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Climate Change Adaptation Options for Coastal Communities and Local Governments

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Abstract: Extreme weather events and failure to adapt to the likely impacts of climate change are two of the most significant threats to humanity. Therefore, many local communities are preparing adaptation plans. Even so, much of what was done has not been published in the peer-reviewed literature. This means that consideration of adaptation options for local communities is limited. With the objective of assisting in the development of adaptation plans, we present 80 adaptation options suitable for coastal communities that can be applied by local governments. They are a catena of options from defend to co-exist and finally, retreat that progresses as impacts become less manageable. Options are organized according to their capacity to protect local properties and infrastructure, natural systems, food production, availability of fresh and drinking water and well-being of the local population, as these are likely to be affected by climate change. To respond to multiple threats, 'soft' options, such as awareness raising, planning, political articulation and financial incentives, insurance and professional skills enhancement, can be encouraged immediately at relatively low cost and are reversible. For specific threats, options emphasize change in management practices as pre-emptive measures. Key audiences for this work are communities and local governments starting to consider priority actions to respond to climate change impacts.

Keywords: climate change; adaptation; coastal community; local government; responses

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) reports that by 2100 anthropogenically-induced climate change is likely to lead to a rise in global temperatures of 1.5 °C to 2 °C above pre-industrial levels [1]. This will significantly affect environmental feedback systems leading to, among others, more frequent and intense extreme weather and climate-related events [1]. In this context, in 2019, the World Economic Forum ranked extreme weather events and failure to adapt to the likely impacts of climate change as the two most significant threats to humanity [2].

At the 2015 United Nations Framework Convention on Climate Change, Conference of the Parties (COP21) in Paris, 195 countries agreed to increase efforts to mitigate and adapt to climate change [3]. Mitigation of climate change refers to controlling the emission of greenhouse gases to retard the global warming process [4]. This is based on the understanding that temperature rise is directly related to the amount and type of greenhouse gases emitted into the atmosphere. Mitigation, therefore, refers to avoiding anthropogenically-induced climate change [4]. Despite the Paris agreement, the emission of greenhouse gases continues to increase [5] and, considering the political discourses of key countries, such as the US and Brazil, it is likely this pattern will continue in the years to come. As anthropogenically-induced climate change appears to be unavoidable [1], adaptation (the process of adjustment by which risks are managed to improve community safety and well-being [4]) becomes essential.

Risk stems from a combination of one or more threats and the capacity to respond to them [6]. A threat is something 'likely to cause damage or danger' [7]. For climate change, threats depend on how environmental feedback systems are affected. IPCC (2018) forecasts that by 2100, if global temperature rises (only) between 1.5 °C and 2 °C above pre-industrial levels, environmental feedback systems will lead to: extreme temperatures in many densely populated areas; more frequent and intense extreme weather and climate-related events, including droughts and floods; sea-level rise between 0.26–0.93 m; increased ocean acidity and de-oxygenated oceanic waters; and significant biodiversity loss [1]. The consequences of these global scale changes will be profound. The availability of potable water is likely to be affected by extended drought periods and the intrusion of seawater into inland waterways (caused by sea level rise and storm surge in coastal areas) [8]. Terrestrial and freshwater ecosystems will be affected by drought, flood, intrusion of seawater and change in temperatures [1,8]. Marine ecosystems will suffer through increased ocean acidity and water temperature and decreased oxygen levels, which are predicted to cause the loss of 70 per cent to 99 per cent of coral reefs [8]. A significant decline in biodiversity is predicted and likely to include local loss of pollinators, which with other threats, will put at risk food production [1]. Community well-being is expected to be affected by higher temperatures, more frequent and extreme weather events, and sea-level rise and storm surge will more frequently cause flooding in coastal and low-lying areas resulting in damage to infrastructure and properties [1]. How society responds to the forecasted risks is, therefore, paramount to the success of short and long-term sustainable development, community resilience [9] and resultant community well-being.

