Fukushima Daiichi

Japan's Resilience to Nuclear Plant Meltdown

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Abstract

My thesis explores the boundaries of resilience in social-ecological systems (SES) experiencing nuclear power plant disasters by studying the 2011 meltdown at the Fukushima Nuclear Power Plant in Japan through the question, *to what extent has Japan demonstrated resilience to the Fukushima Nuclear Plant meltdown?* I use two models to assess events and actions in Japan before, during, and after the meltdown in order to break down the definition of resilience at different scales of space and time. The first model is a panarchy of adaptive cycles, formulated by C.S. Holling (2001), depicting a traditional SES spatial-temporal cycle - including levels of growth, accumulation, restructuring, and renewal. The second model is the Protective Action Decision Model (PADM) as formulated by Michael Lindell and Ronald Perry (2012), depicting contextual, psychological, and situational impacts on decision-making. In my research, I use Fukushima as context for expanding the foundation and use of each model so that they are more relevant to the unique characteristics of radiation. I find that while the social-ecological system in the immediate Fukushima prefecture decouples, the respective social and ecological systems continue to express signs of resilience separately, creating new SES opportunities elsewhere. Outside of Fukushima, individual and national scales in Japan use the processes from a panarchy of “revolt” and “remembering” to attempt to recover resilience after disaster.

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Without those mentioned on this page, I would never have reached the last word of this thesis. The support, inspiration, and love from the people in my life have helped pull these pages out of the jumbled mess in my brain.

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1. Framework of Study

1.1 Resilience and Social-Ecological Systems

Sustainability has disseminated into the rhetoric of today's world. Buildings, businesses, cities; you name it and there is a sustainable version of it. There are certainly circumstances in which "sustainability" is an applicable description, but knowing when to use it correctly can be difficult. Most people don't know what it means to be actionably sustainable, or how the definition changes in context. Melinda Benson and Robin Craig argue that using sustainability as the backbone of climate change goals is problematic because "sustainability assumes that there are desirable states of being […] that humans can maintain" (2014, 779). In particular, desirable states of being are impossible to maintain during recovery to disaster. Disasters inherently cause abrupt changes to a system, unlike the steady-state goals of sustainability. The phrase "resilient" has come to be a possible alternative in order to combat fuzzy interpretations of sustainability, with mixed results. At its most basic definition, resilience refers to one's ability to bounce back after a crisis, trauma, or change. So why introduce resilience if sustainability is so widely used? Unlike sustainability, resilience, as an alternative, assumes a changing state of being much more realistic to what we experience every day, making the term more applicable to abrupt changes from disaster.

The definition of resilience that Benson and Craig use can be summarized as the capacity for a system to undergo change while still maintaining function, and includes the ability to reorganize and learn. Their definition is just one of many, because like sustainability, resilience definitions have become numerous and more complex over time (dating back to classic articles like that of Holling 1973). Equally numerous are possible critiques, including the abstract nature of the concept, often used without "a direction or goal, and is often employed without reference to its subjects" (Bahadur and Tanner 2014, 202). Similarly, it is used as "a rhetorical devise with little influence on actual decision making" (Benson and Craig 2014, 780). These specific critiques are especially important to note in this paper because the following research will, in effect, attempt to move the concept from the abstract realm into the practical.

Social-ecological systems (SES help constrain the practical context of resilience. SESs are nested layers of place-based communities located anywhere from a street, to a region, a nation, or beyond. Described by Neil Adger in Kulig et. al., the resilience of each individual system can inform the other: "ecological resilience stimulates a community's capacity to change, including complementary changes within social resilience of that same community" (2013, 759). According to Ager, *both* systems can develop layers of dependency on the other (Kulig et. al. 2013). Walker et. al. suggests the opposite: humans have dominated the SES relationship in the past and therefore dictate the resilience of an SES (2004).

During disasters, SESs experience an abrupt shock, throwing all components of the system into a jumbled mess. Determining where in an SES resilience stems from (ecological, social, or a combination of the two systems) can be a first step in making disaster resilience less ambiguous. Considering resilience through multiple actors at multiple scales involves a lot of moving parts within a context. In some cases, resilience of a given actor or scale might only be achieved at the disadvantage of another actor or scale. Sacrificing resilience across thresholds is what the Resilience Alliance calls 'general' versus 'specific' resilience (2010). General resilience can be widespread, taking into account the systematic fluctuations of everyday life, being prepared for any change at any time. Specific resilience, however, clearly defines the actors and scales of resilience, whether it be a community, individual, or resilience to specific events, such as disasters.

1.2 Resilience and Disaster

The role of humans in an SES adapting to disasters brings me to the second contextualization that is necessary for my research: disaster resilience. While humans have little control over the when, where, and what of a disaster, we still play a substantial role in the function of SESs in the event and recovery stages. Capacity, vulnerability, hazard, and risk are all characteristics of SESs that determine a system's resilience to disaster. Vulnerability, for example, is a socially constructed reality perpetuated by social orders that can leave certain people without the resources or capacity to respond successfully (Vacano and Zaumseil 2014). This does not mean that vulnerability or hazard must be eliminated in order to have a successful disaster response, but rather "[it is] these characteristics of social–ecological systems (SES) that will determine their ability to adapt to and benefit from change" (Walker et. al. 2004, para. 1). It is also the introduction of concepts like capacity and vulnerability into disaster resilience theory that has shifted disaster management to focus on human responsibility (Vacano and Zaumseil 2014).

Human responsibility in risk reduction is not always acknowledged, however, as many community stakeholders see vulnerability as something to be dealt with post-disaster (Cutter et. al. 2008). By slightly shifting the narrative of disasters to consider characteristics like vulnerability to constantly be in effect, we are more likely to consider realities of risk as something to work within, rather than to fight against. This is especially so in radiation disasters, as the line between pre- and post- disaster becomes increasingly blurred as the timeline of hazard extends beyond initial events. Addressing when vulnerability is a concern becomes complicated during radiation disasters, as the definition of when a disaster "ends" gets thrown out the window, seen in the following section.

1.3 Radiation Disasters

Today's ever-changing technological advancements imply that we must consider both social-ecological systems and disaster resilience differently. The potential for disasters at nuclear power plants (NPP) and other types of radiation accidents create hazards unlike earthquakes, hurricanes, and the like. So what makes them different? The primary differences are the unique characteristics that radiation creates pre-, during-, and post-disaster.

The world was rocked by an NPP explosion for the first time in 1986 when a test at the Chernobyl Nuclear Power Plant went wrong. The subsequent explosion caused airborne radioactive material to spread across parts of Ukraine, Belarus, and Russia, with traces even found in Western Europe (WNA 2016). A number of first responders died from acute radiation sickness as they attempted to stifle the flames of the explosion, with other reported deaths from thyroid cancer associated with the disaster (though different stakeholders claim different numbers of casualties) (WNA 2016). The timeline of thyroid cancer is just one aspect so telling of what still needs to be learned. Zhang et. al. reference this, saying that there has been "no scientific consensus on whether long-term residence in low-dose radiation areas causes health hazards for the time being. Some implications can be found in the exposed group of [the] Chernobyl accident. By 2008, among those exposed to radiation from the Chernobyl accident, a total of 6,848 contracted thyroid cancer, all of whom were under the age of 18 in 1986" (2014, 9295), compared to the total of over 300,000 evacuees that governments managed to record (WNA 2016).

Chernobyl taught the world of both the physical side effects of large-scale radiation exposure, as well as the psychological impacts. Radiation is not visible and not well understood by the general public (Coleman et. al. 2013), making it both impossible for people to recognize environmental cues and intrusive in psychological well-being (Lindell and Perry 2012). Though fear of radiation is highly intrusive, the differences between "short-term" and "long-term" health effects are often not well articulated (Coleman et. al. 2013). In fact, Norman Coleman and others have acknowledged the unique role that radiation plays in actual and perceived health, fear and risk, “polarization of opinion regarding nuclear power” and “sensationalism by the media” (2013, 141).

The general knowledge of radiation is limited for two reasons. One is that Chernobyl occurred only thirty years ago, and when researching a hazard that has the potential for long-term danger, thirty years is considered short. The second explanation could be bureaucratic secrecy and manipulation that has characterized both weapons manufacturing and nuclear power plants all over the world (Petryna 2002). Survivors’ stories have still been shared, however, fighting the bureaucracy. Many authors have attempted to bypass the official narratives of Chernobyl in order to share the stories of real people. A survivor named Anna, for example, shares in the book *Life Exposed* that “she worries about her inability to have children, a condition that she blames on her kidney disease and on radiation” (Petryna 2002, 76).

Physical side affects after Chernobyl shed light on the dangers of radiation-contaminated resources. Milk, food, and land all point to contaminated resources that limited capacities of affected populations (Yamashita and Takamura 2015). Chernobyl illustrates the intense dangers that high-vulnerability and low-capacity citizens experienced, much like that in Fukushima, Japan in 2011. To expand how we conceive of radiation disasters in the future, I use the models explained in the following two sections to frame events at Fukushima.

1.4 C.S. Holling: “adaptive cycles"

Ecologist C.S. Holling has studied SESs through a framework he calls a panarchy. A panarchy is a nested set of adaptive cycles at multiple scales of time and space. On its own, an adaptive cycle uses a set of processes that “create and maintain […] self-organization” by going through stages of growth, accumulation, restructuring, and renewal (Holling 2001, 391). The stages can be broken into four quadrants in the adaptive cycle model, as seen in Figure 1. While Holling’s article goes deep into the meaning of each quadrant, for the purpose of this paper I have divided the sections simply into points A, B, C, and D, each with a corresponding description assigned by Holling. Point A is *exploitation/growth*, B is *conservation/accumulation*, C is *release/restructuring*, and D is *reorganization/renewal*. When applying adaptive cycles to disaster research, crisis occurs at point B, initiating a drop in systematic function. These cycles are starkly different from sustainability models because they assume that a “steady state” cannot be maintained.

