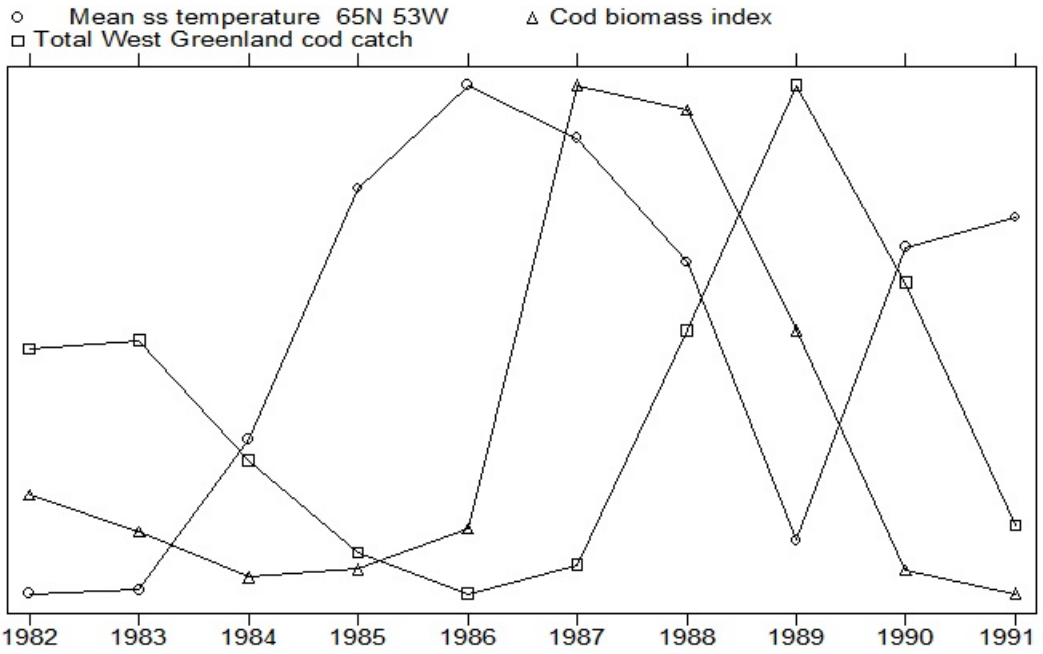

Figure 4: Mean sea surface temperature, cod biomass, and cod catch off west Greenland, 1982–91. The vertical scales for each series are different: sea surface temperatures 1–2.6 degrees C; cod biomass index 5.2–639 thousand tons; cod catches 6.6–108.8 thousand tons. Data sources: COADS, Rätz 1992, Horsted 1994.

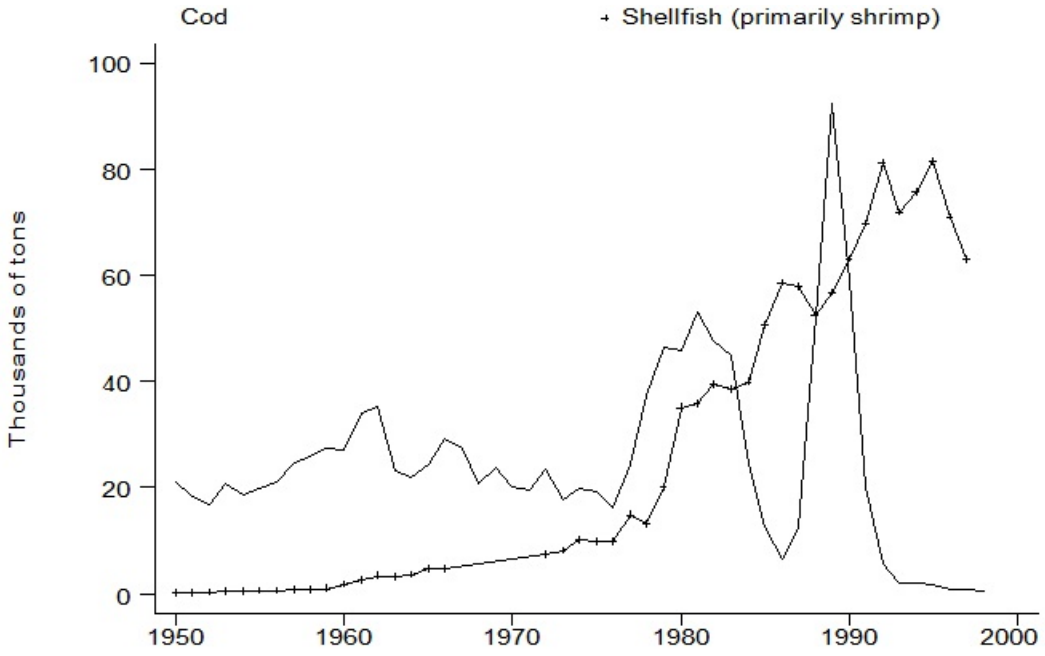

Figure 5: West Greenland's cod and shellfish catch, 1950–1998. Data sources: NAFO, Statistics Greenland.