Despite the sensibility of responding to the threats of climate change through strategic and planned adaptive actions, much of what has been done lacks critical assessment in the peer-reviewed literature [10]. This means that appraisal of adaptation options for local communities is limited, and communities may take actions that are not best practice, and may be expensive, lack efficacy and be maladaptive [11]. Identification of adaptation options for local communities, councils and/or local industries is the first step in strategically responding to the threats of climate change to reduce risk to issues of concern, and the motivation for this study. Focus is on coastal communities, because they are particularly vulnerable to climate change impacts [11]. In addition, about 10 per cent of the World's population "live on coastal areas that are less than 10 m above sea level" [12]. Eighty adaptation options were identified as suitable for coastal communities and can be applied by local governments. With the objective of assisting with the development of adaptation plans, these options are described and discussed in the context of the broad adaptation options of retreat, co-exist and defend.

2. Materials and Methods

Adaptation options were first identified via a systematic literature review. Systematic reviews identify articles using clearly defined search criteria, and systematic, explicit and reproducible methods to select and critically examine relevant literature [13,14]. This approach is common in the health sciences and has been applied increasingly to environmental and climate change studies [15,16].

The peer-reviewed literature was systematically searched using Scopus©. Keywords used in the search were: climate change, adaptation, coastal, sea level rise, local government and storm surge ("TITLE-ABS-KEY ("climate change" AND adaptation AND coastal AND "sea level rise" OR "storm surge") AND DOCTYPE (ar) AND PUBYEAR > 2009"). Articles not in English, published prior to 2010, and book reviews were excluded. The Scopus search retrieved 114 results. These were analyzed and works that did not directly mention adaptation options were excluded. Based on this criterion, 44 works were selected for further analysis and reviewed in full.

Adaptation options identified were categorized in tables according to focus and response to threats (multiple threats, property and infrastructure, coastal flooding, inland flooding, fire, natural systems, farming, fresh and drinking water and well-being of communities). It was then noted that some category components (e.g., housing) lacked implicit adaptation options. In these cases, additional information was sourced from technical reports.

Because local demographic characteristics and cultural systems play important roles in defining adaptation options, a complete list of responses specific to a locale is unlikely to be identifiable from the literature. Hence, what we present here are widely applicable adaptation options found in the peer-reviewed literature plus those found in other sources that are likely to guide adaptation.

3. Results

3.1. Broad Adaptation Options: Retreat, Co-Exist and Defend

Climate change adaptation, disaster risk reduction and hazard assessment are strongly linked [17], and it is evident that this intersection is a strategic planning challenge for coastal communities [18]. Herein, we focus on the role of climate change on flood hazards, sea level rise, storm surges/cyclones and coastal erosion, as well as the interactions of these climate change affected hazards. It is in this nexus of climate change adaptation and disaster risk reduction where some of the major challenges exist for local governments and planners (e.g., [18]).

The focus on 'defend, co-exist, or retreat' is closely aligned with the define-analyze-implement-reassess (DAIR) framework developed as a general community and rural planning template for hazards affected by climate change [18]. Our study evaluated three possible strategies for decision-making related to coastal development and management of existing coastal resources: (1) relocate assets and people to safe areas (retreat); (2) defend existing and new structures against climate change affected hazards using largely structural measures; and (3) co-exist or adapt to changing conditions by a combination of innovative planning measures [18,19].

3.1.1. Retreat

Retreat, as the name suggests, refers to moving communities, structures and/or assets from areas that are likely to be significantly affected by the impacts of global warming to areas less vulnerable to climate change impacts [20]. This can be the case, for example, of inhabited areas expected to experience increased frequency and extent of flooding and storm surge. While it is a radical approach, it seems that more than one million people have already been forced to retreat in response to natural hazards [21,22]. While retreat is taking place in at least 27 different places, it is not an easy option [23]. In addition to the obvious cost of the land, which in many cases is bought by the government, and of reallocation, it has psychological and socio-cultural implications that, in many cases, cannot be mitigated [21,22].

Examples of retreat include Native Americans on the Isle de Jean Charles in Louisiana off the Gulf of Mexico, who collectively decided to retreat in 2016; inhabitants of Grantham in Queensland, Australia; and in Oakwood Beach (New Jersey) on the fringe of New York City [12].