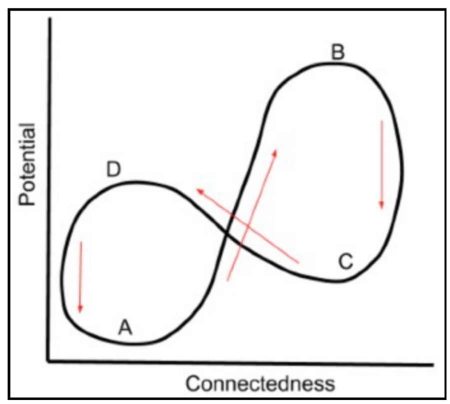

Figure 1: Adaptive cycle experiencing exploitation, conservation, release, and reorganization.

When an adaptive cycle completes the processes of self-organization, the reorganization results in a cycle that is not identical to the one before it (Holling 2001). Ideally the differences between the current and previous cycles are so negligible that the cycle appears rigid like Figure 1. This is not always the case, however, with new cycles ranging from having better, worse, or simply different functionality.

Though the model in Figure 1 is a two-dimensional representation, adaptive cycles in Holling’s original 2001 article include a third dimension that specifically refers to resilience (Figure 2). Using the third dimension, his model twists *backward* between points B and C and *forward* between points D and A, the forward movement representing increased potential for resilience. As such, if a cycle adapts successfully, point D is more likely to recover resilience lost at previous stages of the cycle. Holling also uses the labels of ‘potential’ and ‘connectedness’ for the two dimensional axis of the model, in which potential means setting “limits for what is possible - it determines the number of alternative options for the future," while connectedness "determines the degree to which a system can control its own destiny" (2001, 394).

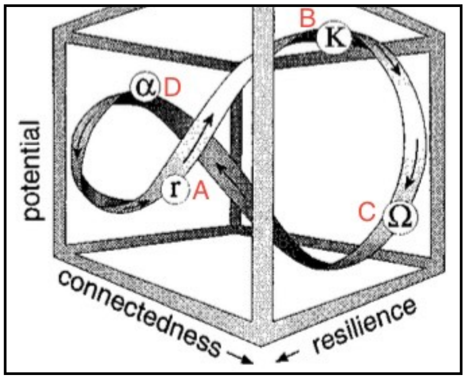

Figure 2: Resilience in adaptive cycles modeled by C.S. Holling.

When different levels of adaptive models are nested together, they create a panarchy, as seen in Figure 3. Each of the cycles operate at different time and space scales, in which larger cycles create slower change, constraining cycles below. Smaller cycles are fast and disruptive, upsetting the status quo of cycles above.

An example of such a panarchy would be to consider a community. Individuals in the community suddenly decide to take a stand against plastic bag use by bringing reusable grocery bags while shopping. The decision to create a community-wide agreement can happen quickly. Changing plastic bag legislation in the government, however, could take years. The difference between the two cycle speeds suggests that larger cycles are more stable at any given moment, capping movement within smaller cycles that could throw off the function of the entire panarchy. By interfering with the community at point D in Figure 3, the larger cycle creates stable change to the community as it adapts into a new cycle. This could take the form of plastic bag legislation that took a few years to create, but will stay in effect for the foreseeable future. Conversely, the smaller cycle in Figure 3 interferes with the community at point B, pushing the entire conversation of plastic bag use into the public discourse at a time when it was not considered important.

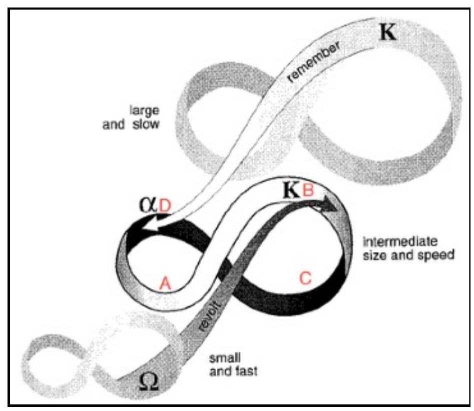

Figure 3: Panarchy of nested adaptive cycles by Holling.

Walker et. al. (2004) note that a panarchy is critical to understanding SES relationships because of the role each scale plays in system function; "because of cross-scale interactions, the resilience of a system at a particular focal scale will depend on the influences from states and dynamics at scales above and below. For example, external oppressive politics, invasions, market shifts, or global climate change can trigger local surprises and regime shifts" (2004, para 8). The nested scales of SESs are comparable to the nested scales of adaptive cycles in a panarchy, and are therefore equally influenced by dynamics of smaller and larger social-ecological systems.

The adaptive cycles creating a panarchy in Figure 3 can be understood through my research by considering smaller adaptive cycles as processes through which individuals interfere with the functioning of Fukushima prefecture. Larger adaptive cycles, similarly, are processes through which cultural memory is created. *Remember* in Figure 3 is meant to connect all the parts of the model to "draw on the accumulated wisdom and experiences of maturity" (2001, 398). In the context of disasters, remembering the role that a disaster or crisis played in the cycle can influence the reorganization of other parts of a panarchy. Such interactions have been seen all over the world in the form of disaster cultures. In order to understand SES responses to radiation disaster, I will exaggerate Holling's adaptive systems model to understand the potential difference between point A and the beginning of a new adapted cycle through point A', explained later in section *3.2 Exaggerating Adaptive Cycles*.

1.5 Protective Action Decision Model

C.S. Holling's article explains a framework for the general nature of SES systems. When applied to disaster research, a panarchy can be supplemented with the Protective Action Decision Model, PADM for short, in order to define *specific* disaster response. PADM combines contextual, psychological, and situational influences to better understand protective action in response to crisis (Lindell and Perry 2012). When individuals and communities go through the PADM steps, the process is influenced by place-, people-, and system-specific pre-conditions, highlighting the impacts of SES characteristics on disaster response (Cutter et. al. 2008).

PADM is designed as a sequential flow chart, seen below, meant to visually represent the most likely step-by-step process of decision-making in case of crisis (Lindell and Perry 2012). Lindell and Perry note that although the model represents the *most likely* process, it is rarely followed in order or to completion (2012). The stages of the model itself include: the exposure to and absorption of information (understanding how a disaster impacts you), perceived threats (what you think about your danger level), and behavioral response (evacuation or some other form of protective action) (Lindell and Perry 2012).

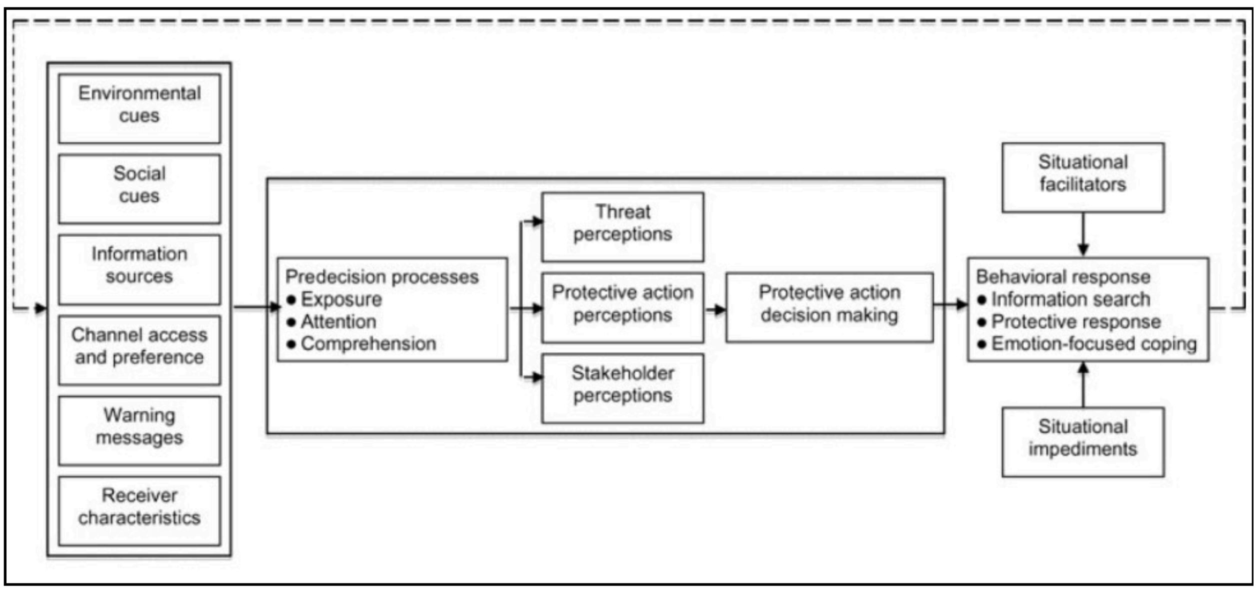

Figure 4: Protective Action Decision Model by Lindell and Perry (2012).

While a panarchy addresses overarching system changes, PADM can provide a platform to dig deeper into disaster response circumstances, which can bolster or alter the outcome of a panarchy in practice. The PADM model is a process that occurs in quick intervals, repeated thanks to the feedback loop seen in the dotted arrow at the top of Figure 4. The reoccurring nature of the PADM process is vital to recovering resilience after radiation disasters because they do not end in the same way as other types of disasters. As long as radiation is affecting social and ecological systems, there are risks and hazards to consider taking protective action.

The decision-process, while shaped by outside influences, is inherently individual. As such, the PADM model and Holling's adaptive cycle model work together to address multiple scales of my research. Specifically, this research breaks Japan down into local, prefectural, and national scales. When applied, PADM frames individual processes during the disaster, while treating prefectural and national bodies as individuals in their own right. By looking at three levels of Japan through PADM and adaptive cycles, I am able to bring together individual and community resilience. To be resilient on one's own is to garner the ability to work within one's own constraints, at any scale. Community resilience builds upon individual resilience, combining community members and resources. For example, resources can be spread and redistributed to increase capacity for all members of a group. Kulig et. al. note that the relationship between individual and community resilience is to be considered "synergistic" (2013, 760). As PADM is considered alongside adaptive cycles, different components of PADM are highlighted more than others at each stage of an adaptive cycle to emphasize strong influences on decision-making throughout the cycle's lifespan. As such, I use PADM slightly differently than Lindell and Perry suggest, focusing on only some of the components at any given time in the adaptive cycle (though all components continue to be part of the PADM lifecycle).