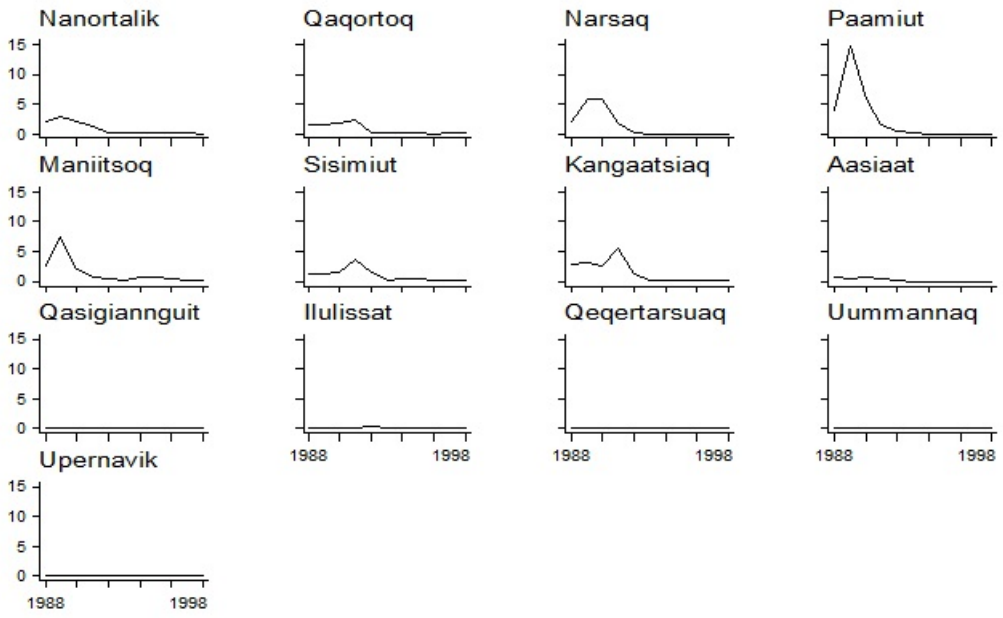

Figure 6: Codfish landings (thousands of metric tons) of thirteen west Greenland municipalities, 1988–98. Data source: Statistics Greenland.

