Name of the case study	Siglufjörður – Collapse of the herring fishery and the social consequences – Iceland [Loss of resilience]
What about this case makes it interesting? How does this case contribute to understanding of resilience and/or regime shifts in the Arctic?	The case of the herring fishery in Siglufjörður is relevant to many fishing-based centers around the Arctic and beyond. Siglufjörður went from being the herring capital of Iceland to a collapsed industry, in part due to exploitation practices but also due to changes in water conditions that moved these fishing grounds. This kind of change is common in the sea and cannot be controlled by management. The tendency to invest in boom times and to focus on a single activity and species reduces resilience to disturbances to the fishery. There have been efforts to increase diversification in the village, though at the time of writing their impact cannot yet be evaluated. In time this case may shift from being an example of loss of resilience to one of adaptability or maybe even transformation. Siglufjörður grew from just about 100 people in 1890 to a large community, peaking in 1949 (approximately 1200 in 2015 (9)). This growth was due its location as spring-spawning Norwegian herring could be fished here, in summer and autumn, in the north and east of Iceland. First Norwegians came to use Siglufjörður as a base for fishing, taught Icelanders how to fish this species and the fishery took off. Climatic conditions turned favourable for herring in the beginning of the 20th century, so populations boomed off the coast of Iceland and so did the fishery. This was the first regime shift that the region experienced during the period that is considered here. The Icelandic government invested in developing Siglufjörður further as the herring capital of Iceland. Working in the fishery business gave many young men and women previously unknown opportunities to earn a good wage and the town's population grew quickly reaching a peak in 1949. In the 1960's development in fishing technology provided record catches. However, the stocks had already been declining under the fishing pressure. In 1965, a sudden change in water temperature and salinity levels due to drift ice and polar water coming to the feeding grounds put an extra strain on the herring population. As its plankton food source grew scarce the stocks collapsed. This was the 2nd regime shift for the region and during the period that is considered here. There is not a *single* reason for the collapse of the fishery, but it is a result of a combination of human pressure and unfavourable climatic conditions. Nevertheless, it proved to be disastrous not only to Siglufjörður, but affected the whole of Iceland leading to high outmigration nationwide. Siglufjörður's economy and reason for existence was based on the herring and there were few alternatives livelihood options available. Fishing for alternative species, such as capelin, grew and provided income for some fishermen. Until 2014 Siglufjörður's population had been gradually declining. A new tunnel completed in 2010 has significantly reduced the travel time from Siglufjörður to Akureyri, a larger centre in the region, and made the trip safer all year round. There are hopes for developing the tourism sector further with these improved connections. To this day the town is still fishery-dependent.

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., J. Steingrímur, H. Ögmundardóttir, and I. M. Belkin. 2004. Sea changes ashore: The ocean and Iceland's herring capital. *Arctic* 57(4):325-335. (2) Hamilton, L. C., O. Otterstad, and H. Ögmundardóttir. 2006. Rise and fall of the herring towns: Impacts of climate and human teleconnections. Pages 100-125 *in* R. Hannesson, and S. F. Herrick, editors. *Climate change and the economics of the world's fisheries: Examples of small pelagic stocks.* Edward Elgar Publishing, Cheltenham, UK. (3) 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)**
	Iceland	Siglufjörður		20th century to present	Herring fishery	Herring 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		X building of tunnel to increase					Herring collapse due to overfishing and

			economic options: tourism, work					climate changes

	Biophysical	**Social**
1. Basic description of coupled social-ecological system in focus **(**What are the key components and stake 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.	a) What types of ecosystem(s) and other major biophysical features are present? - Marine ecosystem: waters off the east/northeast coast of Iceland, which are feeding grounds for spring-spawning Norwegian herring - Harbour of Siglufjörður - Fjords around Siglufjörður - Coastal waters along Norway and Faroe Islands (1, 2) b) How are the case boundaries defined in terms of ecosystems or biophysical characteristics? - The whole north-east Atlantic as herring has a migratory lifecycle	c) Who are the key groups of people in this case? - Icelandic fishers - Citizens of Siglufjörður (now home to 1219) - Icelandic government d) What kinds of livelihoods are important in the system? - herring fishing - fishery related jobs in general e) What institutions are key to this case? If possible, define what scale it addresses. - Laws protecting herring fishing in Icelandic waters for Icelanders - Quotas f) How are the case's boundaries socially defined, and how do these social boundaries relate to biophysical boundaries? The case is based around the effects of the herring boom and crash on the northern coastal settlement of Siglufjörður Note: Norwegian fishermen played a key role in beginning Siglufjörður's path to becoming the herring capital, and probably also suffered from the disappearance of the herring.