1.6 Research Statement

Nuclear energy has been a controversial topic for decades now. Predominant arguments for nuclear energy center around the lack of carbon emissions and the ability to produce mass amounts of stable electricity. Understanding the relationship between SES function and radiation hazard in our modern age is the dilemma that has led me to *investigate the extent to which a country can be resilient to nuclear power plant disasters.* In order to do so, disaster resilience must be reframed and reimagined in order to account for the distinct characteristics that occur in radiation crises across both space and time. In the context of the Fukushima Daiichi Nuclear Plant meltdown, many authors have suggested that Japan's resilience is based on a long history of earthquake culture. Rather than accept those theories at face value, I use adaptive cycles and the Protective Action Decision Model to analyze processes occurring at different scales of time and space within Japan.

In this paper, I first outline the 2011 Fukushima Daiichi meltdown and the consequences that Japan faced as a result. I then set the stage to understand three levels of Japan: individuals (or villages, in some cases), Fukushima prefecture, and the nation as a whole. Each of the three levels I study represent a layer in a nested set of SESs. Similarly, each experiences a different level of adaptive cycle, which can be nested together to create a panarchy. Ultimately, I argue that local SES's show increased signs of resilience because they are able to assert agency in relocation, though at great cost. I also argue that the SES of Fukushima prefecture splits apart, leaving the social and ecological systems to recover on their own, decreasing collective resilience but leaving potential for resilience within each system respectively. Nationally, I argue that the greater SES of Japan continues to make slow progress toward recovering national resilience through research and other learning engagements. At all levels of Japan, the timespan of typical radiation disasters indicate that studying Fukushima must become a multi-generational endeavor.

2. Fukushima, Japan

2.1 A Brief Overview of Japan

Before using Japan as a case study about disaster response, there are two relevant characteristics of the country that need to be examined first: 1. geographic significance, and 2. Japan's shrinking workforce. Japan is an archipelago located in the Pacific basin where four major tectonic plates meet (Karan 2009). As the plates grind together, they produce both minor and major earthquakes and tsunamis. These events have been recorded in Japanese history for as long as historians can find, creating a culture of disaster that is even found within physical artifacts: "Japan's coastline is dotted with gnarled stone tablets, the size of mini-tombstones, warning future generations to build their houses further from the shore.[…] One Japanese seismologist calculated that, since the fifth century, the archipelago had been subjected to some 220 earthquakes of catastrophic force" (Pilling 2015, 6).

It is due to disaster culture that Japan was one of the early developers of seismic building code, using buildings in Tokyo as examples of suitable infrastructure after the Great Kanto earthquake of 1923 (Karan 2009). Expanding on such disaster preparedness is said to be one of Japan's most urgent modern day problems, considering the high risk that the region faces (Karan 2009). Additionally, the country is very mountainous, with only small, flat areas near the coastal regions used as heavily populated land, creating dense metropolitan centers (Karan 2009).

Recent development goals aiming for "residential redevelopment" intend to push rural populations towards major cities in order to change metropolitan workforce demographics (Karan 2009, 276). By bringing in more young people, major industries that function in bustling cities like Tokyo are able to operate smoothly. Due to changes in both fertility and mortality rates, Japan's population has been steadily aging over the last century (Karan 2009). From the 1950s to 2000, Japan's 65+ age group jumped from being 5% of the population to just over 17% (Karan 2009). Increasing proportions of older residents have lowered the proportion of "young people entering the workforce" (Karan 2009, 172). This has caused tension in the Japanese population, and is even featured heavily on national news, affecting everything from medical and social to economic functioning. As Fukushima recovers from the nuclear plant meltdown, the diminishing presence of a viable workforce in the area has strained the economic output of the region, making it less desirable to repopulate.

2.2 The Great Eastern Japan Earthquake

On March 11th of 2011, Japan experienced a 9+ magnitude earthquake just off the northeast Honshu coastline, in the Tohoku region. The area is home to the Fukushima Nuclear Power Plant (owned and operated by the Tokyo Electric Power Company - TEPCO), located in Fukushima Prefecture. The plant was said to have done well structurally during the earthquake, but was damaged by the subsequent tsunami of roughly 15 meters (Wang et. al. 2013). Before the tsunami inundated the structure, the plant reverted to backup power generators, ensuring that the safety controls were still operational. The plant's seawall, however, was merely 5.7 meters according to Wang et. al. and the World Nuclear Association (2017a). Because of this discrepancy, the tsunami flooded the Fukushima Daiichi plant, knocking out the backup power, without which the plant was kickstarted into the meltdown of Daiichi reactors 1, 2, and 3 (Wang et. al. 2013).

Along with the meltdown of reactor cores, escaping hydrogen gas interacted with oxygen from the air, leading to a number of explosions (Wang et. al. 2013). The venting of air led to the release of radioactive material and the evacuation of nearby residents (Wang et. al. 2013; Hayano and Adachi 2013; Zhang et. al. 2014). Within the following months, the reactors were put into 'cold shutdown' for permanent decommission (WNA 2017a). For context, the explosions at Fukushima were rated a Level 7 on the International Nuclear and Radiological Event Scale, a scale in which Level 1 is considered an "anomaly" while Level 7 is a "major accident" (INES 2017). The only other accident designated as such are the Chernobyl explosions (Zhang et. al. 2014).

In a report after the accident, the International Atomic Energy Agency (IAEA) suggested that a major impediment to disaster mitigation and response in the region was a lack of belief that the hazards were real. Stakeholders, including residents, local government, and TEPCO officials believed that the nuclear plant was safe enough that a disaster of such a degree would never happen (WNA 2017a). This sentiment is supported by an article written by Etsuko Kinefuchi on the "articulations of Japan's nuclear power hegemony" (2015). Kinefuchi argues that the nuclear power program of Japan has gone hand-in-hand with narratives of nuclear plants as 'absolutely safe,' 'green', and 'necessary for energy independence' (2015). This is not to say that the narratives did not serve a purpose; if the absolutely-safe narrative had not been initiated, how many residents of Japan would have felt comfortable living near nuclear plants at the time of the Fukushima meltdown? Even so, they paved the way for social and political ambivalence to the risks and hazards associated with nuclear power plants.

The IAEA claims that such ambivalence was one of the factors that caused TEPCO to ignore up to five warnings about the plant's tsunami risk (WNA 2017a). Wang et. al. state that 22 of the 35 stakeholders arguing for the warnings to be dismissed "had ties to the nuclear power industry" (2013, 132). Re-evaluations of the safety warnings resulted in changes to the plant's safety design that ended up with a lower sea-wall than originally suggested.

2.3 Evacuation

Due to venting of the reactors and the following explosions, radioactive materials were released into the air, including Iodine 131 and Cesium 137. Immediately after the earthquake, concerns for residents spurred a number of official evacuation orders from March 12th, starting with residents living within three, and then ten kilometers from the plant (Hayano and Adachi 2013). Increasing concerns after the explosions that began later that day triggered the expansion of the evacuation zone to 20 kilometers, with shelter-in-place orders for up to another 10 kilometers (Zhang et. al. 2014). All told, the number of people evacuated from their homes ranges by source from around 100,000 or 160,000 to over 200,000 people (WNA 2017a; Nagai et. al. 2017; Brumfiel 2013). Hayano and Adachi (2013) studied the population movement throughout the evacuation zone using GPS data, and estimated that only around 2,000 people were within the area when the radiation levels were highest on March 14th.

The evacuation orders, while necessary to make sure that residents were safe from radiation harm, caused many problems of their own. First, evacuations were rushed, with confusing and poor information shared with residents, sending some evacuees on wild odysseys to find evacuation shelters (Zhang et. al. 2014; Brumfield 2013). Second, evacuations in general can be physically challenging for vulnerable populations, particularly older residents. As such, the mere act of evacuation is said to have caused up to 1,000 deaths (WNA 2017a). The movement of such populations in the wake of a violent earthquake, combined with inadequate emergency health-care for many individuals, led to many problems (Sugimoto et. al. 2012). Lastly, because of the nature of the danger (meaning the extended timeline of cleanup for radiation contamination), the evacuation has been prolonged far into the foreseeable future (WNA 2017a) (Zhang et. al. 2014).

Evacuation maps of the area demonstrate that much of the original evacuation zone is still uninhabitable, a record of which has been kept by the Japanese Ministry of Economy, Trade, and Industry (METI). Studies of evacuee health and lifestyle indicate that the number of residents still displaced hovers around 120,000 people (Iwasaki et. al. 2017). This particular trait of radiation disasters is something that is said to greatly affect the psychological health of survivors, and therefore the physical health as well (Brumfiel 2013; Nagai et. al. 2017).

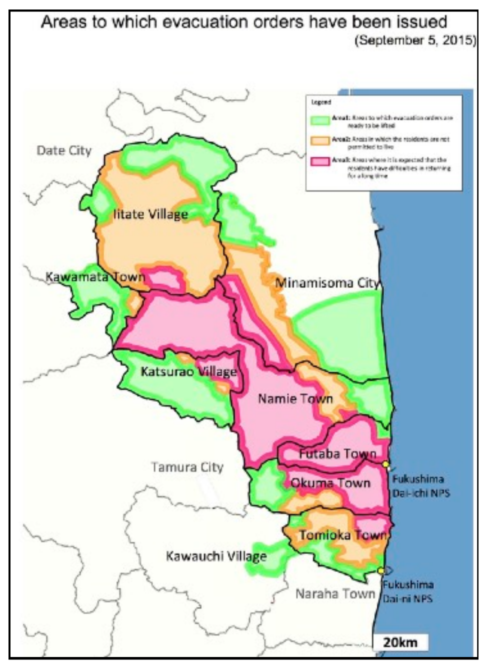

Figure 5: Evacuation orders to be lifted (green) and orders to remain (orange and pink), updated by METI (2015).