The community of Belongil Beach, in Byron Bay (Australia) adopted a managed retreat approach. The decision was based on the understanding that "infrastructure, private property and residential development are located within the coastal erosion 'immediate hazard zone', which is the area of shoreline predicted to erode as the result of a 100-year average recurrence interval (ARI) design storm". The erosion areas were identified and classified in accordance to the expected time for erosion. Based on this, different zonings were established: "Immediate coastal hazard precinct: buildings are to be entirely modular and relocatable (by 4WD vehicle); trigger distance for relocation of development is 20 m from the coastal erosion escarpment; no building is to be within 20 m of the erosion escarpment. 50-year precinct: all residential housing is to be relocatable (by 4WD vehicle); trigger distance for relocation and/or demolition of development is 50 m from the erosion escarpment. 100-year precinct: trigger distance for relocation and/or demolition of development is 50 m from the erosion escarpment" [23].

3.1.2. Defend

Defend includes strategies implemented to protect assets from the impacts of flooding. It can involve the construction of seawalls and reforestation of riparian areas [20]. Defend is the most common response, as its disadvantages tend to be limited to financial costs, which can significantly vary depending on the circumstances. However, due to multiple reasons (e.g., storm surge maybe more intense than forecasted), defense tends to eventually fail; in which case either retreat or co-existence will be the options of choice.

Saibai, which is one of the nearly 300 islands that constitute the Torres Strait Islands archipelago (Australia), is an example of a locality where the local population had to implement defensive measures [24]. In 2016, it had an estimated population of 465 people, 85.6% of whom were Torres Strait Islander or Aboriginal. The 108 km^2 island has an average elevation of one meter with its highest point being 1.7 m above mean sea level [25]. Therefore, it is prone to flooding, especially during the wet season, which coincides with the cyclone season and king tides [26]. The combination of increasing mean sea level rise twice that of the global rate, coastal erosion and extreme weather events leave only defensive responses other than the option to retreat. Due to the high cost associated with building a seawall around the island, the first response was to use sand bags [27]. As the situation worsened, the community built a handcrafted seawall that was substituted in 2017 by a Government built seawall [28]. Half a year after the $24.5 million Government built seawall was inaugurated, it was breached by a high tide [29].

3.1.3. Co-Exist

Co-existence with climate change related threats refers to coping with the new conditions [30]. This option is based on the understanding that, while in specific situations nothing can be done to mitigate certain impacts, retreat and defend are either not necessary, excessively costly, or not possible. The option involves acceptance of losses, and communities must accept the risks of climate change and respond intermittently to the effects. Co-existence, besides being an expensive option in monetary terms, can be extremely traumatic due to the exposure to crisis events that may include loss of life. Despite its disadvantages, at present it appears to be the option most commonly adopted.

Examples in Australia of co-existence with threats imposed by climate change include towns such as Townsville and Cairns, which are intermittently but significantly affected by cyclone and floods, and Brisbane, which is periodically affected by flooding of the Brisbane River.

Cyclone Yasi, for example, caused extensive damage from Cooktown to Townsville. It almost destroyed everything in its path, including 9000 km of roads and 4500 km of rail, crops, houses and businesses [31]. Restoration costs, from just this one cyclone, was around $7 billion [31].

Brisbane floods are also frequent. Substantial floods, during which one-third or more of Brisbane city was inundated, occurred in 1841, 1844, 1890, 1893, 1898, 1974 and January 2011. Reconstruction of damage caused by floods costs some $100 million per year [32]. In addition to financial costs, the 1893 flood was associated with the loss of 35 lives, the 1974 flood with 14 deaths and more than 300 people injured; and the 2011 flood included 33 deaths (three others are still missing). The reconstruction of Brisbane from just this last flood exceeded $5 billion [18,32].

3.2. Punctuated Adaptation Options

The broad adaptation options of retreat, co-exist and defend are possible for all identified threats associated with climate change with efficacy varying with specific threats and circumstances [33,34]. Within these, the literature identifies specific adaptive actions that reflect defensive or co-existing strategies that fall short of the ultimate strategy of retreat. The actions tend to be presented as discrete or punctuated choices without consideration of comparative efficacy, synergies, or priority.