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?	- Pre-1800s: Norwegian spring-spawning herring had been fished for centuries along Norwegian coastal waters - Mid-1800s: Norwegians discover that this stock can be fished in summer and autumn north and east of Iceland - By 1880: Norwegian-dominated fishery changed life in Iceland by providing salting jobs and building of wooden houses - 1880: Icelanders who had learned how to fish for herring started a herring fishing company in Siglufjörður - 1890: Siglufjörður is home to less than 100 people - Late 1800s: first boom of Icelandic herring fishery faded due to worsening climate and falling market prices - Restrictions on access to shoreline for landless workers broke down and a labour market formed* - 1903: Norwegians arrive in Siglufjörður and soon established the first processing factory, salting line and storage facility. Employment for Icelanders in the region. - Early 1900s: herring fishing resumes and was a factor lifting Iceland from poverty to affluence. Larger vessels and purse seine technology increased catches. Labour-intensive export provided many people with cash wages for the first time - 1903-24: many farm labourers and young women moved to Siglufjörður doubling the population by ten-fold →1450 - After 1915: Icelandic vessel dominated - 1922: parliament decides that only Icelanders are allowed to fish in Icelandic waters and process catch* - 1920s: temperature-mediated habitat switching northwards of phytoplankton and hence herring due to changes in AMO which brings warmer waters, herring becomes more abundant of the east coast of Iceland* - By late 1930s: population had doubled again - 1944: first independent government* - 1940s: investment by government to build up catching and processing capacity - catches fluctuate but with general upward trend - 1949: Siglufjörður reaches peak population with 3100 all year round citizens - 1950s: automation in the factories required fewer workers - 1958: assertion of jurisdiction over fisheries out to 12 miles by the government. Further investment into new technology - Mid-1960s: innovations sonar and power block-assisted purse seines of nylon led to record catches* - 1965: sudden change in water temperature due to drift ice and polar water led to cold waters until 1971. Great Salinity Anomaly 70's (GSA70s). Availability of food for herring diminished due to short spring bloom of phytoplankton. * - By late 1960s: catches from this herring stock had been falling and were almost non-existent from Icelandic waters. Rising catches with falling stocks due to high fishing pressure had led to an abrupt jump in fishing mortality.* Herring

Identify disturbances or events that challenged, built, or reduced resilience or adaptive capacity in the system.	collapse affected all of Iceland leading to high level of outmigration. - Mid-1980s: The stock survived in Norway under protection and recovered slowly - Late 1990s: herring appears again in moderate numbers in Icelandic waters as salinity rises to similar levels as before 1965 (1, 2, 3) - 2006: Siglufjörður was merged with the village, Ólafsfjörður, on the other side to form the municipality of Fjallabyggð - 2010: Completion of Héðinsfjarðargöng tunnel shortening the travel distance to Akureyri from 300km to 77km and also making the journey safer*	
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 of herring stocks to unsustainably high catches by several nations not just in Icelandic waters Increased stock's vulnerability to climatic changes and high fishing pressure Adverse climate: Great Salinity Anomalies (GSA70s) and large volumes of cold polar waters driven by NAO circulation/circulation anomalies Climate change curtailed the phytoplankton and hence copepod production- the food source for herrings (1, 2, 3)	b) Have there been major social disturbances that are relevant for the case? - Investment and development by government, which turned Siglufjörður into herring-centre - Collapse of the herring fishery - Sudden increase of unemployment - Increased outmigration (1, 2)
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? - Climate change is linked to variability in NAO leading to changes of water temperature and salinity, which decreased the amount of phytoplankton, and hence	b) What are the key social drivers of change? - Shift from labour to capital intensive fishery and jobs in general leading to fewer jobs - Location of natural resources and hence access to them