Stories from survivors have been shared through books, articles, interviews, and more. Each story is different, unique to the person. Yet at the same time, they often all express the same ideas of scattered evacuation, fear, and the unknown. Shared in a *Nature* article, the accounts of Kenichi and Yuka Togawa express similar feelings:

> The family drove from one full evacuation centre to the next, until they reached a dark, cramped gymnasium in Kawamata, around 40 kilometers northwest of the plant. There they were given a small patch of hardwood floor to call home. But they were still deeply worried about the radiation. "We didn't know much about radiation's effects, and we didn't know if Kawamata was safe or not," says Yuka (Brumfield 2013, 291).

Even after the family was settled into temporary housing, the experience continued to haunt them. In the interview, Kenichi talked about how evacuation separated members of his judo club, and instead of a once active lifestyle, he now drinks and stays home on the couch. Yuka shared that she was more prone to anger and outbursts. Regardless of institutional or governmental influences, at the end of the day, the experiences of the individual are all unique.

2.4 Energy Consequences

By no means did the meltdown only affect Fukushima residents. As a resource poor country, Japan has imported most of its energy in the form of oil (FEPCb). In the 1970's, however, after oil shocks caused problems in the country's energy stability, Japan began to diversify energy sources. During the transition from oil, nuclear power was framed to the public as a 'quasi-domestic' resource, able to increase energy security and provide a green, clean energy source (WNA 2017b; Kinefuchi 2015). Nuclear energy gained political popularity over time, and by 2010 accounted for 30% of the country's energy production (Koyama 2013). Along with coal and natural gas, nuclear power became a base-load energy supply due to its stable generation (FEPCa).

After the accident in 2011, trust in the use of nuclear energy plummeted. In fact, when Tatsujiro Suzuki analyzed the impacts of the meltdown on public opinions of energy policy, he found that "the proportion of the public that wants to shut down all nuclear plants immediately increased from 13.3 percent in June 2011 to 30.7 percent in March 2013" (2015, 595). The discourse veered away from long-time influences of official energy narratives like the 'safety-myth', 'green and clean', and energy independence (Kinefuchi 2015), as well as the soft-power media presence of Astro-boy and other pro-nuclear children's cartoons (Szasz and Takechi 2007).

Shortly after the accident, NPPs began to shut down for mandatory safety checks. Eventually, the last of Japan's 50 plants shut down for inspection in May of 2012 (Koyama 2013). While this greatly affected the nuclear industry, the effects also trickled down to the rest of civilian life. As a result of the shut-downs, energy markets switched back to liquid natural gas (LNG), increasing both the country's greenhouse gas emissions and the total trade deficit for Japan (Koyama 2013). LNG use raised Japan's greenhouse gas emission levels so much that the government began implementing feed-in-tariffs (or subsidies, if you will) for renewable energy sources in order to balance out the carbon emissions.

In time, the pressure on the country's energy system pushed the Japanese Prime Minister to give the go-ahead to restart the Ōi Nuclear Power Plant in June of 2012 (Koyama 2013). Since then, only five plants have been restarted, though many in the fleet are operable and can begin the lengthy restart process (WNA 2017b). The decision to reopen the door to nuclear energy within the Strategic Energy Plan involved working closely with the Nuclear Regulation Authority (NRA) (METI 2014), but very little with public civilian stakeholders. As a result, the growing anti-nuclear sentiments did not translate into a strong political power. Instead, the need for a base-load energy supply took precedent.

3. Methods

3.1 Research Question

Even operating under Benson and Craig's most basic definition of resilience, in which a system undergoes change while maintaining function, Kulig et. al. point out that in order to effectively monitor any change in function there must be an element of "time" to the study. The study of resilience in the most complete sense of the word must bring together the specific with the general, the immediate with the future, and expectation with reality, all of which involve a multi-layered, multi-temporal scope.

On top of that, new technologies complicate how resilience is implemented. In order to better understand NPP disasters and the unique challenges they offer, I specifically situate my research in Japan, studying the *extent to which the country demonstrated resilience to the Fukushima Nuclear Plant meltdown.* I focus on the extent of demonstrated resilience rather than attempting to define a dichotomy of resilient or not. The approaches I take to answer this question are not meant to decisively measure the full range in resilience of any individual or community. Instead, they help conceptualize how countries manifest resilience at different scales in ways specific to radiation-centered disasters. As Fukushima is a nuclear disaster of remarkable scale, second only to Chernobyl, and has a unique set of event characteristics, this study will seek both a focused and broad understanding, without falling into a rigid dichotomy of resilience.

3.2 Exaggerating Adaptive Cycles

In order to contextualize radiation disasters like that of Fukushima in the larger framework of radiation theory, I analyze the meltdown using adaptive cycles. Holling suggests that when an adaptive cycle completes the stages of growth, accumulation, restructuring, and renewal, the new cycle that emerges is different than the previous. I argue that when an SES experiences a radiation disaster, the difference between adaptive cycles is exaggerated due to the implications of radiation on time and space of recovery. The separation of point A from point A' represents the exaggerated difference between the completed cycle (point A), and the upcoming cycle (point A').

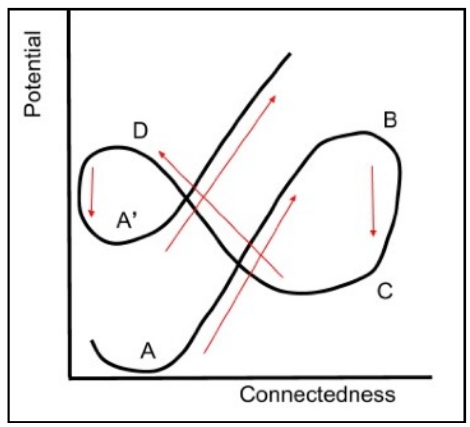

Figure 6: Exaggerated adaptive cycle model derived from C.S. Holling, recreated by author.

Adaptive cycles easily apply to disasters like Fukushima because they already include the complexity of systems with many actors in their structure. Additionally, point B translates to the onset of disaster in the cycle because it demonstrates a drop in system function from point B to point C. When the old cycle starting from point A is complete, the reimagining of the cycle into point A' highlights the concept of *remembering* that occurs in a panarchy when a larger cycle interacts with a smaller cycle (seen in Figure 3). Figure 6 is specifically designed to build on past experiences, especially in disasters like Fukushima that involve radiation exposure. When applied to radiation disasters, the exaggeration of the cycle primarily suggests that if resilience to such a disaster is possible, it will present differently than it has in the past.

Cycles are inherently temporal, so Holling's adaptive cycle and panarchy as a whole support the study of disasters and resilience because they allow research to be based on time. By the time the SES reaches point A', fundamental aspects of the system have the potential to change dramatically. As different stakeholders attend to their respective goals in disaster recovery, connectedness within the system falters, but is still possible. As the goals align again, there is a higher possibility for the SES to continue on to reach point B', C', and D'.

3.3 Using PADM

In order to thoroughly investigate this topic, the adaptive cycle model will be supported by the Protective Action Decision Model (PADM). This additional model will help distinguish between event characteristics at all stages of the crisis. The PADM model is helpful in studying Fukushima because it directly evaluates the "subjects of resilience" (Bahadur and Tanner 2014) by identifying contextual, psychological, and situational factors of resilience in Japan. The way PADM is used for this research involves first identifying key actors at different SES scales (e.g. local, prefectural, and national). From then on, events and actions by the actors are assessed at each stage of the crisis. As the SES goes through the stages of an adaptive cycle, certain parts of PADM are more prevalent than others. The sections PADM process occurs almost simultaneously, the adaptive cycle makes the role of each PADM component more or less influential at any given time.

Though the PADM model is typically geared toward any protective action, a process that is generally short lived, it is also flexible enough to apply to "long-term hazard adjustment" (Lindell and Perry 2012, 625). The model's typical application is described as being "situations in which emergency managers are transmitting information concurrently to large numbers of people who are responding to a single 'focusing event'" (Lindell and Perry 2012, 625). Radiation disasters may have a "focusing event" that triggers exposure to radionuclides, but the crisis itself does not end at that event. Even if evacuees are safely moved, the stakeholders of the SES are still in a highly uncertain situation that requires planning for the future. PADM is typically not applied to disasters seven years after the event. However, because there is still radiation affecting both people and land in Japan, the model was still relevant to decisions being made at all scales of the country. Similarly, Japan is still home to nearly 49 other nuclear power plants at varying capacity. PADM can help the hazard-adjustments that are necessary moving forward to prepare the country for future disasters.

3.4 Studying Fukushima

In order to address the research question stated above, I use a collection of research that helps sketch a full picture of the events at multiple scales. This includes studying the context from as small of a scope as an individual's psychological state, to as large of a scope as governmental and industrial state.

Evidence for these case studies comes from an array of different sources. Included is the Fukushima Health Management Survey, as well as subsequent follow-up surveys, found in research by Yasamura et. al. (2012), Nagai et. al. (2017), and Murakami et. al. (2017). Psychological evidence is further built upon by research into social capital and anxiety, by Iwasaki et. al. (2017), and the role of fear in anecdotal evidence by Geoff Brumfiel (2013). Zhang et. al. (2014) researched migration in Fukushima prefecture, referencing a number of different reasons at multiple scales, including fear of radiation. To highlight communication and evacuation details, Murakami et. al. (2017) also delves into risk communication, while Hayano and Adachi (2013) use GPS snapshot data to record population movement in the evacuation area during the first days of the disaster.

The previously mentioned sources represent a smaller, more individual scope of the events. To expand outward, Wang et. al. (2013) study nuclear power regulation. This expands my research to government and industry areas, such as the study of Japan's energy policy before and after the accident by Ken Koyama (2013) and Kiyoshi Nishimura (2016). Finally, the research includes cultural impacts, such as nuclear power in Japanese language and culture by Etsuko Kinefuchi (2015).