3.2.1. Adaptation Options for Responding to Multiple Threats

While some adaptation options are limited to address just one challenge, others are likely to have a systemic ameliorating effect and can be subdivided in five main approaches (Table 1).

Table 1. Options for responding to multiple threats.

Adaptation Options	References
Education and public awareness (co-exist)	[6,35–38]
Community participation (co-exist)	[20,36,38–40]
Integration between different government levels and financial incentives (co-exist)	[17,40,41]
Labor and professional skills enhancement (co-exist)	[10,42]
Flooding intensity map (co-exist)	[41]
Planning and legislation (co-exist)	[20,36,40–46]
Warning systems (co-exist)	[6,20,35]
Disaster management plan and evacuation plans (co-exist)	[35,41]

- Raise public awareness to encourage the local population to adapt and be prepared for the likely impacts of climate change and to foster community participation in decision-making.
- Planning (1) to avoid the worst consequences of the forecasted weather events, which involves production and frequent update of flooding and hazard maps; (2) legislation focused on (a) not permitting development on land vulnerable to hazards, or (b) establishing construction codes appropriate for the forecasted climatic conditions; and (3) plans to rapidly and efficiently respond to disasters, with disaster management and evacuation plans and warning systems to alert residents about imminent threats, such as fire and flooding.
- Political articulation and financial incentives to facilitate the integration between different government levels (regional, state and national) so that complex and expensive responses (e.g., rapid evacuation and/or construction of dykes) can be put in place in a timely manner. Financial incentives need to be also focused on both residents and industries so that economic constraints are not the main obstacle to allowing adaptation options to be implemented.
- Insurance to cover personal and government costs specifically associated with recovery after, for example, inundation, fire, weather events and/or failed crops.
- Labor and professional skills adjustment and enhancement so that new construction codes and new farming standards can be put in place.

3.2.2. Adaptation Options for Protecting Property and Infrastructure

In the context of risks associated with climate change, the main threats to properties and infrastructure on coastal areas are: flooding caused by sea level rise, storm surge, tide, freshwater flooding and wave run-up [47]; as well as fire, especially during droughts.

(1) Flooding

Flooding is already a problem in many places and it is likely to be aggravated with future sea level rise and with the intensification of storms. While inundation will mostly affect the coastline, it can also affect inland low-lying areas. If no adaptation options are put on place, property losses can be expected.

• Coastlines and beaches

For the protection of the coastline, identified adaptation options included two main approaches (Table 2). The first is construction of physical barriers (e.g., seawalls, breakwaters, gabion, groins and sluices). This response type tends to squeeze the intertidal habitat, resulting in a reduction in habitat and a usurpation of the natural resilience of the habitat usually because of poor understanding of structural and ecological dynamics. Consequentially, but with an anthropocentric bias, this response should only be initiated "where erosion presents an imminent threat to public safety or infrastructure that cannot practicably be removed or relocated. Where erosion protection structures are necessary, maintaining physical coastal processes outside the area subject to the coastal protection works is required to avoid adverse impacts on adjacent coastal landforms and associated ecosystems" [48].

Table 2. Options for responding to coastal fringe flooding.

Adaptation Options	References
Construction of physical barriers	
Seawalls, breakwaters, gabion, groins and sluices (defend)	[30,35,41,44,49–54]
Environmental management	
Protection of mangrove, wetlands, dunes forests and reforestation of areas close to waterways (defend)	[30,38,41,44,50,52,55,56]
Creation of artificial reefs (defend)	[57]
Prohibition or control of the removal of beach sediments (defend)	[20]
Beach nourishment (defend)	[44,50,58]

The second is less construction oriented and involves improved environmental management, with approaches such as (a) protection of existing ecosystems and reforestation of areas adjacent to coastlines to reduce flooding from storm surge and dissipate the energy of waves, and hence, lessen the impact of wave run-ups; (b) beach nourishment focused on maintaining coastlines at a predetermined width (This can "disrupt species living, feeding, and nesting on the beach", as well as the habitats at dredging sites; also "it is infeasible in areas where the wave energy is very high" [50,55]. Despite the likely negative impacts, beach nourishment is a common and frequent practice in many coastal areas.); (c) prohibition or control of the removal of beach sediments, because removal may accelerate beach erosion and disturb fauna; and (d) creation of artificial reefs to dissipate wave energy (and help to support marine biota).