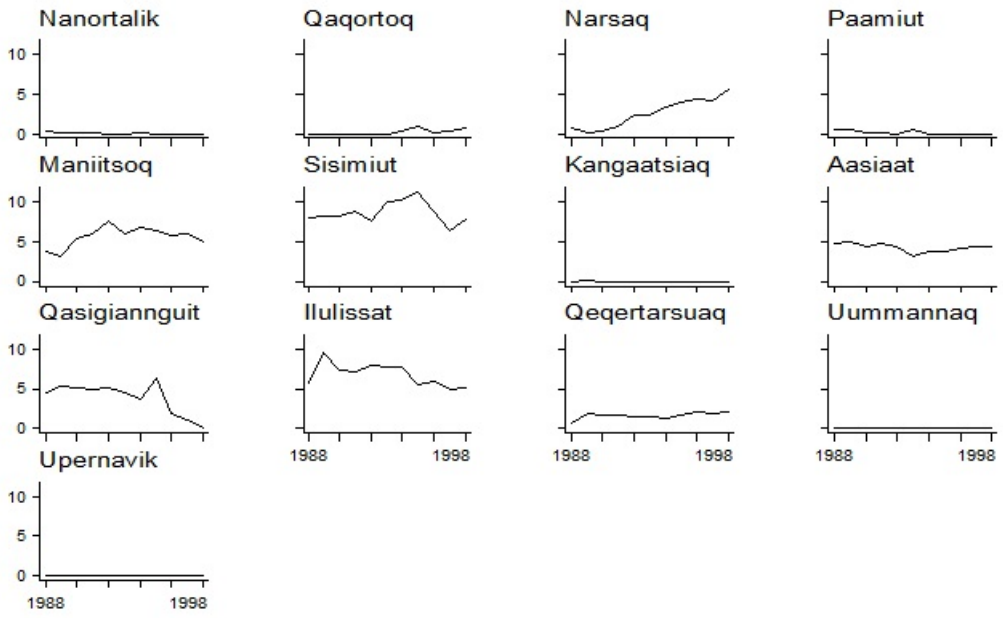

Figure 7: Shrimp landings (thousands of metric tons) of thirteen west Greenland municipalities, 1988–98. Data source: Statistics Greenland.

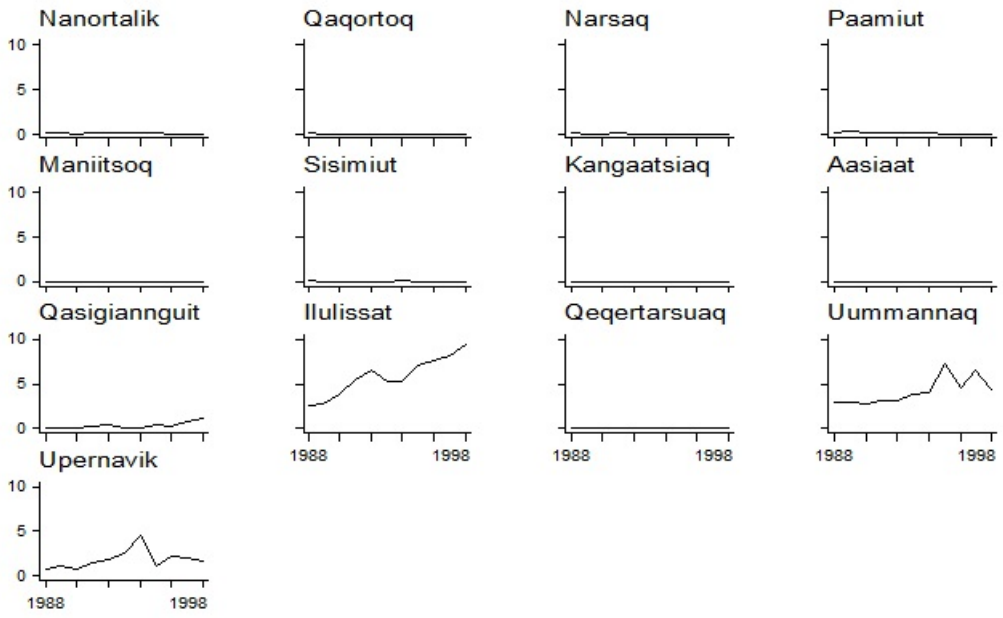

Figure 8: Greenland halibut landings (thousands of metic tons) of thirteen west Greenland municipalities, 1988–98. Data source: Statistics Greenland.