In order to effectively use the above sources, evidence from each will be organized by the points in Figure 6, as well as the corresponding parts of PADM. The results are displayed in a table format that includes the breakdown of Japan into different scales, so that the individual, community, and country-wide impacts are clearly defined. Finally, a chart is used to graphically represent overall characteristics of Japan on a sliding scale of resilience. The chart uses stakeholder scale (individual versus community) and resilience potential to demonstrate the ranges at which resilience can exist.

4. Event Analysis

4.1 Point A: Development

The goal of Table 1 is simple: understand community stakeholder perceptions of the nuclear power plant. Each level of stakeholder within the nested SESs of Japan has a different level of capacity, and perceptions of risk and hazard can affect how that capacity is managed. The agreements and tensions between different perceptions can dictate the relationship, or lack thereof, between individual and community resilience. Protective action before an event can take the form of disaster preparedness. PADM stakeholder perceptions are highlighted in this stage because they can influence whether or not actors in the SES believe preparedness is necessary.

Adaptive Cycle	**PADM (Lindell and Perry 2012)**	**Fukushima Case Study**		
		Minamisowa City, Futuba, and others	**Fukushima Prefecture**	**General/Country**
Point A: development	**Stakeholder Perceptions:** "authorities… evaluators… watchdogs…industry/ employers, and households" (620-621). Stakeholder relationships determine how many hazard adjustments happen pre-disaster.	Local government, residents, labor force (Zhang et. al. 2014); **NPP workers doubled as disaster evacuees** with families (Brumfiel 2013).	TEPCO **failed to instill a nuclear disaster-aware culture** in local residents and lower-level plant workers so as to not "upset" them with fear of the "worse-case scenario" (Hirata and Warschauer 2014, 177); the "safety-myth" (Kinefuchi 2015).	Japan **diversifies energy sources** after 1970's oil shocks to include nuclear energy (FEPCb); **nuclear power was relied upon for up to 30% of power** at the time of the 2011 meltdown (FEPCa).
		Iitate village comprised of 28.1% 'elderly' people, **"a good example of the aging of Japanese society"** (Sugimoto et. al. 2012, 629), many working in the agricultural industry.	TEPCO **ignores warnings about tsunami risk**, with a committee that included stakeholders in the NPP's success (Wang et. al. 2013).	**Poor nuclear regulation stemming from bureaucracy** within governmental regulation organizations (Hirata and Warschauer 2014).

Table 1: Table for Point A: development, including PADM and event context by scale.

Point A therefore sets the stage for potentially poor resilience because of problematic risk perceptions from stakeholders like TEPCO and regulatory agencies. Safety regulation was good enough until it was, well, not. The large, institutional bodies of the prefectural and national SESs appear heavily influenced by the hegemonic articulations of nuclear energy mentioned by Kinefuchi (2015). The narratives of "absolutely safe", "green" energy created a lot of incentive for the industry and government to maintain the status quo. The local SES of individuals in

Fukushima do not have the political power at this stage as the other stakeholders. They are not helpless laypeople however. Residents of Fukushima constitute the very foundational workforce of the plant itself, as well as the economic and social engines of the prefecture that tie it to other parts of the country.

4.2 Point B: Crisis

The crisis stage in Table 2 is signaled by the earth's shaking and includes all reactor meltdowns and explosions. The process of evacuation is primarily found here, though it trickles into the next stage of the adaptive cycle as well. In Table 2 the physical characteristics of the disaster and the social and institutional understanding of radiation stand out from the other PADM processes occurring. Point B builds upon the development section above because it highlights the lack of pre-event investment in educating the public about radiation exposure. When lack of understanding is combined with a lack of environmental cues from radiation, the physical and psychological implications on evacuees are long lasting.

Adaptive Cycle	PADM (Lindell and Perry 2012)	Fukushima Case Study		
		Minamisowa City, Futuba, and others	Fukushima Prefecture	General/Country
Point B: *crisis*	**Environmental cues:** "other hazards, such as ionizing radiation and some toxic chemicals, provide no environmental cues" (618).	Residents feel shaking from earthquake, but **don't know of radiation danger unless cued through evacuation orders or reactor explosions**. Only residents who worked at the plant would know that a meltdown was likely and would release radiation (Brumfiel 2013).	March 11, 2011 Tohoku earthquake of 9+ magnitude, followed by tsunami that inundates Fukushima Nuclear Plant and kickstarts **meltdown** of reactors Daiichi 1, 2, and 3 by wiping out backup generators; releases radioactive material into air.	"the archipelago had been subjected to some **220 earthquakes of catastrophic force**" (Pilling 2015, 6).
	Warning networks: recipients of broadcasts often receive them directly or through "intermediate sources," which can result in confusion due to "conflicting messages that require searching for additional information" (618), can be informal or formal systems.	"Due to the **lack of clear evacuation instructions** and the reluctance of some local governments to accept evacuees, some evacuees have to suffer from several transfers within a few months after the accident (Zhang et. al. 2014, 9293).	GPS movement of residents compared to **evacuations orders for 3km, 10km, and 20km** on March 12th; when iodine levels were highest on March 14th, only ~2000 residents were within the 20km zone (Hayano and Adachi 2013). Evacuations of around 150,000 people in Fukushima Prefecture (Zhang et. al. 2014), higher evacuation estimates from other sources.	"TEPCO not only conducted its own study, but also had a third party study the possibility of large tsunamis, in response to a call from Japan's nuclear regulator" (Hirata and Warschauer 2014, 175) but **the company never acted on what the study found.**
	Threat Perception: "people's expectations of the *personal impacts* from an extreme environmental event," which can help predict behavior such as evacuation (620).	"Unlike scientists, ordinary citizens are more **inclined to believe rumors and conspiracy theories** related to radiation" (Zhang et. al. 2014, 9797).	**Evacuation orders reflect the growing concern by officials over the course of the disaster**, starting at 3km and increasing to include 10km, 20km, a "shelter in place" at 30-40km, and "planned evacuations" in outer areas of the prefecture.	Japan's **"absolutely safe" narrative** of the nuclear power industry used to distance from residual biases from atomic bombings (Kinefuchi 2015).

Table 2: Table for Point B: crisis, including PADM and event context by scale.

Poor communication from local government and TEPCO left local residents to work with insufficient information for both evacuation and general health and safety. Multiple accounts, like those of the Togawa family and vulnerable populations referenced in Sugimoto et. al.

(2012), provide examples of how circumstances left local residents to create narratives for themselves of what was expected of them, and what they should expect from the future.

What this table fails to fully convey is that while each scale within the crisis influences the others, individuals are more influenced by personal circumstance than other scales. For example, for older populations on the outer edges of the evacuation zone, it was found that "ambiguous official information disseminated through media after the nuclear crisis had confused the inhabitants and resulted in self-imposed 'grounding' and lack of physical activity" (Sugimoto et. al. 2012, p. 629). Conversely, individuals who worked at the nuclear plant had a different understanding of the disaster. Kenichi Togawa was one such worker who worried about the plant. Having worked maintenance on the cooling systems at the plant, Kenichi realized that a meltdown was possible under certain conditions. Even though his family was safe temporarily safe after the earthquake, Kenichi knew to evacuate even farther from the plant (Brumfiel 2013). Not all Fukushima residents would have such foresight.

During this stage different types of resilience begin to interact with one another. Zhang et. al., for example, write that while elderly people have often been believed to be more psychologically resilient, they tend to have less physical resilience. As such, the "increase in the elderly population thus renders a community as a whole more vulnerable and less resilient to disaster. Elderly take more health risks during the first stage of the accident - evacuation time" (2014, 9293). The reason that nested scales are so vital to this research is because they highlight that no one part can make or break an SES or resilience. The role that vulnerable populations play in the SES gives insight into the capacity of the SES, but does not determine how that capacity is utilized.

4.3 Point C: Response

In some ways, Table 3 includes situational factors typical of any disaster as well as those specific to radiation disasters. For example, heavy traffic during evacuation is fairly standard for many disasters, but the distribution of iodine pills is something particular to NPP disasters. During crisis response, successful actions are often directly contradicted by the failure of others. Improved mental health services, thyroid health checks, and the suspension of the country's nuclear program all demonstrate the first steps of recovering resilience in the region. However, few of the distributed iodine tablets were taken and difficult evacuation conditions present a lapse in follow-through of disaster support by the government.

Shutting down all 50 nuclear plants throughout the country restricted the energy sector for a significant period of time. This strained the energy capacity of the nation, and eventually resulted in the government bringing nuclear energy back into future energy plans. It would have been equally concerning if the government had no interest in safety checks at other NPPs, especially amid ongoing public calls to end nuclear energy. The decisions to shut down, and then restart, the program equate to sacrifices that are made between different kinds of resilience. On one hand, NPPs are risky in circumstances like Fukushima. On the other, they make sure that the country-wide SES of Japan is able to retain function.

As different stakeholder, SES, and resilience scales are sacrificed to bolster others, its becomes clear that there are gaps in Japan's resilience as a whole. Yet when studied in the context of Japanese society and the history of the Chernobyl disaster, there are clearly ways that the country tried to learn and adapt from events. Because of the abstract nature of resilience, it is easy to romanticize the idea that the concept does not require sacrifice, or detract from other actors in a system. Fukushima is a glimpse into how individuals, communities, and nations experience bumps along the road to resilience.

Adaptive Cycle	PADM (Lindell and Perry 2012)	Fukushima Case Study		
		Minamisowa City, Futuba, and others	**Fukushima Prefecture**	**General/Country**
Point C: *response*	**Situational Facilitators/ Impediments:** specifics of the crisis event that alter the effectiveness of the PADM process, such as overwhelmed emergency lines or conversely, a full tank of gas.	**Iodine tablets** were distributed to residents of Minamisoma City, but **few were taken** because residents were already evacuated and therefore assumed they were not in danger (Zhang et. al. 2014).	Anecdotal stories express **heavy traffic in evacuation**, causing left-behind vehicles and difficult or confused evacuation routes (Brumfiel 2013).	"The society had traditionally paid little to more routine disorders such as depression" (Brumfiel 2013, 291), making it **difficult to receive mental health support**; better mental health education has been pushed for since the meltdown, including through surveys.
	Protective Action Decision-Making: "the end result of protective action assessment is an adaptive plan…at minimum…includes a destination, a route of travel, and a means of transportation" (622), includes behavioral responses.	Up to 1000 deaths have been reported from extended evacuations rather than radiation exposure (WNA 2017a); **evacuation is particularly hard on vulnerable populations** such as aging or physically disabled residents, leading to increased mortality rates during and after evacuation (Zhang et. al. 2014).	Surveys such as the Fukushima Health Management Survey and others include **full-body and thyroid health check ups**.	**All 50 nuclear plants shut down** for safety inspections, increases use of liquid natural gas (LNG) and other fossil fuels (Nishimura 2016). This **constricts the available energy supply to the nation and raises the country's greenhouse gas emissions.**

Table 3: Table for Point C: response, including PADM and event context by scale.