• Inland areas

Adaptation options for avoiding inland inundation include elevating existing or constructing new canals and river walls, dykes, or sluices (Table 3). These options can be costly and if not planned for the highest predicted flood levels may prove ineffective. Environmental management approaches can also be applied to impede surface flows and enable water infiltration. These, however, are likely to be ineffective during extreme weather events.

Table 3. Options for responding to inland flooding.

Adaptation Options	References
Dykes or sluices (defend)	[30,35,41,44,49–54]
Creation or elevation of existing canal walls (defend)	[15,21,22,24,41,56,59]

• Infrastructure

Responding to flooding risk particularly focused on protecting local infrastructure that supports what is generally considered to be essential services are a subset of inland flooding. Identified in the literature are actions such as (1) securing infrastructure (e.g., by elevating roads and airports, protecting energy transmission lines and diversifying energy reticulation and sources); (2) increasing waste and water treatment capacity; and (3) reducing water flows that may cause inundation and necessitating construction of dykes, seawalls and elevated canal walls to prevent sea water inundation (Table 4). However, this last approach will offer no protection to flooding caused by freshwater run-off, which may occur due to river level rise or storm water run-off during heavy rain. In these cases, dykes and sea and canal walls may be maladaptive and exacerbate problems by creating barriers that impede water flow.

Table 4. Options for responding to the impacts of flooding on infrastructure.

Adaptation Option	References
Secure infrastructure	
Secure energy transmission lines (defend)	[6]
Elevate roads and airports (defend)	[60]
Redesign road system (defend)	[6]
Diversify energy supply (co-exist)	[6]
Increase waste and water treatment capacity	
Increase waste and water treatment capacity (co-exist)	[41]
Reduce water flows	
Drainage facilities and water pumps (defend)	[19,30,44,53]
Reduce paved areas to improve permeability of the soil or adopt water permeable pavements (defend)	[61]

• Housing

Reducing the risks associated with flooding to residential homes is a political issue for local authorities, with many community members assuming that local government will take responsibility for reducing risk. Adaptation options identified in the literature vary from being of short-term benefit and low cost (e.g., landscaping) to requiring costly structural modification of homes to significantly reduce risk from all but more extreme events (e.g., substitution of material and building techniques and codes so that houses are cooler, more resistant to flood and extreme weather events) (Table 5) The option of constructing dwelling levees might be appropriate in specific circumstances at the extreme of a predicted flooding area, but would probably attract neighbor criticism or result, in the flooding event, in an unflooded island isolated from essential services.

Table 5. Options for responding to the impacts of flooding on housing.

Adaptation Option	References
Levees around houses and other vulnerable structures (defend) Efficient drainage system (defend) Gardens designed to safely redirect water (defend)	[62]
Secure vulnerable equipment above the forecasted flooding level (co-exist) Design and use roofs capable of coping with high intensity rainfall events using impact and moisture resistant materials (e.g., metal rather than terracotta) (defend)	[6]
Design and reinforce existing structures (defend)	[20]
Maximize use of water-resistant materials (e.g., concrete, fiber cement) (defend)	[6]
Raise floor heights (defend)	[6,30,35,42]
Limited life of houses to minimize financial outlay (co-exist)	[6]
Multistory building with the lower level planned as non-living areas (co-exist)	[35]
Build as transportable and or floatable homes (co-exist)	[6]

(2) Fire

While bushfires are common in many parts of the world and are part of natural processes, longer drought periods are likely to intensify fires and increase their frequency. Hazard reduction burning of fire-prone areas to create a mosaic of patches (in Australia, from 1 to 7-year intervals between burns) is advisable but will need careful monitoring and adaptive management to ensure the desired mix of vegetation types. There is the potential for community debate on the benefits and efficacy of hazard reduction burning, so community engagement on the rationale, planning and implementation of a program is essential.

