Name of the case study	Sisimiut – Cod to shrimp fishery transition – Greenland [Transformation]	
What about this case makes it interesting? How does this case contribute to understanding of resilience and/or regime shifts in the Arctic?	As in other Atlantic fisheries, Greenland experienced a cod-to-shrimp transition in the 20th century mediated by climatic changes and overfishing, which followed an initial seal-to-cod transition (1, 2). This case study compares two communities in West Greenland, Sisimiut and Paamiut, in terms of their natural and social capital and how these factors influenced the different outcomes. Sisimiut's historically more diverse economy and strong social capital, including locally driven initiatives, meant that it could make use of shifting natural resources quickly and adapt to changes. Paamiut's (see case study template for Paamiut) cod fishery developed slower than that of Sisimiut until it was built up as a specialised cod-centre by the Danish government. By the time the processing plant was built the cod catches started to become already unpredictable and the expected in-migration did not materialise. The focus on cod led to a lack of diversity in skills and initiatives in Paamiut, and led to Sisimiut's success when the cod disappeared. Although shrimp started to appear around Paamiut as well, the initial small quantities did not make up for the loss in catches of cod. By the time shrimp started to become more common off the shore of Paamiut, Sisimiut and other centres further north on the west coast had already built necessary processing plants. Finally, snow crab populations started to appear around Sisimiut, which became a centre for the new fishery. Paamiut also had snow crab stocks in the vicinity but processing facilities lagged until the government transferred a processing vessel to Paamiut, as yet another external intervention. These two cases show that access to natural resources does not guarantee prosperity, but depends very much on the human and social capital of a community. Top down development and lack of local initiatives left Paamiut in a less adaptive state. Today, snow crabs comprise only a small part of landing values in Greenland, whereas shrimp and Greenland halibut are the two main species (4). This case is deemed to be an example of transformation given: 1) the structure of the industry has changed completely: technology and machinery are needed at sea and for processing, markets, and who is fishing; and 2) the fishing grounds and targets have changed, so fishers can use much of their sea-faring skills to navigate, but require different ecological/biological knowledge.	
Template completed by:	Cornelia Ludwig, Stockholm Resilience Centre	**Key references: Cite in the text using (1), (2), (3) etc. and provide a reference list at the bottom of the template.** (1) Hamilton, L. C., B. C. Brown, and R. O. Rasmussen. 2003. West Greenland's cod-to-shrimp transition: Local dimensions of climatic change.

		Arctic 56(3):271-282. (7) Hamilton, L. C. 2007. Climate, fishery and society interactions: Observations from the North Atlantic. *Deep-Sea Research Part II: Topical Studies in Oceanography* 54(23):2958-2969.
Reviewed by (name and affiliation)		

Category (mark with X)	**Resilience/ Adaptability**	**Loss of resilience**	**Transformation**
			X

Case study details:	**Country**	**Place**	**Scale – space**	**Scale – time**	**Sector(s)**	**Other (e.g. disturbance)**
	Greenland	Sisimiut	200 nautical miles around community		Fishing	Cod collapse

Drivers (mark with X in appropriate boxes)	**Climate**	**Geopolitical**	**Mineral/ oil extraction & infrastructure**	**Tourism**	**Shipping**	**Biological invasion**	**Rapid demographic change**	**Other: *state here***
	X					Snow crab (?)		Cod collapse, increase in shrimp, snow crab arrival

	Biophysical	**Social**
1. Basic description of coupled social-ecological system in focus **(**What are the key components and stake	a) What types of ecosystem(s) and other major biophysical features are present? - Marine system off the coast of west Greenland, with previously predator-dominated regimes (cod and other ground fish), now with a crustacean-dominated regime	c) Who are the key groups of people in this case? - Fishermen, local actors and residents of Sisimiut - Local and Home Rule politicians d) What kinds of livelihoods are important in the system?