4.4 Point D: Reorganization

Adaptations made by a system recovering from disaster are meaningless unless they directly better the system's preparedness for a future disaster. During *reorganization*, a system transitions from short-term disaster response to long-term hazard adjustment. Most hazard adjustment takes the form of taller tsunami walls or improved building codes. Japan's national adjustments to radiation hazards instead come as revised energy goals and the implementation of research on radiation affects. Hazard adjustments can happen at smaller scales as well, though they may appear less obvious.

Since the evacuation, very few people from Fukushima have been allowed to return to their homes. For those that have, economic recovery is difficult; in Fukushima "major industries, ie. agriculture, fishing, retail and manufacturing industries, were all affected to varying degrees" (Zhang et. al. 2014, 9298). Zhang et. al. believe that, although "population decline may reduce human impacts on the environment and improve living conditions to some extent, its adverse effects on disaster-stricken areas may far outweigh its benefits" (2014, 9293). This quote is best applied to disasters like earthquakes or tsunamis, where the economic impact of migration out of the region can harm the wellbeing of those that stay. Decontaminated areas of radiation disasters are the next closest examples to what Zhang et. al. refers to. Without the return of the social system, the ecological systems of Fukushima cannot be utilized as a resource.

This is not always the case. In general, SES resilience relies on the entire system remaining connected. In radiation contaminated areas, remaining connected is not always possible. Even considering where the evacuation orders have been lifted, it is unrealistic to expect people to live in temporary shelters for more than seven years in order to return home. Instead, previous Fukushima residents move all over the country to try and restart their lives. The migration out of Fukushima is a more obscure representation of hazard adjustment.

Additionally, the ecological system of Fukushima prefecture, while still functioning to a degree that supports ecological processes, can no longer support social ones. I argue that when the region was exposed to radiation, the social-ecological system of Fukushima prefecture split apart. I consider the process of Fukushima residents migrating to other parts of the country as the decoupling of the region's SES. If the ecological system of Fukushima cannot support the social, the most productive move is for the social system to connect with a different SES in another region. That way, both the social and the ecological systems of the original SES in Fukushima can recover on their own. This can be considered sacrificing the general resilience of Fukushima for the specific resilience of Fukushima's respective systems.

Adaptive Cycle	PADM (Lindell and Perry 2012)	Fukushima Case Study		
		Minamisowa City, Futuba, and others	**Fukushima Prefecture**	**General/Country**
Point D: *reorganization*	**Feedback:** In the short term, the "return to initial inputs" including cues, information sources, warning messages, etc. (624), long term adjustments can be slowed down by a "perceived lack of urgency" (624).	Features of Minamisoma City that were **monitored** include "1. Spatial radioactivity, 2. Cultivated land and soil, 3. Rivers and seas, 4. Drinking water, milk, vegetables, fruits, meat and fish, and 5. Exported manufactured goods" (Zhang et. al. 2014, 9290).	Implementation of **research and surveys**: Fukushima Health Management Survey (Yasumura et.al. 2012), other cross-sectional studies (Nagai et. al. 2017), other original surveys on social capital (Iwasaki et. al. 2017).	Japan's **Strategic Energy Plan** revised in 2014; includes review of energy structure issues, the Fukushima Accident, energy mixing, system reform, etc.
	Perceptions of Hazard Adjustments: perceptions of which hazard adjustments are possible or necessary can be affected by resources such as "effectiveness, cost, required knowledge," etc. (620).	Fear has played a role in **Minamisowa's shift from agricultural farm work** to lifestyles that include "inactivity and confinement" (Zhang et. al. 2014, 9295).	Study examining social capital and stress suggests "social capital as a shield against psychological distress, we also **suggest decision makers implement evacuation plans which ensure… continuity among social networks**" (Iwasaki et. al. 2017, 407).	Restarting of the nuclear industry to "ease power-supply demand problems" (Koyama 2013, 276) combined with **feed in tariffs on renewables** as an incentive to decrease LNG and fossil fuel use (WNA 2017b) (Koyama 2013).
		Anti-nuclear population of civilians rise to 30.7% (Suzuki 2015), but restarts occur anyway out of concern for energy and economic stability (Koyama 2013).	"Families residing close to the FDNPP still believe that they should **avoid internal radiation by purchasing food from other areas** at higher costs" (Zhang et. al. 2014, 9296).	Many Japanese **citizens do not trust the government's assessments** that food from Fukushima has been screened and is safe to eat, or that "few cases of significant radiation exposure among evacuees" were found (Brumfiel 2013, 293).

Table 4: Table for Point D: reorganization, including PADM and event context by scale.

Not all SES scales in Japan experience the reorganization stage in the same way as the prefectural scale. Interestingly, the largest SES, represented by the Japanese government, is at odds with the smallest SES. Even though anti-nuclear sentiment was on the rise, "the Japanese Prime Minister in June of 2012 gave the go-ahead to restart the Ohi [sic] nuclear power plants in south of mainland Japan in order to help ease the strain of not having a fully functioning nuclear energy program" (Koyama 2013, 276). Though the Ōi plant was shut down a year later for scheduled maintenance, and back on the market again mid-2018 (WNA 2017b), it still represents a disconnect between public opinion and governmental decision. Since then, five plants have been restarted, and many others are operable and able to apply for restart (WNA 2017b). Individuals pushing for a change in energy policy do not have the same power as other stakeholders in Japan's SES. For many, resilience is about working within the capacity that each stakeholder has to make decisions.

4.5 Point A': Reimagining

The final stage of *reimagining* is founded upon two main ideas. The first is that the old adaptive cycle of the Fukushima SES is starkly different than the new. The second is that the exaggerated difference between the old and new cycles is prompted by hazard intrusiveness and information gathering that creates radiation disaster culture. Hazard intrusiveness in this case refers to an increased amount of time and energy spent considering the impacts of the Fukushima nuclear plant meltdown. The experience of evacuation has disseminated through

Adaptive Cycle	**PADM (Lindell and Perry 2012)**	**Fukushima Case Study**		
		Minamisowa City, Futuba, and others	**Fukushima Prefecture**	**General/Country**
Point A': *reimagining/ memory*	**Hazard Intrusiveness:** pervasiveness of thoughts and actions related to experienced disaster; "hazard intrusiveness related to the recency, frequency, and intensity of people's personal experiences with hazard events" (620).	Anxiety and fear have played a role in increased emigration from Minamisoma City, as residents (especially with children) "are **deeply concerned about the long-term health effects of radiation**" (Zhang et. al. 2014, 9295). **Economic frustration** in Minamisoma City after the disaster is influencing residents' migration patterns (Zhang et. al. 2014, 9288).	"Some researchers have found that **the degree to which evacuees are tied to their home communities also affects their willingness to return.** Individuals who have lived in the area for generations or for an extended period of time tend to exhibit more attachment to their home communities" (Zhang et. al. 2014, 9297), hence a higher rate of older residents move back 'home.'	**Survivors of the triple disaster showed signs of heightened stress** when compared to survivors of just the earthquake and tsunami events (Iwasaki et. al. 2017).
		"The average level of mental **stress among displaced Futaba residents is unusually high** compared with all Japanese citizens" (Iwasaki et. al. 2017, 406).	"As **young people are more willing to adapt to a new lifestyle**, these individuals are more inclined to migrate" (Zhang et al. 2014, 9298).	It is difficult for evacuees to put the disaster behind them when the **government struggles to support relocation** through compensation.
	Information Gathering: the feedback loop of the previous section includes seeking new information in the short term. This process can be extended to be applicable to hazard adjustment information, though such is often perceived to lack urgency.	Case studies of Minamisowa City, Futuba, and other cities and villages that **represent the individual experiences of residents** during and after events. Audiences from these studies can be anywhere from other citizens of Japan, to national and international research on Fukushima.	"**Decision-making by individuals who have been displaced must be facilitated**, so that they can make informed decisions and achieve some closure" (Yamashita and Takamura 2015, 705).	Though the Fukushima plant is no longer operational as an NPP, the **plant and surrounding community are now able to be used for research** to help further radiation and NPP disaster information.

Table 5: Table for Point A': reimagining/memory, including PADM and event context by scale.

the former Fukushima population and beyond, changing the way they live, and think about the future.

While in many ways intrusive thoughts seem to detract from evacuees' quality of life, I think it also offers an interesting question as to whether fear of radiation is necessary in making resilient decisions that ultimately benefit the individual and country as a whole. Over time, fear of the lasting effects of radiation may diminish, especially as research on Fukushima advances. The migration of individuals away from the prefecture means there are fewer resources being funneled to a prefecture that doesn't have the means to fully function as an SES. Rather, those resources can be extended to evacuees attempting to start new lives.

The emigration is not without its drawbacks, however. For example, the emigration of the young labor force out of Fukushima prefecture means that those who remained or returned lack economic support. Migrants fleeing Fukushima because of fear consider the region an unlivable place. The decision to leave Fukushima is one way that evacuees can assert agency over their lives. Asserting agency as an individual can be significant, given that choice can be taken away from them by institutional and governmental decisions. The final stages of disaster response are powerful in that way; the status quo is shaken during disaster just as much as the earth itself.

