**Coastal Resilience: The Future of Cities with Rising Sea Levels**

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 With hurricanes becoming more frequent and water levels rising with climate change, the conversation around coastal cities has taken a turn to talking about protection during these drastic changes in the environment. All along the east coast of the United States and Florida, we are seeing an increase in people moving in, despite the rising sea levels, insurance rates and dangerous factors associated with it. Between July 2021 and July 2022, Florida’s population increased by 400,000 people. It’s the fastest growing state in the country for the first time in 65 years, a striking statistic for also being the state with the third largest population in the country (Cogan, Marin, Vox.. 2023). This has become an even more pressing issue as hurricanes are becoming stronger, pushing the abilities of our seawalls and waterways. The connection between hurricane frequency and climate change is uncertain, as Science News said in an article released after the record breaking number of hurricanes in 2020 (Gramling, Caroline, Science News). The following year proved to be yet another record breaking season, according to Bill Chapell from NPR. With 21 named storms in the Atlantic hurricane season, 2021 was the third most active hurricane season in history.

Professor Christopher Koliba, who has done extensive research on critical infrastructure and flood mitigation, commented on the most recent Hurricane Idalia, saying “Simply rebuilding after each disaster is just not going to be sustainable. Climate change is exacerbating extreme weather events. These disasters will continue to grow in number and severity, with no regions of the country or globe spared” (2023). Despite being a more mild storm, Idalia cost 12-20 billion dollars in damages, while Hurricane Ida in 2021 accounted for 60 billion. With the price tag getting higher on the cost of hurricane season, Floridians are forced to reckon with rising insurance rates. Florida is currently suffering from the highest insurance rates in the nation, and continues to rise with rates going up by 40% in the past year alone (Allen, Greg, NPR.. 2023).

Traditional concrete sea walls were designed for regular tides and limited force, not the intense waves and consistently high water levels we have been seeing. These are essential as ocean water overtopping these barriers can cause sewer systems to flow into the surrounding ocean, damaging the ecosystems and natural life there. Flooded homes and damaged shores have become normalized as climate change has taken its toll. More and more insurance companies have been pulling from Florida, with Farmers insurance being the most recent in July of 2023, as the state has become a hurricane hotspot (Otte, Jedidajah, The Guardian, 2023). As the insurance crisis is getting worse in Florida, this conversation becomes even more important. As of now, the average homeowners insurance rate is roughly $4,000, which is significantly higher than in other states. The state funded Citizens Insurance has been keeping the crisis relatively stable, but as their eligibility rules become tighter, the future is not looking so certain for Florida residents.

With more people moving to Florida and other vulnerable states every day, how can we increase the resilience of these protective measures to keep urban areas intact as sea levels continue to rise? The resilience of the coast is dying along with the rising waters, but what is resilience? By evaluating the effectiveness of different sea walls and how they relate to coastal resilience, stakeholders can create stronger coast lines and be better prepared as climate change becomes a reality with rising sea levels. Through this process the best practices for ensuring the resilience of ecosystems and urban areas can be better protected in response to greater weather vulnerabilities.

As defined by Bridie McGreavy, an expert and researcher on the concept of resilience, it is the ability of an ecosystem to maintain its state while being able to use adaptive capacity to go back to its original state when disrupted. McGreavy argues that how we talk about and define resilience is essential in what it means (McGreavy, 2015). Resilience was originally discussed in terms of the environment, which then created the idea of ecological resilience. Ecological resilience emphasizes coping and how environments can withstand shocks and rebuild themselves when there is destruction. It is a concept that was first born in the 1960’s, and was more thoroughly defined in the 1970’s by Crawford Stanley Holling, who thought that “Ecological resilience theory suggests that change in a system is both inevitable and critical” (Nordenson, 2018). This is helped by ecological memory, an idea that suggests that ecosystems have a memory or a blueprint of how it should be, and after a change they naturally go back to that state.

When it comes to resilience in relation to sea walls, putting in a sea wall is a dramatic shift within the ecosystem. Not only does it take away the habitat of a variety of marine life, it completely changes the way currents flow and how the environment is set up. They act as a barrier for birds and sea creatures to access parts of their habitat. The change in the water levels and tidal flow can also be a dramatic and potentially detrimental change, according to Lisa Marlin from the Green Coast, a renewable energy and green living focused website (2022). This can affect the fishing industry and other businesses that rely on the ocean to make profit, such as the tourism industry. Coastal resilience is important in any conversation related to shores, not just to prevent flooding and the destruction of homes, but to keep coastal wildlife, and therefore businesses, alive. The discussion on resilience is essential in this conversation because it is what our urban areas need in order to survive in the coming years. To keep coastal cities and ecosystems intact, we must increase the resilience of the coasts.