holders) If possible draw a systems diagram or conceptual map of the case – this can be a series of diagrams to capture different periods in the case and the drivers/ actors/ events that characterize the period.	- Greenland Ice Sheet Key components include the commercially interesting species: - Cod (*Gadus morhua*): top predator and thus dominated the ecosystem - Atlantic halibut (*Hippoglossus, hippoglossus*) and Greenland halibut (*Reinhardtius hippoglossoides*) - Shrimp (*Pandalus borealis*) - Snow crab b) How are the case boundaries defined in terms of ecosystems or biophysical characteristics? The waters off the coast of west Greenland, within 200 nautical miles, as well as the coastal areas that harbour Sisimiut's fishing community.	- Different fisheries and hunting importance changed over time: first came Atlantic halibut and seal hunting, then Greenland halibut, cod, and shrimp, and then finally snow crab - Hunting and fishing is still important for food supply (2) e) What institutions are key to this case? If possible define what scale it addresses. - Danish government - Home Rule government - Local actors - Subsidies for hunting from the state (2) - Not key, but present: Home Rule regulation that requires 25% shrimp be landed and processed on shore. All inshore fished shrimp MUST be landed and processed onshore in Greenland (4) f) How are the case's boundaries socially defined, and how do these social boundaries relate to biophysical boundaries? - Fishing community of Sisimiut located on the west coast of Greenland. - Today Sisimiut is home to about 5500 people. (3) - Denmark (government)

2. Timeline Draw a timeline of *key* events/ developments to the case. Points to include: Make clear the period of time over which the change is being considered. Provide a brief description of event/ actors, and ecological impacts. Mark particularly significant events with *. Consider both biophysical and social dimensions. Additional points that can be considered: Is it possible to identify periods of change from one type of system to another, transformations? Identify disturbances	(All items from (1) unless stated otherwise) Around 1910: commercial fishing started in Sisimiut. Initiatives came first from outsiders, but Greenlanders did inshore catching and processing work, often with own equipment. Danes fished for Atlantic halibut and taught Greenlanders how to fish it. Before 1920: seal hunting as traditional livelihood. Around 1920: Irminger current carried cod to southwest Greenland from spawning grounds at west Iceland. Cod fisheries grew with warmer water bringing in cod (*Gadus morhua*) to spawn in southwest Greenland. Warmer water and overhunting also led to decline in seal hunting, the traditional livelihood. Seal-to-cod transition. Focus for economy and infrastructure on this new industry. Greenlandic initiatives at Sisimiut started and marked new stage of development. 1924: canning factory came to Sisimiut 1928: Elias Kleist & partners, Sisimiut residents, first Greenlanders to purchase own private fishing vessel. 1931: Greenland's first shipyard built in Sisimiut 1930s and 1940s: Cod becomes more important as everyone with a boat could fish for this species. Shrimp needed larger vessels. mid-1930s: Atlantic halibut had disappeared, aided by overfishing by European long liners. Canning factory owner decided to shift to shrimp. 1935: shrimp fishery started slowly, (in 1950 Disko Bay being the most important in the inshore shrimp fishery) - 4 former halibut boats started fishing for shrimp - Gradually, stocks were also found further south. New technology opened up new fishing grounds for shrimp (rockhopper, etc.) 1938: Elias Kleist & partners start fishing for shrimp near Sisimiut. post WW2: Heavy fishing pressure of cod from international fleets. 1948: technical school opens in Sisimiut. 1953: Greenland status changes from Danish colony to Danish county. 1950s and 1960s: cod landing comparable in Sisimiut and Paamiut (two communities separated by 500 kilometres along the coast). Late 1960's: decline of cod due to overfishing and arrival of cold waters. Sisimiut fishery shifted towards shrimp. Cod-to-shrimp transition