As the dust settles from reactor explosions and hurried evacuations, information gathering, at all levels, becomes vital. As with most hindsight, there is the recognition that with more complete information during the disaster itself, the events might have turned out differently. Ranging from studying the plant itself, to radiation exposure as physically and mentally challenging, there have been a wide collection of surveys and other information gathering that can help Japan (and consequently the rest of the world watching) better understand the potential for similar circumstances in the future. After Chernobyl, political agendas interfered with publicly shared radiation research and education (Petryna 2002). Japan's political sphere is not without bias, but even so, governmental information gathering suggests that although Japan might not be fully resilient to the disaster, it is taking steps that can help achieve that goal in the future.

4.6 A Larger Picture of Fukushima

I end my analysis of Fukushima with Figure 8 because it best demonstrates that the SES framework depends on interactions across different scales (Walker et. al. 2004). Levels of community and resilience potential range across a spectrum, continually interacting with one another. In some cases, interactions across scale create support. In others, they contradict. Creating resilience in one way has the potential to weaken resilience in another. This can be seen as "changing migration patterns" that strengthen the resilience of individuals who leave Fukushima, though "older residents less likely to leave" recover less resilience by remaining in a dissolving SES. Residents that don't return home have the potential to build resilience in another SES somewhere else, but are sacrificing the potential recovery of resilience in the original Fukushima prefecture SES in doing so. This sentiment is found in the analysis of point A' above.

Another example of sacrifice in radiation disasters is fear and anxiety in evacuees. On one hand, fear and anxiety over radiation hazard causes residents to take protective action like migration. Yet the trauma from experiencing an NPP meltdown can be extreme (Brumfiel 2013). It is possible that experiences that require sacrifice call for what could be considered "urgent" resilience. Urgent resilience would recognize a need for adaptation felt so strongly that it encourages resilience, but at cost. For example, extreme psychological trauma unchecked is dangerous for long-term health. Yet an individual changing their lifestyle can be considered through a small adaptive cycle, influencing larger cycles above (like the Fukushima SES) by revolting the status quo of what their lifestyle *should* look like.

I found evidence of adaptive cycles at each scale of SES within Japan. None of the scales experienced the cycles in the same way, because that is how a panarchy of adaptive cycles works. Small cycles resulting in individual migration, for example, happened quickly after the disaster, changing the foundation of the prefectural SES. Large cycles resulting in national restructuring, however, have happened slowly over the past seven years. By using PADM to address adaptive cycles, the "subjects of resilience" that "influence actual decision making" were not only identified, but also arranged in a panarchy to establish multi-scaler interactions (Badahur and Tanner 2014; Benson and Craig 2014).

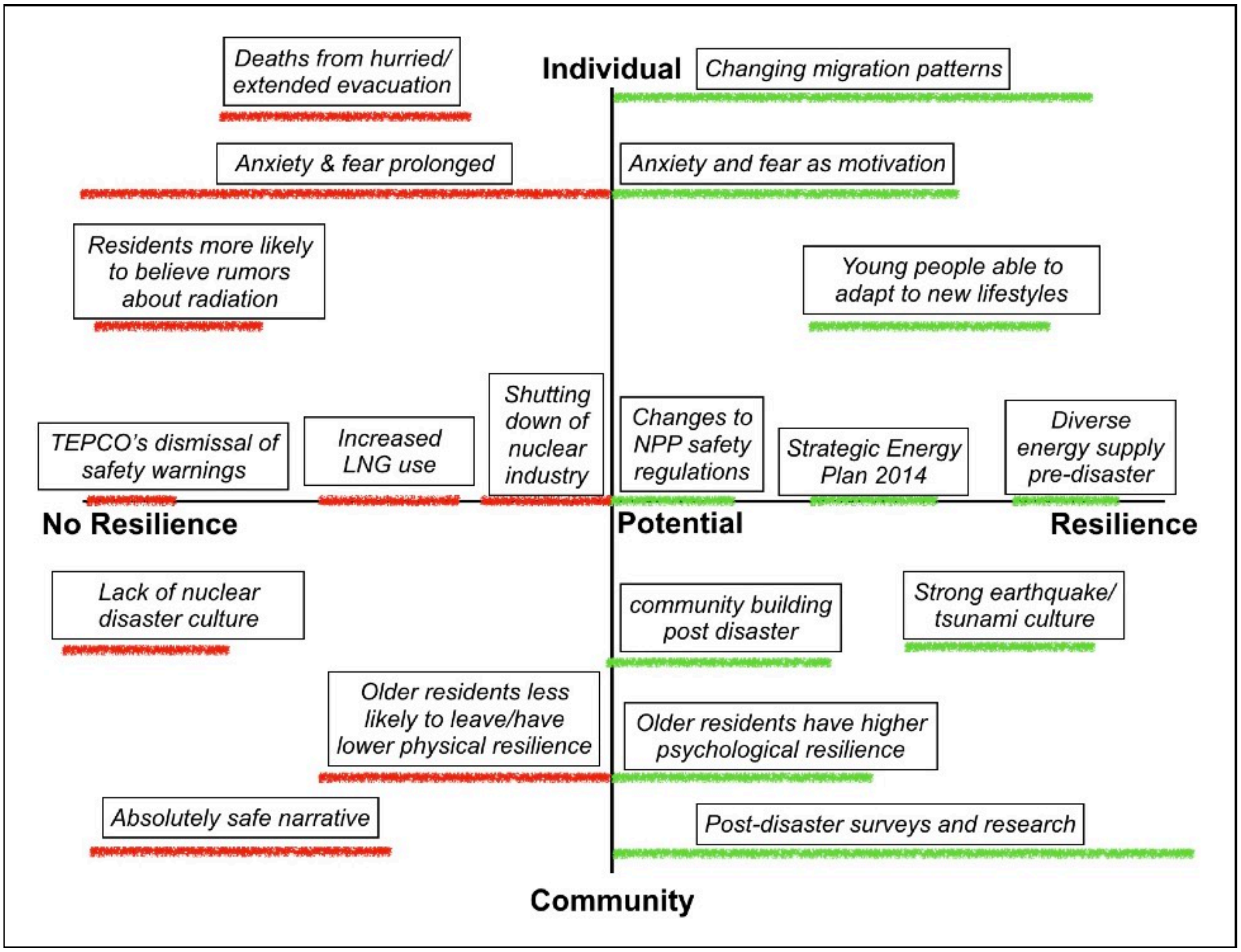

Figure 8: Combined case study features on scale of individual vs. community and resilience vs. no resilience in order to provide full-picture understanding of context.

In particular, two cross-cycle influences in a panarchy (*revolt* from below, *remembering* from above - Figure 3) have been recognized in the Fukushima disaster. Evacuation, migration, and the spreading of radiation following the disaster fundamentally changing Fukushima. Fear and anxiety, national policy updates, and lifestyle changes that continue as the country reorganizes affect the individual and national memory of the disaster. PADM has been so applicable to radiation disasters because the continuance of radiation contamination has meant the crisis is not over. As time passes, I hope to see that the influences within the panarchy of Japan will be able to instill a disaster culture of radiation resilience as intrusive as the disaster cultures of earthquake and tsunami recovery have been in Japan.

Ultimately, my research questions have been undoubtedly difficult to answer. In essence, three different scales of Japan, individual, prefectural, and national, have demonstrated different quantity and quality of resilience over the past seven years. Individually, residents of

Fukushima indicated some resilience by adapting lifestyles in response to their new reality as NPP disaster survivors. Residents undeniably experience heightened fear and stress from the events, sacrificing in order to continue taking care of loved ones. Resilience in the prefecture of Fukushima is more obscure. Arguably, the decoupling of the prefecture's SES suggests that function is not maintained. However, because the individual systems (social and ecological) are able to continue functioning in their own way, I am inclined to denote a small level of resilience specific to the respective systems is attained. Finally, the national and more general resilience of Japan recovers slowly through the reconsiderations of policy, regulation, and cultural narratives of disaster.

5. Comparison and Generalization

5.1 Fukushima as the New Chernobyl

Though the compounded nature of an earthquake, tsunami, and NPP meltdown make the Fukushima events unique, exposure to radiation is not new. The Fukushima meltdown may be the most recent of large-scale radiation exposure, but perhaps the most notable of such disasters was the explosion at the Chernobyl Nuclear Power Plant in 1986. While other forms of radiation exposure range from minor leaks at NPPs to the effects of secret weapons manufacturing during WWII, Chernobyl and Fukushima are unique in the scale of evacuations that resulted. Because Chernobyl happened so many years before Fukushima, the former accident was at an obsolete Soviet-designed power plant with 1980's nuclear regulation, and a limited understand radiation hazards (WNA 2016). Fukushima was set in an extremely different context, but nonetheless utilized what was learned from Chernobyl.

Radiation exposure at Chernobyl was compounded by lax regulation of contaminated food and milk. This mistake was a major reason the Japanese government knew to monitor food and agricultural resources after the meltdown and to deliver iodine tablets to evacuees. The mistakes made at Chernobyl were exacerbated by poor safety standards, but automatic shut-off regulations have improved greatly since then (WNA 2016). Finally, the clean-up processes at Chernobyl put thousands of lives at risk (WNA 2016). While both accidents required technicians to work closely with the plant while it was (and is, in the case of Fukushima) still dangerous, the Fukushima decommissioning is much more contained than Chernobyl's.

It is more difficult to make cultural and psycholocial advancements to radiation disaster response. Zhang et. al. state that average life expectancy decreases because "living in radiation-contaminated areas is likely to reinforce anxiety, depression and other negative emotions" (2014, 9295). Zhang et. al. explicitly connect the two accidents later on in discussing other research: "S. Powell found that those who had suffered from the Chernobyl accident exhibit higher levels of physiological trauma and weaker psychological resilience than those who had suffered from other disasters. Because the population is living in constant fear of radiation, the evacuees of the Fukushima accident exhibit the same degree of psychological trauma as those of the Chernobyl accident" (2014, 9296).