Frontiers in Marine Science recently published a piece called “Eco-Engineering of Seawalls- An Opportunity for Enhanced Climate Resilience from Increased Topographic Complexity,” written by Md Salauddin, John J. O’Sullivan, Soroush Abolfathi and Jonothan M. Pearson. This journal discusses the differences between the traditional use of hard sea walls versus newly adapted seawalls to work better with the changing climate. This specifically focuses on wave overtopping, which is the amount of water that is discharged by the sea over the protective structure, which is in this case is a wall. This topic is important to discuss in relation to urban areas because wave overtopping can lead to flooding in populated areas.

In the study, it analyzes the difference between two types of coastal seawalls: hard and artificially roughened. A hard seawall uses flat concrete against the ocean, and is the most common type used. The typical structure is what we tend to see on the ocean, made out of concrete, bricks or rubble mound structures. These are often not visually appealing and are expensive to maintain, as they have a short life span if not well maintained. To build a sea wall, it typically costs $2,000 per linear foot, not including the permits and engineering services that are included in it (Marlin, 2019). Maintenance tends to be $100-$250 per foot according to Sarah Noel from Home Guide, which can get expensive quickly depending on how much shoreline the seawall takes up (Noel, 2023). But even with the high cost, they can last a long time with general maintenance. An artificially roughened seawall uses methods such as “vertipools” and “flowerpots.” These are generally called “additive measures” that change the surface of the sea wall to have texture and maintain ecological life, as described in the “Eco-Engineering of Sea Walls” article written by professors M. Salauddin, J.J. Sullivan, S. Abolfathi, and J.M. Pearson from the University of Dublin (Sauluddin, et al. 2021). This type of sea wall with an irregular surface disperses the wave energy, while a smooth surface simply reflects it.

From the sources, they are suggesting that artificially roughened sea walls are a relatively new concept, especially when discussing their benefits in relation to climate change. Artificially roughened sea walls didn't come up in scholarly articles until recently, as shown by the lack of information on them. Previously, the curved seawall, vertical sea wall, and the rubble or mound seawall were the alternatives to the traditional wall. This lack of information suggests that artificially roughened seawalls are a modern concept that has come into use as engineering of seawalls has advanced with climate change and changing flood levels. Since it is a more modern method of building coastal resilience, it is likely that it was created to combat the effects of climate change and is more up to date than other more traditional methods.

This study, done by Frontiers Marine Science, is the first study to compare how the different types of sea walls directly affect wave overtopping. A wave chamber was used with a wave maker and a wave absorption device, while researchers used different types of artificial sea walls in this environment to determine which was a better fit to limit wave overtopping. Wave overtopping volumes were determined with a method created by Pearson, “measuring the increment of mass of water in the measuring container after each overtopping event” (Sauluddin, et al. 2021). The study specifically focused on wave overtopping as a method of determining coastal resilience because overtopping is most commonly used when discussing climate resilience on coastal structures (Sauluddin, et al. 2021). It then used different types of sea walls with the wave chamber to determine the different benefits related to them. There are two differences in types of waves: impulsive and non-impulsive. Non-impulsive waves are usually associated with deeper waters while impulsive waves are with shallower water despite having larger waves. Impulsive waves are more likely to hit coastal barriers, unlike non-impulsive waves. Both were tested with the wave chamber.

 In the results of the study, they explicitly say that the “proportion of waves that overtopped the seawalls was also shown to reduce significantly (by up to %100) as the roughness of the seawall was increased” (Sauluddin, et al. 2021). Used in a real life setting, this study suggests that using artificially roughened sea walls could limit wave energy and wave overtopping when applied in urban settings. Though urban areas could simply build on top of the sea walls to make it higher and prevent wave overtopping, it is expensive and only a short term solution as water levels will continue to rise with climate change. When applied, the methods highlighted in this study have potential to increase the coastal resiliency of urban areas.
 Currently, there are two types of resilience models used when it comes to coastal resilience, according to Structures of Coastal Resilience. There is the risk and replacement method, which looks at the financial value of assets (home, business, etc.) and the potential damage to it, then decides if it is worth the cost of a protective measure. For example, if the cost of rebuilding a house is 300,000 dollars, while building a sea wall to protect it is 350,000 dollars, the stakeholders would just pay to rebuild the home instead of the sea wall. The other method is a planning for hazards model, a model discussed in the Structures of Coastal Resilience book, written by Catherine Seavitt Nordenson, Guy Nordenson, and Julia Chapman. The model “emphasizes the health and safety of both people and ecosystems over the protection of existing financial assets” (Nordenson, et al. 2018). This method looks at what benefits everyone instead of just those with the ability to pay to replace expensive damages. Especially with high damage hurricanes and flooding becoming more of a reality in places like Florida, paying for damages every year is not realistic for many communities. This method considers how resilience can be more innovative to create long term solutions instead of returning to the previous method.