or events that challenged, built, or reduced resilience or adaptive capacity in the system.	1969: processing plant for peeled shrimp in Sisimiut. 1960s-1990s: various Great Salinity Anomalies (GSA) due to North Atlantic Oscillation (NAO) changes, and discharge from the Greenland Ice Sheet, led to unfavourable conditions for cod, but peaks with higher cod catches did occur during that period. Water was too cold for spawning and there was a lack of recruitment when Irminger current stopped flowing northwards. Early-mid 1970s: shrimp fishery started to expand rapidly for Sisimiut. Shrimp replaced cod economically, but benefits were distributed differently. 1979: Greenland is granted limited sovereignty of Home Rule government. 1980s: major shrimp resources centred on Sisimiut and further north. Sisimiut was less specialised and adapted to the new resource by investment. Growth of population. 1989: snow crab fishery evolved in Nuuk and Sisimiut. Sisimiut residents invited Canadian fishermen so they could learn about their fishing techniques. Early 1990s: cod was essentially gone, but shrimp catches were peaking for Sisimiut, which helped maintained high landings. Population growth in Sisimiut. Today: most shrimp is frozen at sea and packaged whole. This creates a stronger market, but there are fewer jobs. In order to maintain employment, Home Rule government requires 25% shrimp catch to be landed and processed onshore. Sisimiut's dominance persists even after its environmental advantage was evened out by the detection of shrimp further south.	
3. Disturbances What are the key disturbances in the system (present and past)	a) Have there been major biophysical disturbances that are relevant for the case? • Depletion first of Atlantic halibut, then of cod stocks, first by international fleets and later by Greenland fishermen. Heavy fishing pressure from international fleet after WW2 on cod. Trawlers rapidly removed larger and mature specimens. Increased stock's vulnerability to climatic changes • Adverse climate: unusually cold waters reflected NAO north Atlantic circulation/circulation abnormalities and	b) Have there been major social disturbances that are relevant for the case? • Decline in seals and changes in traditional livelihood - Collapse of the cod fishery (1, 2, 3)

	discharge from the Greenland Ice Sheet leading to Great Salinity Anomalies (GSA) during 1960s to 1990s. This led to unfavourable conditions for cod to grow. The Recruitment from Iceland through the Irminger current ceased when it stopped flowing northwards (1)	
4. Drivers of change Clarify what impacts these drivers have on the SES and if these are direct or indirect	a) What are the key biophysical drivers of change? • Lack of predatory pressure due to cod and other fish stocks depletion played some role in the increase of crustaceans on Greenland's shores • Climate change is linked to variability in NAO, leading to changes of water temperature (5), and therefore breeding and growing conditions for cod and crustaceans. Colder water is advantageous for crustaceans and disadvantageous for cod (6, 7)	b) What are the key social drivers of change? • Shift from labour to capital intensive fishery and jobs in general • Market value and demand for crustacean products (Japan strong force on market). Higher prices for frozen whole shrimp, instead of peeled and processed, led to fewer jobs on shore • Location of natural resources were close to Sisimiut • Small boat owners were disadvantaged for participating in shrimp fishing. Cod could be fished by anyone with a small boat • Capital was concentrated and there was an uneven wealth distribution • Local actors and companies that take initiative for local development and have foresight
5. Sources of adaptive capacity: What factors allow(ed) the system to adapt to disturbances in the past and present? Give a brief assessment of recent or on-going changes	a) Within the ecosystem? (-) Biodiversity and healthy populations would provide resilience to the marine environment, but the fishing pressure led to the collapse of the former regime	b) Within society (e.g. people, social capital, management, institutions, infrastructure): (+) Local initiatives were driven by residents in Sisimiut to adapt to a changing natural resources base (+) Sisimiut's economy was historically quite diverse and created a broad range of workforce skills (+) In-migration to Sisimiut. With the successful transition from cod to shrimp, and also snow crab, increased human capital and brought new skills coming into the area

(+/-/0 = increasing/ reducing/ not affecting adaptive capacity)		(+) "government decisions are influenced by family networks that tie political leaders to their home communities" in Sisimiut (1) (+) Technical schools were established in Sisimiut (+) Generally: hunting contributes to food supplies for subsistence and commercial basis (2)
The next two sections break down the information in Section I. While it is not necessary to fill these sections, if you have additional information pertinent to specific rows below feel free to enter the material.		
II.1-8 SES, resilience and adaptive capacity		
	Biophysical	**Social**
II.1. Where do we find changes and resilience in the face of change?	a) Within nature	b) Within society - Some communities try to diversify the local economy - Enterprising spirit and social cohesion lead to early new-orientation - Hunting and fishing by private people for subsidence
II.2. What are the system's key components?	Key Ecological components (e.g. lakes, coastal zones, caribou) - Cod (*Gadus Morhua*) - Atlantic halibut (*Hippoglossus, hippoglossus*) and Greenland halibut (*Reinhardtius hippoglossoides*) - Shrimp (*Pandalus borealis*)	a) Actors in society (e.g. individuals, groups, public or private organizations)? How are people organised – by geography, livelihood, family, etc.? Residents in the costal communities are organised in: • Families • Individuals and private companies