Other research on the Chernobyl incident suggests that there are still largely place-based differences that impeded more successful disaster resilience. While Japan is still reeling with traumatized citizens, it has not been dealing with the extent of political upheaval and corruption that Chernobyl was experiencing in the 1980s. When speaking of radiation research, Adriana Petryna mentions that "the Belarussian government has tended to suppress or ignore scientific research; it downplays the extent of the disaster and fails to provide enough funds for the medical surveillance of nearly two million people who live in contaminated areas" (2002, 5). Similarly, when the Soviet Union had sovereignty over the area immediately after the accident, the government set higher radiation threshold limits that allowed them to escape "key ethical questions about the health effects of Chernobyl" (Petryna 2002, 50). The discrepancies between public information and private government research contributed to increased tensions between stakeholders in Chernobyl.

A quote by Petryna perfectly summarizes Chernobyl events that complicated recovery. She describes Chernobyl after the explosions as such: “widespread unaccounted for radiation exposures, state interventions and failures to intervene, expanding clinical and bureaucratic regimes, and market economic changes came to bear on a rational-technical course of illness and suffering” (2002,15). Fukushima and Chernobyl are not entirely comparable. There are place-based differences that make the disaster and the response completely different from one another. However, both disasters occurred on such catastrophic scales, so their comparison is inevitable. Even now, only seven years after Fukushima, Chernobyl is decades farther into a recovery that will take decades more, and research comparing the two events continues to be produced. If Fukushima and Chernobyl can tell the world anything, it is that although such disasters will likely be uncommon, they are possible. By acknowledging that there are still hazards from NPPs, more countries around the world may begin reacting accordingly.

5.2 Other Technological Disasters

As mentioned, Japan’s experience of the triple disaster is quite unique. Not only is it unprecedented in complexity of disaster, but the nuclear plant explosions themselves are second only to Chernobyl in intensity and scope. Because of this, extracting broader implications from the event is largely difficult and speculative.

The Bhopal disaster in India in 1984, right before Chernobyl, is likely one of the most closely related technologic disasters after Chernobyl. Though it did not result in longterm relocation of residents, it did supersede both nuclear disasters in casualties, and rivals in the realms of fear, loss of trust, and implications of disaster research. Sheila Jasanoff has written extensively about the Bhopal disaster - in particular about the “right to know” and the role of the law in aftermath. She highlights the “asymmetries of power - between the state and the corporation on one side and the gas affected people on the other” (2008, 684) that were the driving forces behind the event’s main complications. In the evolving nature of NPP disaster response, the asymmetries of power and agency between stakeholders seems to connect the contexts of Fukushima, Chernobyl, and Bhopal.

Additionally, keeping all scales of an SES accountable is a concern for any disaster. This is complicated because of undefined expectations of the technology sector in terms of accountability, as Jasanoff mentions in her 2008 paper on Bhopal. Jasanoff write, “most modern regulatory systems place on the producers of hazardous substances, such as industrial chemicals, the burden of generating and disclosing information about the characteristics of their products…in effect, a huge, uncontrolled field experiment was conducted on unsuspecting human subjects” (2008, 684). In order to demand accountability, appeals for change must come from all levels of a context. By themselves, individuals in Bophal likely do not have enough political power to incite change. Leaving it up to the government alone, however, would likely result in even less accountability.

What Chernobyl, Bhopal, and Fukushima all share is a set of stakeholders with different priorities. Tensions between stakeholders are present in most disasters, but radiation and the broader genre of technological disasters have a unique relationship with humans. Humans build NPPs, run them, and then try to fix them when there are accidents. The question of blame is something that is so tumultuous that it aggravates relationships between stakeholders even more. By acknowledging the role of each stakeholder in a system, there is less ambiguity about why decisions are made.

6. Learning from the Past, Internationally

Fukushima provides a great recent case study through which to understand resilience to nuclear plant meltdowns, but it still begs the question of whether the consequences of what happened are accessible enough by the larger international community to make appropriate changes. Can any country be resilient to nuclear plant disasters? Already, the implications of the meltdown have spread to other countries. Germany and Switzerland have declared that they are planning to phase-out nuclear energy, regardless that leading nuclear disaster authors like Wang et. al. suggested that “these decisions would not only cost millions of dollars but also [leave] the countries struggling to find alternatives to meet the gap of electricity supplies” (2013, 127).

Beyond just political decision making, citizens in countries that already have an established nuclear energy sector, like China, have changed their perceptions of risk since the accident. Huang et. al. surveyed residents living near nuclear plants in China and found that risk perception had shifted from “limited risk” to “great risk” (2013). This suggests that the larger international community is experiencing similar degrees of hazard intrusiveness as the citizens of Japan. Researchers have already found that intrusiveness can be linked to future disaster responses; “researchers have found a positive relationship between level of threat belief and disaster response across a wide range of disaster agents, including floods,…earthquakes, and nuclear power plant emergencies” (Lindell and Perry 2012, 621).

Does creating an international perception of fear help any one individual country become resilient? Japan is not the only country to be heavily reliant on nuclear energy, but admittedly, not all countries need to be. Investing in other forms of base-load energies that are stable and ‘green’ could be a productive response to both Chernobyl and Fukushima, but like any resource, such options are not available to everyone. It is possible that one reason Japan was able to recover some resilience to the Fukushima meltdown is simply out of necessity. After the disaster, Japan lost 30% of its energy supply, with very few viable alternatives, begging the question of whether or not a country so dependent on an energy source can be resilient to disaster in that same resource.

When considering if any country can be resilient to NPP disasters, it seems reasonable to at least conclude that the potential to present resilient-like characteristics is possible. France, for example, has an even higher dependence on nuclear energy than Japan, with roughly 75% of energy generation coming from nuclear (WNA 2018). Given that France now has two different NPP disasters to learn from (with extremely different levels of successful response), as well as a strong culture of reliance on the energy source, France has the right incentives to prepare for such disaster. That being said, there is still a lot to understand before the word ‘resilience’ should be applied to a radiation disaster with any confidence.

7. Next Steps

Like any disaster, an NPP meltdown is above all else a shock to an SES system, inherently disrupting function. Preparedness can go a long way in creating a system with effective disaster response, seen over and over again through earthquake and fire drills, and the like. Though not a guarantee, simple disaster preparedness is one of the many ways governments across the world have responded to devastating events. Table 1 showed us that before the events at Fukushima, TEPCO intentionally left nearby citizens in the dark on possible hazards, for fear of suggesting a “worst case scenario” (Hirata and Warschauer 2014, 177). Since then, the Japanese government has recognized the need to instill stronger NPP disaster preparedness in both its power plants, and its people. The Japan Atomic Energy Agency, or JAEA, started running disaster drills at NPPs in 2016, with a total of four drills completed (JAEA 2018). The implementation of this policy since the Fukushima disaster solidifies the argument made in previous sections of this paper about the speed at which Japan has the potential to create resilience on a national scale.

Disaster drills are not enough to build resilience to radiation disasters, however. Such disasters have thus far demonstrated such pervasive consequences that more fundamental changes must be made to Japan's NPP disaster preparedness endeavors. Assumptions that it is possible to maintain a steady-state by many policies, like those encouraged through sustainability models, encourages approaches to disasters that will eventually fail. Attempting to control a system or cycle in the event of a disaster ultimately results in failure to function. As an alternative, I suggest reexamining the theoretical objectives of disaster preparedness policy.

When suggesting to reexamine such policy, I can not pretend to have the answers. Instead, I suggest that future policy in Japan must be crafted while keeping in mind that in the face of disaster, policy will not be foolproof. A goal should be to create policy that is likely not perfect when all hell breaks loose, but does not completely fail either. Adaptive cycles utilize a lot of the same theoretical principles I suggest here, encouraging change and adaptation. At point B in an adaptive cycle, where disasters occur, the number of possible futures for the cycle is high (via the axis "potential"). With so many possible futures, both good and bad, policies that focus on a part of the adaptive cycle with such a high scale of potential must acknowledge that the outcome of the cycle cannot be predicted.

8. Further Research

Adaptive-cycle thinking can be implemented in more than just policy renovations. Disaster research as a whole can be expanded to ask more questions about the relationship between adaptive cycle and disasters. The study of radiation disasters in particular must be continued throughout our lifetime in order to fully understand events like Chernobyl and Fukushima. As that research unfolds, more and more factors will create futures for each context that we won't be able to predict.

My research has been limited by a number of things. The largest impediment, however, has been time. In the last seven years, so much has been accomplished in rehabilitating and supporting the community and land of Fukushima, with so much more left to do. On top of that, Japan's government has proposed all sorts of policy changes that have yet to be mentioned in this paper because it is difficult to assess their success yet. By repeating the questions from this research over the next fifty or one hundred years, we will get closer to a more complete understanding of radiation disasters. Chernobyl has already shown us that a lot can happen in thirty years, and yet the world still lacks the basic information necessary to respond to similar disasters accordingly.

The larger purpose of this study has been to understand the extent to which resilience can be attained. A critical assumption to question and build upon would be whether or not resilience is even the correct theory to be using. I do not necessarily imply that there is a better word already out there, but Fukushima sets the stage as an opportunity to develop new theoretical groundwork on disaster response. If this were the case, the research suggest for others would question a few basic assumptions of resilience: can there be adaptation without resilience? Is resilience always a good thing? Can you be resilient while also dependent? My research often involved using resilience definitions as a yardstick for what could be accomplished in a system. I encourage other researchers to question whether or not the yardstick itself is what needs to be changed.

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Images

Figures 2 and 3:

Holling, C.S. 2001. “Understanding the Complexity of Economic, Ecological and Social Systems.” Ecosystems 4:390–405.

Figure 4:

Lindell, Michael, and Ronald Perry. 2012. “The Protective Action Decision Model: Theoretical Modifications and Additional Evidence.” *Risk Anal : Off Publ Soc Risk Anal* 32 (January):616–32.

Figure 5:

Japan Ministry of Economy, Trade, and Industry (METI). 2015. *Areas to which evacuation orders have been issued.* http://www.meti.go.jp/english/earthquake/nuclear/roadmap/evacuation_areas.html

**All other figures and tables were created by author.