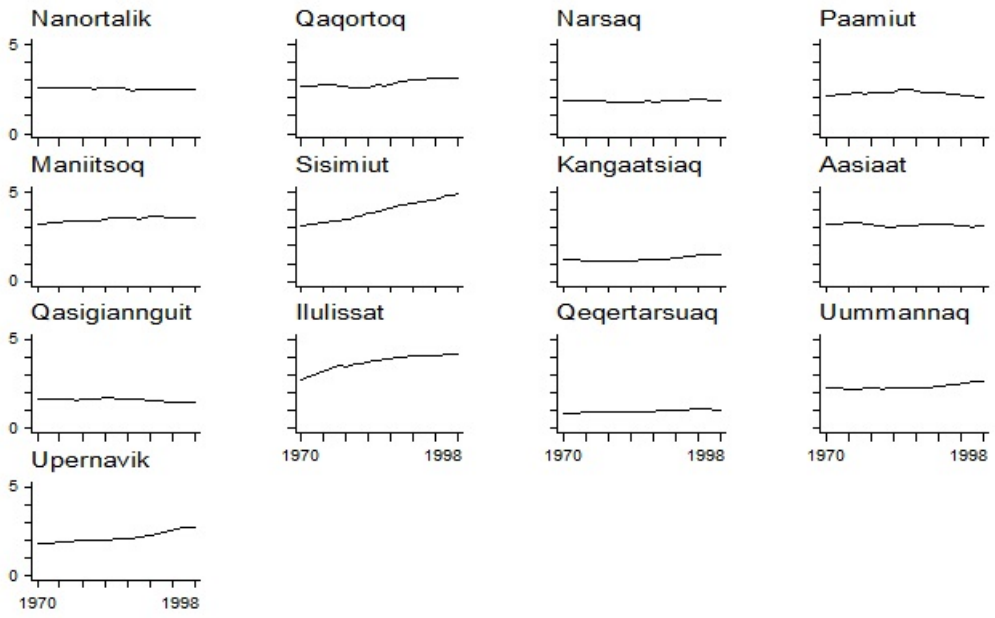

Figure 9: Greenland-born population (thousands) of thirteen west Greenland municipalities, 1970–98. Data source: Statistics Greenland.

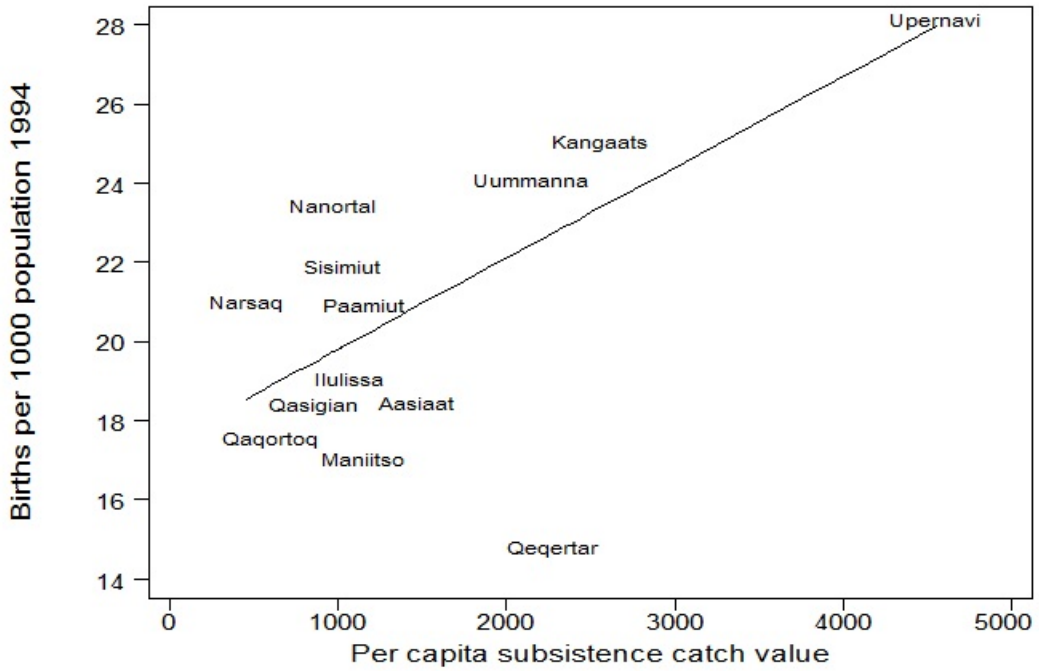

Figure 10: Birth rate and per capita subsistence catch value (kroner) among 13 west Greenland municipalities. Data sources: Lyster 1997; Statistics Greenland.