	copepods, which are the food source for herring (1, 3, 4)	- Herring moratorium quotas allocated by the government - Market forces - Lack of knowledge/awareness of climatic variations and signs of declining biomass (1, 3, 5) - Local actors and companies that take initiative for local development and have foresight (the museum, small shops, cafés, hotels at waterfront, art space, gallery, studios, etc.) - Government investment by building tunnels to connect Siglufjörður to other economic centres (6)
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 (+/-/0 = increasing/ reducing/ not affecting adaptive capacity)	a) Within the ecosystem? - Return of herring once salinity levels reached previous levels (+)	b) Within society (e.g. people, social capital, management, institutions, infrastructure): (+) State provided capital for new trawlers and a factory for catching cod (minor), haddock, capelin, shrimp and redfish instead (+) Barrel making factory switches to making pre-fabricated houses (+) Extension of territorial waters to 50 miles in 1972 and to 200 miles in 1976 led to increased employment opportunities onshore (1) (+) Building of tunnels in 2010 between Siglufjörður and Ólafsfjörður for faster access to Akureyri should also increase chances for income through tourism (-) Tunnels could also lead to further decline since shopping is done in larger centres (6) (+/-) Tourism could lead to second home ownership, which can have a positive and negative affect on social fabric of

		small villages (6) (+) Turning the history into a museum (+) Turning old factory buildings into culture and art spaces (6) (-) Outmigration towards towns to find work
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 - Return of herring in moderate numbers due to change of water currents, temperature and salinity (2)	b) Within society - Attempt to diversify the local economy after the break down of the fisheries focusing on tourism and alternative fish species (1, 2)
II.2. What are the system's key components?	a) Key Ecological components (e.g. lakes, coastal zones, caribou) - - Atlanto-Scandian herring (*Clupea harengus*) - Copepod (*Calanus finmarchicus*) - Carpelin - Cod - Shrimp - Redfish - Haddock - The harbour and fjord of Siglufjörður - Herring feeding grounds off the coast of Iceland (1)	b) Actors in society (e.g. individuals, groups, public or private organizations)? How are people organised – by geography, livelihood, family, etc.? - Individuals and families reside in the village (new and old) - Private companies - Fishermen - Workers in fish companies - Artists/creative people - Icelandic government

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	b) From society to nature – modifying nature, extracting resources (e.g. hunting, mining, water pollution) - Fishing and sometimes depletion of stocks: herring - Tourism and culture
II.4. What are key interactions?	a) What are the key ecological interactions within the case? - Climate and herring: sudden change in water temperature due to drift ice and polar water led to cold waters and Great Salinity Anomaly 1970's (GSA70s) → did not support herring life cycle in the vicinity of Iceland - Predator/prey relationship between herring and copepods - Predator/prey relationship between copepods and phytoplankton - (Availability of food for herring diminished due to short spring bloom of phytoplankton which is prey for copepods) (1, 7) b) What are the most important biophysical tele-connections to distant systems?	c) What collaborations, conflicts, or other key linkages exist between actors? Past: - Collaboration: Norwegian fishermen taught Icelanders how to fish herring - Conflict: landowners lost workers for the land to the salting factories and fishing industry in Siglufjörður (1,2) Collaboration: - Of residents/local businesses to create art projects and festivals d) Between local actors and distant actors? Market pressure through demand fuelled intense fishing efforts

	Like above, climate, north Atlantic salinity abnormalities, etc. Migratory stocks	Government investment to develop Siglufjörður for herring fishing industry (1) Government investment into increasing mobility and connectedness by building tunnels and roads Fishing technology
II.5. Culture	a) How is the relationship between society and nature viewed? The reason for the existence of Siglufjörður is the location and closeness to natural resources, i.e. herring Fishing culture is still part of identity for the village b) What meanings are attributed to nature and to interactions with nature?	c) What are key cultural features of relevance for the case? Fishing culture and village identity is still important to Siglufjörður's residents today (6) Village economy is still dependent of fisheries 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 herring stocks - Changes in water circulations bringing colder waters and changing salinity levels (1, 2, 3)	b) Describe important social shock and stresses (e.g. austerity policies, changes in government policy, introduction of new technologies, etc.) - Change from labor to capital intensive fisheries - Technical advancement of fishing equipment, bigger boats (sonar and power block-assisted purse seines of nylon) - Sudden increase of unemployment - Outmigration of (young) adults - Reduction of human capital