For stakeholders involved, such as homeowners, politicians or business owners, this is an important topic. According to one research project done by Grace Molino, Melissa Kenney and Ariana Sutton Grier at Brown University, “Coastal communities (stakeholders) are interested in increasing their resilience to these threats so that they are better prepared to manage them, mitigate the impacts, and bounce back from disasters more quickly” (Molino, et al. 2020). Having this knowledge before it happens is important for stakeholders to prepare and have the opportunity to increase their coastal resilience. In Mapping Coastal Futures, the first chapter of Structures of Coastal Resilience, Nordenson emphasizes the importance of flood risks, writing, “In the context of storm surge hazard mitigation, a probabilistic assessment of surge allows property owners, communities, and agencies to proactively address flooding to reduce property damage and prevent the loss of life” (Nordenson, 2018). She writes that stakeholders can’t grow their resilience or take preventative measures if they don’t know of their flood risks. With that information they have the opportunity to make a change and encourage less damage when flooding occurs. With the urban life that lives by and depends on the coast, these conversations are important to have as climate change shows up more frequently and severely in our lives and damages our communities.

A method of creating artificially roughened seawall has already been used in Singapore. The National University of Singapore has done work to make a hybrid seawall, with concrete tiles that can be added onto already existing vertical hard sea walls. This is especially important in a city where seawalls makeup over 60% of the coastline. In a wedge shaped rock pool, the tiles attach to the wall and are designed to last 20 years. Taking over 12 years to develop and put into practice, the tiles have shown that they are making a difference in protecting the coastal city. In an article from the Straits Times, Professor Todd who worked on the project said, “Building a hybrid seawall that softens hard coastal defenses with green elements might be a bit more expensive and complicated than building a regular sea wall, but this will come with biodiversity and cultural benefits” (Auto, 2022). For Singapore, this method worked really well for them to increase their coastal resilience.

Marine ecologists at City University in Hong Kong created a similar method with sea wall tiles, with the goal of creating higher habitat complexity to increase their coastal resilience. Another goal of theirs was to decrease the water temperature, which is often warmer in areas that use traditional sea walls instead of natural rock formations because of the lack of energy dispersion. Creating a type of tile with grooves and varying shapes, they were able to add them onto existing traditional hard seawalls in different coastal neighborhoods around Hong Kong. According to GlobalSpec in an article written by Siobhan Treacy, the creviced tiles saw an “increase of 19% to 51% in the number of species and an increase of 59% to 416% in the number of animals” (Treacy, 2020). This suggests that textured and creviced tiles encourage the growth of marine life and help maintain healthy ecosystems, while enhancing biodiversity.

The future of Florida is dim if the government and communities don’t put in the work to increase its coastal resilience before it’s too late. Big storms like Idalia and Ian are making a negative impact on the towns of the coast, and as this continues it is becoming more and more important to consider the value of coastal resilience in stakeholders lives. As of now, the technology to protect coasts is mainly being made by universities and being implemented in an experimental way. While this is helpful for those communities, it does little to improve resilience and combat flooding on a wider scale. If these small projects with artificially roughened sea walls and tiles could be taken to a larger scale, it would make more of an impact.

The cost motivation is there as well. As insurance rates are rising in Florida, using tools to increase stakeholders' resilience could decrease their insurance costs and the likelihood of extreme damage in big storms. While this may take some help from the government and other larger organizations, it is ultimately in the best interest of all stakeholders and parties involved as it decreases the number of damage fees that would be applied later. Though it would be expensive up front, applying more advanced technology like this would ultimately be a net gain as it further protects coastal communities and limits the damage fees. With this technology that artificially roughened sea walls provide, environmental benefits to the surrounding marine ecosystems can be seen. Especially looking into homes and businesses that have previously been damaged or are placed in high flood risk areas, this makes a big difference. Instead of paying to move citizens out of waterlogged areas that shouldn’t have had homes in the first place, the government could put their money into preventative measures in grants or community projects.

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