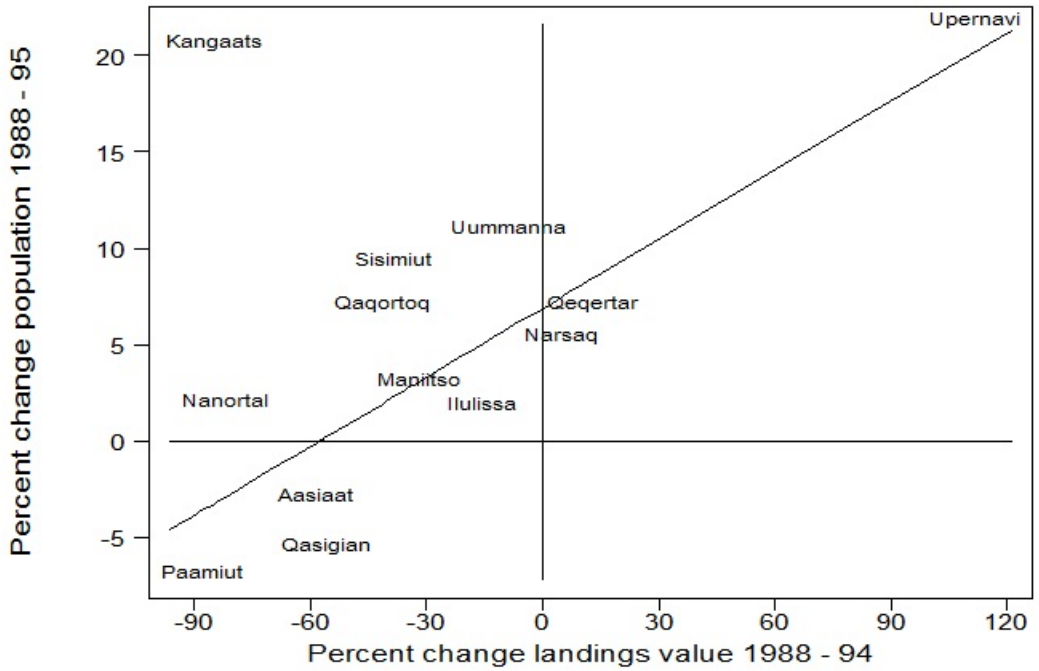

Figure 11: Relative changes in Greenland-born population and commercial landings (in 1994 kroner) among 13 west Greenland municipalities. Raw data: Statistics Greenland.

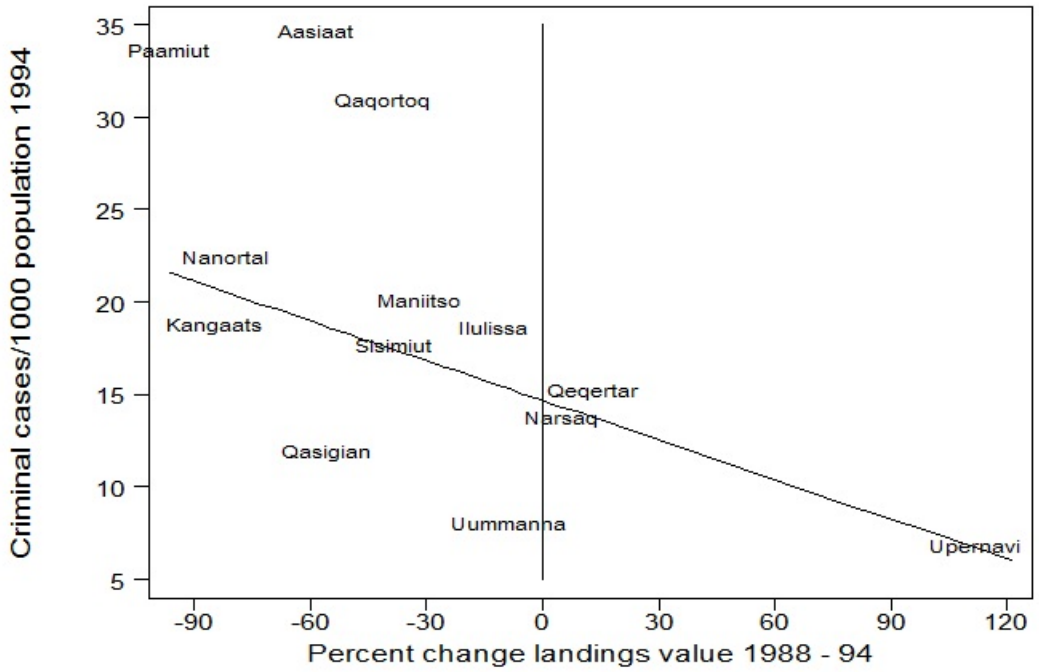

Figure 12: Crime rate and change in commercial landings value (in 1994 kroner) among 13 west Greenland municipalities. Raw data: Statistics Greenland.

NOTES

1. The government-owned Great Greenland company purchases seal and other furs, often at above-market prices, thus providing an indirect subsidy to hunters and hunting communities. Meat from hunting, however, has direct value both as a food source and a local market commodity. Lyster (1997) estimates the total value of seal meat consumed in Greenland households or sold in markets—considering either the market price or a "replacement cost" for the meat—at roughly 100 million Danish kroner (15 million U.S. dollars) in 1993.

2. Figures 6–12 and our discussion focus on landings rather than catch data. Fish catches (and their socioeconomic benefits) cannot as readily be connected with individual municipalities. Trends in landings (or catches) of various species correlate with marine ecological changes, but of course not perfectly. They also respond to other factors, such as government decisions about investments in trawlers and processing plants (Rasmussen and Hamilton 1999).