In 2019, the Sunshine Coast of Queensland, Australia experienced delayed arrival of the usual spring and summer storms and with strong winds and arson activity resulted in an ember storm never previously experienced. While loss of human life and property damage was relatively low because of effective and targeted fire control by emergency services, wildlife suffered and the vulnerability of homes became evident under extreme fire weather conditions that hazard reduction burning could not mitigate likely impacts. Risk reduction might involve creation of wider fire breaks around homes in a community that enjoys its leafy suburbs. In any case, the Sunshine Coast community will need to mitigate the impacts of fire with shutters and sprinkler systems in high-risk zones and using building materials that are fire resistant (Table 6). This will necessitate changes in building codes.

Table 6. Options for responding to the impacts of fire.

Adaptation Options	References
Shutters and sprinkler systems (defend)	[62]
Building materials that are fire resistant (defend)	[62]
Hazard reduction burns in fire-prone natural areas (defend)	[63]

3.2.3. Adaptation Options for Protecting Natural Systems

Major changes are expected to occur within land and marine natural systems in the next century due to not only climate change, but also deforestation, over-use of resources and pollution. Broad adaptation options to minimize disruptions to local natural systems are largely changed management that includes: (1) better environmental management, including the creation of artificial reefs and environments, (2) improved adaptive management of fire and efficient irrigation of natural and or restored areas; and (3) provision of incentives for conservation in farming areas, including benefits from carbon sequestration opportunities (Table 7).

Table 7. Options for responding to the impacts of climate change on natural systems.

Adaptation Options	References
Create artificial environments for the maintenance of species populations (defend) Provide incentive for conservation in farming areas, including benefits from carbon sequestration opportunities (defend)	[41]
Expand the protected area estate and revegetation (defend)	[6]
Establish ecological corridors (defend)	[41]
Translocate species at risk to secure locations (defend) Plan and plant gardens that provide habitat for native species and drought and flood resistant (defend) Improve composition of tree species in reforested areas (defend) Creation of artificial reefs (defend) Regulate the use of agritoxics (defend) Identify and protect climate change refuges (defend) Restoration of ecosystems (defend) Improve biodiversity management (co-exist) Efficient irrigation of natural and or restored areas (co-exist)	[19,62,63]
Prohibit or control the removal of beach sediment (co-exist)	[20]

3.2.4. Adaptation Options for Protecting Food Production

Due to change in mean temperature and rainfall, severe drought and extinction of animal pollinators, food production is predicted to be at risk and may prove to be one of the most significant threats to humanity from climate change [3]. Adaptation options proposed in the literature tend to be relatively low cost management actions that do, however, require strategic research to inform changed management practice: (1) adapt cropping techniques and species; (2) improve water, environmental and soil management; and (3) provide financial and technical assistance to farmers to deal with weather-related changes (Table 8).

Table 8. Options for responding to the impacts on farming and food production.

Adaptation Options	References
Adapt cropping techniques	
Adopt vertical farms (co-exist)	[64]
Substitute crops with drought and salt resistant cultivars (defend)	[20,41]
Plant an undercover to crops (co-exist) Diversify cropping species (co-exist) Adjust planting and harvest dates (co-exist) Regulate the use of agritoxics that exterminate pollinizers (co-exist)	[53–55]
Improve water, environmental and soil management	
Reforestation of areas likely to flood (defend)	[56]
Improve management to enrich the soil with organic matter (defend) Improve irrigation systems and dig local dams (defend)	[56–61]
Provide financial and technical assistance	
Financial and technical assistance to farmers (co-exist)	[56–61]

3.2.5. Adaptation Options for Protecting Availability of Fresh and Drinking Water

Water is one of the most important resources for life. Yet, the availability of fresh and drinking water are likely to be reduced by climate change. Historically, many regions of the world suffer intermittently from lack of water, and this situation is likely to be aggravated by climate change, not only because of drought periods, which are likely to last longer and be more severe, but also due to salinization of fresh water systems in coastal areas caused by sea level rise. Adaptation options identified (Table 9) are largely at the property level and include:

- Installation of devices to prevent seawater from back flowing into storm drains;
- Create farm dams and in other locations;
- Require households and businesses to install rainwater tanks to supplement the reticulated water supply system;
- Develop and apply desalinization technologies; and
- Create irrigation systems to ensure hydration of vegetation.