		(1, 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? Climate change leads to increased variability of NAO and hence water temperatures and shifts in salinity (3, 4)	b) What types of slow social processes (e.g. aging, population growth, loss of language) are driving important changes in social institutions and behaviours? Reduction of human capital due to outmigration, however, 2015 has seen a slight rise again in population (9)
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 is influencing the NAO/AMO, and the changes in salinity and water-temperature are causing and will continue to cause rapid habitat changes and temperature-mediated hence regime shifts (3, 4)	c) Can social stresses or major changes be attributed to ecological regime shifts? Through human actions which releasing greenhouse gases, and contributing to climate change, may be linked to changes in NAO (4) d) Are there specific social practices that might be contributing to ecological regime shifts
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 alternate regime shifts A case study can contain more than one type of regime shift	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)? - Regime 1: colder waters in the north Atlantic near Iceland - Regime 2: warmer waters in the north Atlantic near Iceland (both influence habitat extensions for herring and its main prey) 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) - Habitat location and biomass of herring changed - The disappearance of herring meant the collapse of Siglufjörður's fishing industry, and hence livelihoods for the majority of residents	
II.8.b. Feedback mechanisms within the system that maintain each regime	Ecological feedback mechanisms Water-temperature and salinity depending on the NAO determines habitat extension of the main species in this case (1, 2, 3, 7, 8)	Social feedback mechanisms Fishing pressure and fishing technology exert strain on the herring population when the temperature shifted back to a less favourable condition (1, 2, 3)
II.8.c. What key changes drive regime shifts? Describe how these changes alter the state of the system or feedback processes. -	a) Drivers of ecological regime shifts (either social or ecological). Climate change and normal changes in NAO will lead to changes in water-temperature and salinity. High fishing pressure through technological advances will induce additional strain when conditions become less favourable (1, 2 3, 7, 8) b) How do these changes alter biophysical feedback processes? Changes in temperature, and hence conditions for species in the food chain, will affect herring distribution and biomass itself (1, 2, 8)	c) Drivers of social regime shifts (either social or ecological). Climatic and fishing pressure leads to a collapse of fishery livelihood d) How do these changes alter the social feedback processes? The breakdown of the main livelihood in the community leads to unemployment, which in turn leads to outmigration and loss of human capital which makes in harder for the community to recover and find alternative livelihoods
II.8.d. Ecosystem services substantially impacted by regime shift -	a) Changes in ecological processes that produce ecosystem services - The changes in temperature and salinity due to climate change and change in NAO leads to changes in habitat of	b) Changes in demand for ecosystem services (market and non-market) The demand for herring is strong, which means continued stress for the herring population (even though Norway

	prey and target species and affects conditions necessary to reproduce (1, 2)	spring-spawning herring has been Marine Stewardship Council certified since 2009 (10)) 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. In 1922, the parliament decided that only Icelanders were allowed to fish in Icelandic waters and process the catch Moratorium on fishing herring in 1972 by the Icelandic government and introduction of the quota system (5)
II.8.e. What is (+/-) impacted by changes in ecosystem services directly or indirectly	a) Impacts from regime shift on ecological components (-) Herring as a resource for fishing, and basis for livelihood, decreased due to the climatic changes and over-fishing	b) Impacts from regime shift on social actors (-) Unemployment of fishermen due to the disappearance of herring (-) Closing of herring processing factories
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 - globally climate change is being addressed which in turn can influence the outcome of NAO (on the other hand warming of oceans may counteract colder waters from another shift in the circulation of cold polar waters)	Socially oriented interventions - residents are trying to diversify livelihood in Siglufjörður - local actors are setting up shops, attractions and festivals to draw in tourists and stop residents from leaving - the government built a tunnel to connect Siglufjörður more easily to Akureyri which makes access easier for tourism and locals

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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.