	- Snow crab - Coastal and off-shore waters of west Greenland - Greenland Ice Sheet - Atlantic ocean currents	• Local government and community representatives therein
II.3. What are the key linkages? E.g. ecosystem services, resource extraction. These linkages should exist. If there are not mutual links between social and ecological components the case is not a social-ecological system.	a) From nature to society (e.g. ecosystem services) - Resource extraction: fish, crustaceans - Hunting and fishing for subsistence and for cultural identity of Greenland-born (2) - Mining, hydroelectric and aluminium are being explored (2)	b) From society to nature – modifying nature, extracting resources (e.g. hunting, mining, water pollution) - Fishing and sometime depleting of stocks: halibut, cod, other fish species, crustaceans, seals - Resource development for mining, hydroelectric and aluminium is being explored (2)
II.4. What are key interactions?	a) What are the key ecological interactions within the case? - Climate, i.e. north Atlantic circulation/circulation abnormalities that leads to GSA and reduces recruitment from Iceland and growth of cod in cold waters - Predator/prey relationships between cod and shrimp, possibly also snow crab b) What are the most important biophysical tele-connections to distant systems? - Like above, climate, i.e. north Atlantic	c) What collaborations, conflicts, or other key linkages exist between actors? - Greenland Self-government and communities - Greenland Self-government and fisheries (e.g. transferal of fishing vessel for crab) d) Between local actors and distant actors? - Danish government and fisheries rulings - Fishermen from Canada were invited by Sisimiut residents to teach crab fishing techniques - Market demand influences the viability of the fishery

	circulation/circulation abnormalities, Irminger current from Iceland - Greenhouse gasses released into the atmosphere contribute to climate change (there is even speculation that climate change could help reverse the regime shift from cod to crustacean, (8))	and related industries
II.5. Culture	a) How is the relationship between society and nature viewed? b) What meanings are attributed to nature and to interactions with nature?	c) What are key cultural features of relevance for the case? Natural resource extraction (hunting and fishing) has always been the major livelihoods here. Natural resources are traditionally core to community livelihood. d) What are key cultural practices and beliefs related to nature?
II.6. Disturbance What are important types of stress & shock	a) Describe important biophysical or ecological shocks and stresses (e.g. floods, storms, etc). - Overfishing of cod and Atlantic halibut - Taking older specimens undermined the resilience of the fish stocks - Changes in water circulations bringing colder waters and fewer cod for recruitment	b) Describe important social shock and stresses (e.g. austerity policies, changes in government policy, introduction of new technologies, etc.) - Change from labour to capital intensive fisheries - Technical advancement of fishing equipment, bigger boats - Introduction of destructive fishing practices, like trawling - Generally: Greenland underwent a transformation from traditional lifestyle to industrial/post-industrial in a very short time period (2)
II.7. What are key slow variables Changes that occur over decadal or longer time scales	a) What types of ecological processes (e.g. loss of permafrost, shifts in species composition) are driving important long-term changes in ecological structures and processes?	b) What types of slow social processes (e.g. aging, population growth, loss of language) are driving important changes in social institutions and behaviours? Greenland generally:

	- Warming of oceans: good for cod recruitment, bad for cold-water shrimps - Climate change leads to increased variability of NAO and hence water temperatures (5)	- Transformation to automatic fish processing reduced jobs for female workers -> outmigration - Few jobs for women with high qualification, especially in small settlements with more traditional life styles -> outmigration (2)
II.8. Relationships with ecological regime shifts	a) Are ecological regime shifts driving further ecological change or pressure? b) Are external or internal ecological dynamics potentially or actually producing ecological regime shift(s)? Climate change can influence dynamics of growth and recruitment or fish and crustaceans as well as zooplankton, which affects other trophic levels (5)	c) Can social stresses or major changes be attributed to ecological regime shifts? - A change in human demand for fish/eating behaviour/increased wealth created a demand for more cod and therefore intensification of fishing efforts which led to overexploitation - Technological changes: larger boats with bigger nets and more destructive fishing methods contributed to the depletion of cod stocks and possibly influenced the shift towards a crustacean-dominated regime - Allocations of shrimp fishing quotas by the government - A Danish government-led development of and focus on a narrow fishing based economy in Greenland d) Are there specific social practices that might be contributing to ecological regime shifts Fishing and hunting
II.8 Regime shifts	**If a regime shift exists and is important to this case describe it below.** Please indicate whether the regime dynamics are well-established, contested, or speculative.	
II.8.a. Detailed description of	Briefly describe the structure of each regime. What does each regime look like? What are differences in ecosystem structure and function? (e.g. permafrost loss, vegetation change)?	

alternate regime shifts A case study can contain more than one type of regime shift	The regime in the waters along the west coast of Greenland used to be ground fish dominated; first by Atlantic halibut and later with cod and Greenland halibut, but the changes in water temperature due to changes in NAO/climate change and to a degree the removal of predator species allowed for a steep increase in crustaceans, such as shrimps and snow crab, which led to this new crustacean-dominated regime. How do the properties and behaviours of regimes differ? e.g. collapse of subsistence food sources, fundamental change in types of livelihoods, change in governance institutions, new actors with significant political power who transform decision making) If cod and Atlantic halibut-fisheries were part of a regime on land, then there was a regime shift towards crustacean-fisheries, but different requirements for gear and boat size, as well as new licenses, meant that crustaceans could not be fished by the same people who fished cod. While cod was accessible to many, even with small boats, shrimp fishing could only be carried out by those who had access to bigger boats or the funds to buy appropriate gear and licenses. On land there were different winners and losers based on the regime-shift in the water. Capital was concentrated further and more unevenly distributed. New geographical advantages for some areas due to access to rich invertebrate resources. But closeness to natural resources was only part of the reason Sisimiut did well under the regime shift. Other factors were social, including prior diversification of the economy, as well as local initiatives and forward thinking. The population of Sisimiut has grown since the 1970s.	
II.8.b. Feedback mechanisms within the system that maintain each regime	Ecological feedback mechanisms - Change in water temperature creates more or less favourable conditions. Cold water is favoured by shrimp and snow crab, while warmer waters are better for cod recruitment and growth. Recruitment of cod is, however, quite dependent on currents from Iceland - In part, lack of predatory pressure due to the disappearance of cod stocks and other ground fish, allows for an increase in crustacean populations	Social feedback mechanisms - Market demands for crustaceans and fish keep the fisheries going - Quotas and policies that favour certain groups and people
II.8.c. What key	a) Drivers of ecological regime shifts (either social or	c) Drivers of social regime shifts (either social or

changes drive regime shifts? Describe how these changes alter the state of the system or feedback processes.	ecological). • Market demands for cod and Greenland halibut as well as crustaceans • Policies and quotas for fishing cod and crustaceans • New fishing techniques and intensification • Climate change, due to increased greenhouse gases, leads to a change of ocean temperatures and circulation patterns • All factors influence the biomass of species and influence the balance between regimes and dominating species b) How do these changes alter biophysical feedback processes? • Climate change has been linked to a changes in variability for the NAO and other circulation patterns that bring warmer or colder water, which has direct effects on biomass of cod and crustaceans • All of the above suggest that the biomass of species is influenced by balance between regimes and dominating species	ecological). Cod and Atlantic halibut-stock depletion d) How do these changes alter the social feedback processes? Depletion of cod stocks and halibut led to a shift towards crustacean fisheries which were favourable for owners of larger ships and that who had funds to invest into appropriate gear
II.8.d. Ecosystem services substantially impacted by regime shift	a) Changes in ecological processes that produce ecosystem services The marine system is still providing biomass for harvest, but the majority in landing value comes from shrimp as well as Greenland halibut (4).	b) Changes in demand for ecosystem services (market and non-market) There is a high demand for crustaceans from Japan, but worldwide, shrimp has gained popularity (4, 7). c) Changes in the institutional context of ecosystem services, e.g. changes in access and changes in how ecosystem services are valued as expressed by rules and