Table 9. Options for protecting the availability of fresh and drinking water.

Adaptation Options	References
Devices to prevent seawater from back flowing into storm drains (defend)	[62]
Dams in farms and in other different locations (defend)	[62]
Desalinization technologies (co-exist)	[20]
Household and business tanks to supplement the reticulated water supply system (co-exist)	[62]

3.2.6. Adaptation Options for Maintaining and or Improving Local Community Well-Being

Hotter weather and more intense storms are expected to affect community well-being. While emergency services will need to be prepared, households can act, at a cost, to reduce vulnerability. Adaptation options are largely housing improvements or modification (Table 10) but without guidelines and promoted smart practice, mandated building codes will probably be required that can be delayed by fear of political backlash to the household costs that would stem from retrospective regulation or increased cost of housing construction.

Table 10. Options for maintaining and or improving local community well-being.

Adaptation Options	References
Roofs capable of coping with high intensity rainfall events (defend) 'Green' roofs (defend) 'Green' infrastructure (defend) Improve natural ventilation of buildings (co-exist)	[6]
Better insulate homes (defend) Homes responding to sun orientation(defend) Hot air extraction technology (defend) Lighter-colored, reflective roofs (defend) Internal and box guttering material that can stand extreme weather conditions (defend) Double glazing of windows to support insulation (defend) Technology that decreases greenhouse gas emissions (defend) Well maintained roofs (co-exist)	[56]

4. Discussion

IPCC reports demonstrate that climate change is strongly linked to human activity, and 195 countries are committed to mitigation action to reduce greenhouse gas emissions as well as adapting its urban areas to respond to threats. All societies have a moral obligation to contribute, to the greatest extent possible, to reducing greenhouse gas emissions towards meeting international targets. For reducing greenhouse gas emissions, the primary driver for climate change mitigation lies within national and state energy policy and requires inter and intragovernmental cooperation for maximum efficacy. At the regional level, local authorities can show leadership by addressing their own emissions, informing businesses and households of mitigation actions they can voluntarily take, and by making bylaws that require mitigation action at the household and business levels. However, of immediate concern is the need to be prepared for climate change impacts by reducing risk and vulnerability of regional and household infrastructure: this requires encouraging and supporting adaptation.

4.1. Adaptation Spectrum

The options of defend, co-exist and retreat are not applied separately in urbanized areas. Instead, they progress as impacts become less manageable [30,33,34]. In the Torres Strait Islands (Australia), for example, seawalls were built as a defensive action to avoid flooding. As sea level rose, seawall efficacy diminished and flooding became more frequent [24]. Co-existence then took place until the situation became unmanageable and planning for retreat became an agenda item. In other words, while the academic literature presents the options of defend, co-exist and retreat as different adaptation approaches, they are stages within one spectrum of options. For this reason, in this work, the adaptation options presented were organized according to the component of interest in the affected system, with focus on properties and infrastructure, natural systems, food production, availability of water and well-being of the local population. The idea is that with the implementation of the identified options, retreat may be delayed or avoided.

4.2. Adaptation Options

While people may acknowledge the reality of climate change, they are less aware of its implications at a local and household level (partly because of the imprecision of modelling), and even less aware of actions they can take to contribute to reducing greenhouse gas emissions and how to adapt to reduce their vulnerability to impacts. In this context, local governments can play a significant role in improving community knowledge of climate change, its impacts, mitigation actions and adaptations that can be made in preparation for climatic and resulting change and extreme events. What will be important to communicate is that climate change mitigation action can be also action to reduce impacts. Engagement with local communities should be a pillar for meeting the obligations inherent in demonstrating commitment to sustainable development.

The 'soft' options for adaptation, such as awareness raising, planning, political articulation and financial incentives, insurance and professional skills enhancement, can address mitigation and adaptation concomitantly and be implemented immediately at relatively low cost. The likelihood of such efforts being wasteful is low because they align with sustainability and represent insurance against the worst of climate change impacts.

Community engagement is important because not all adaptation options can be implemented by governments who will be increasingly required to consider community-wide defensive actions in response to imminent threats to life and property. Residents and industries will need to modify their own properties and their management practices to ensure they are climate change ready, and not reliant on government to implement defensive measures as threats become imminent. Progressive implementation of adaptation strategies will have less upheaval of communities and individuals. Therefore, the responsibility of implementing adaption options in a timely manner at the regional level is shared between governments, residents and businesses. Yet, for adaptation to occur strategically and to optimize resource allocation, it should be orchestrated by local governments.

As climate change is likely to affect specific locations in multiple ways, including sea level rise, drought, extreme weather events and biodiversity extinction, it is unlikely that the implementation of just one adaptation option will address all climate change related problems. Hence, it is usually necessary to apply a systematic approach that addresses each threat and reduces the risk to affected areas and people. In this sense, further research would be necessary to develop a tool to assist in determining the most suitable and urgent adaptation options for each specific locale.

While the World Economic Forum has ranked extreme weather events as one of the most significant threats to humanity [2], it is important to keep in mind that risks are not only dependent on the hazard itself, but also on the strategies put on place to deal with challenges. The children's story *The Three Little Pigs* provides an analogy to better understand the risks that stem from weather events associated with climate change and the importance of adequate adaptation. In the story, while the same wolf menaces the three piglets, consequences significantly vary according to the structure protecting each of the piglets. With adequate warning, each piglet could better defend their existing infrastructure individually or collectively. The same is valid for the forecasted extreme weather events. While communities will be hit with the same perturbation strength, the consequences will vary depending on how each place, community and or person has prepared for the events. Those better adapted are likely to be less impacted.

5. Conclusions

While the scientific community largely agrees with the reality of anthropogenically-induced climate changes and the urgency to address it and its impacts, there remains uncertainty about how much temperature will change especially in specific locations. This is partly due to the complex ecological functioning of our planetary ecosystem and our limited understanding of the feedback processes involved in climate regulation, which compromises the development and the results of existing models. Yet, this is but part of the problem. The main challenge is to forecast how humanity will address the issue of reducing greenhouse gas emissions and how to respond to likely impacts in specific areas. Differences in forecasts of human response at national to local levels mean that the literature presents significant differences regarding predicted temperature rise and, consequently for example, by how much sea level is likely to rise, and appropriate response actions. IPCC works with conservative scenarios in which they consider temperature is likely to increase between 1.5 °C and 2 °C and sea level to rise between 0.26 m to 0.93 m by 2100, while the United Nations World Meteorological Organization estimates the temperature is more likely to increase between 3 °C to 5 °C by 2100 [1]. Under the best or worst scenario, adaptation remains necessary and urgent.

The importance of adaptation to environmental conditions as a mean to survival is not new; it was first defended by Charles Darwin in *Origin of Species* in 1859 [65]. Since then, it has been widely accepted that, not the strongest, nor the most intellectually capable, but the most flexible is more likely to survive. While Darwin's studies were not developed for the context of anthropogenic-induced climate change, his logic is equally valid for the forecasted warmer future. Therefore, paraphrasing Darwin, we can now say that those more likely to endure are those that are able to adapt and to adjust best to the changing environment in which they find themselves.

This work presented 80 adaptation options, mostly identified through systematic literature review. Not all options are adequate or necessary for all coastal communities; others would help mitigating impacts yet could be substituted by alternatives that would have a better cost-benefit in the specific region. The discussion here presented, focused on options that are generally suited for coastal areas. Suitability, in this case, relates to options that have positive cost benefits, with fewer negative impacts or with positive side effect consequences.

Adaptation actions can be high to low cost and appropriate at household/business to community levels. Local governments will be required to lead defensive adaptations that reduce risk community-wide. They are also obliged to inform their constituencies of defensive adaptations that allow for co-existence. In both cases, assessment of cost-efficacy in reducing vulnerability is necessary and will depend on evaluation of local conditions and the level of risk associated with threats.

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