		regulations.
II.8.e. What is (+/-) impacted by changes in ecosystem services directly or indirectly	a) Impacts from regime shift on ecological components	b) Impacts from regime shift on social actors (+) Incentive for exploring other routes for the economy early on (Sisimiut) (+/-)Need to form new policies and distributions of quotas by the government (+/?) Social actors work together
II.8.f. Potential cascading effects	Describe, if any, the likelihood of potential ecological cascading effects to other SES	Describe, if any, the likelihood of potential social cascading effects to other SES
II.8.g. Where do actors intervene to alter regime shift dynamics and who can do the intervening?	Ecological oriented interventions	Socially oriented interventions The government has stepped in to manage fish stocks to allow recovery where necessary. Quotas and management by the self-government based on accurate scientific knowledge can influence the dynamics of the marine ecosystem. Fishermen can continue to use/develop fishing gear with less detrimental effects on non-targeted populations.

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GLOSSARY OF TERMS IN THE TEMPLATE

Actor	We use this term generally to look for individuals, groups, organisations, and so on that structure actions and/ or are stakeholders.
Adaptive capacity	Is the capacity of actors in the system to manage resilience in order to stay within a desired state during periods of change. This is related to the diversity in the system behind the provision of a function.
Disturbance	This refers to any disturbance to the system, regardless of scale, duration, intensity and frequency. See shock and stress.
Driver	Actor or process that directly or indirectly affects change in a social-ecological system. External means that the system in question (the scale being looked at) is unable to affect the driver in question – there is no feedback from the system to the driver.
Ecosystem services	The goods and services humans derive from ecosystems. These include: provisioning, regulating, cultural ecosystem services respectively.
Feedbacks	A change within a system that occurs in response to a driver, and that loops back to control the system. A feedback can help to maintain stability in a system (negative or balancing feedback), or it can speed up processes and change within the system (positive or enhancing feedback). Feedback processes play a very important role in determining system thresholds and in maintaining system resilience.
Institution	Here we refer to the humanly devised constraints that shape human interactions, such as rules, norms and laws. These can be formal or informal. Note that we are not referring here to institutions as organisations.
Regime shift	For complex systems, a substantial and enduring reorganization of the system, where the internal dynamics and the extent of feedbacks undergo change.
Resilience	This is a property, in this context of social-ecological systems. It relates to the capacity of a system to cope with disturbances and recover in such a way that they maintain their core function and identity. It also relates to the capacity to learn from and adapt to changing conditions, and when necessary, transform.
Shock	A sudden, unexpected disturbance. This kind of disturbance is often punctual, and has important impacts on large parts of the system.
Slow variable	When analysing complex system is often useful separating “fast” and “slow” variables. Fast variables often represent the primary concern of ecosystem users, for instance game or crop production. Slow variables shape the behaviour of fast ones but change slowly with respect to the overall dynamics of the system. Examples of slow variables might include permafrost thawing for a social-ecological system of Arctic hunters where the fast variable is game, or soil organic matter for an agricultural system where the fast variable is crop production.
Stress	This is a disturbance that has long persistence and often low intensity in impact.
Social-ecological system	This is an interwoven system of human societies and ecosystems. This concept emphasises that humans are part of nature and that these components function in interdependent ways. In the template identifying these interactions between the components aims to identify the processes and actors/ components that interact and particularly the feedbacks between the human-related

	components and the ecosystems/ biophysical components.
Stakeholder	See “actor”
Systems Diagram	This is using a diagram to illustrate the configuration of a system. This is done by defining its structure, function, and feedbacks. For a case there may be more than one diagram if the system changes in character (actors, processes, drivers, disturbances, feedbacks etc.) over time.
Timeline	The goal with the timeline is to capture important events – both punctual and over longer periods of time, identifying the causes of these events and the actors/ processes involved. This should be done chronologically and distinguishing events.