Resilient Lands and Waters Initiative: Hawai‘i

On April 21st, 2015 President Obama recognized Hawai‘i as one of seven places from across the nation where successful partnerships are working to improve the climate resilience of landscapes and seascapes in the face of climate change. The Resilient Lands and Waters initiative is a key part of the Administration’s Climate and Natural Resources Priority Agenda, a comprehensive commitment across the Federal Government to support resilience of America’s vital natural resources.

Sites

Three sites across the state were chosen for the RLW Initiative: He’eia (O‘ahu), West Maui and West Hawai‘i. These three landscape priority areas have ongoing and active management schemes in place with participation from an extensive list of federal, state, and local government agencies as well as community and non-profit organizations. All three locations in Hawai‘i are designated as priority locations by the State of Hawai‘i or NOAA.

Project Goals

The Resilient Lands and Waters Initiative project in Hawai‘i aimed to demonstrate the benefits of landscape-scale approaches to conservation and management that contribute to climate resilience by building upon the existing collaborative inter-agency partnerships.

The main objectives of the RLW project in Hawai‘i were to identify what organizations and partnerships are working in the three sites; how they are approaching the impacts of climate change, what are they doing to increase the resiliency of the landscapes, and what do they need in order to increase their efforts in terms of climate change resiliency.

Through this project, five focus areas across the land and ocean systems in Hawai‘i where impacts of climate change are being seen were categorized as: 1) freshwater; 2) terrestrial; 3) coastal/low lying areas; 4) ocean systems; and 5) the agricultural sector.

Seven common issues affected by climate change across all sites were also identified:

- Invasive species
- Habitat shift/loss
- Drought, stream flow, water availability
- Wildfire
- Sea level rise
- Coral health
- Fisheries and agriculture

Products from the RLW Initiative Project

The PICCC, NOAA and the EPA worked with partnerships throughout the three sites to develop:

- Maps of existing resilience activities for each site (Example of He‘eia map at right)
- Site-specific reviews of climate change science
- Actionable lists of modifications to existing or planned actions to increase resiliency
- An online ESRI Storymap detailing the RLW Initiative efforts and products locally and nationwide

Map of activities throughout the He‘eia landscape that promote or increase resilience to climate change.
Climate Impacts

The West Hawai‘i Resilient Lands and Waters site is located on the northwestern side of Hawai‘i Island. Climate change (CC) is currently affecting this area and these impacts will increase in the future. Climate change stresses for Hawai‘i include increasing air and sea temperatures, changing ocean chemistry, rising sea levels, changes in precipitation, and increased risks from hurricanes. Hawai‘i’s ecosystems are responding to these changes in complex ways.

Air and sea temperature
Globally, 15 of the 16 warmest years on record have occurred since 2000, with 2015 topping the chart as the warmest year on record by 20%. Hawai‘i is growing warmer, with high temperatures in the ocean leading to two consecutive years of coral bleaching in 2014 and 2015. High summer temperatures are projected to create severe bleaching conditions every year by about 2040, which is likely to substantially change the character of coastal ecosystems. Changing ocean chemistry (ocean acidification) will slow coral growth and may weaken reef structure.

Sea level
The rate of global mean sea level rise is approximately 3.4 mm/yr, and is predicted to accelerate. Models project sea levels in Hawai‘i to be a foot higher than current levels, and climbing, by 2050.

Rainfall and storms
In Hawai‘i, measurements show that the dry season has grown longer and drier. Considerable disagreement currently exists between climate models in terms of future rainfall, but any shift in rainfall patterns would result in stream flows varying from present day values. Potential issues arising from altered rainfall patterns include flooding, decreased fresh water availability, drought and consequent irrigation shortages, decline of native aquatic species and increased populations of invasive aquatic species. Changes in rainfall will interact with increasing temperatures in ways that could stress crops and lead to changes in upland forests. Storm frequency and intensity have also been changing throughout the Pacific region. Eighteen named storms were recorded in the Central Pacific in 2015, over three times the annual average. Rainfall and wind speeds associated with hurricanes are increasing; meanwhile, storm tracks are shifting northward, putting Hawai‘i at greater risk.

Community responses
Due to human-caused warming of the global system, the climate in Hawai‘i will transform in the coming decades to a new and changing state, different from the recent past. Those working to conserve and enhance our environment should consider the range of possible impacts of climate change, examine their current efforts, and consider or devise reasonable modifications to current efforts that will achieve greater resilience to climate change.
Current Efforts & Potential Modifications

Table 1 provides a detailed account of climate related impacts in West Hawai‘i and which organizations are currently addressing these issues. Table 2 lays out issues caused or enhanced by climate change along with suggested modifications to create more resilient landscapes.

### Table 1

Potential climate change impacts across the West Hawai‘i landscape and the groups currently incorporating these impacts in their efforts.

<table>
<thead>
<tr>
<th>Area</th>
<th>Freshwater: Terrestrial water systems</th>
<th>Terrestrial</th>
<th>Coastal &amp; low lying areas</th>
<th>Ocean systems</th>
<th>Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inc./dec. streamflow</td>
<td>More, larger wildfires</td>
<td>Flooding and erosion</td>
<td>Coral bleaching, disease outbreaks</td>
<td>Dec. crop productivity</td>
</tr>
<tr>
<td></td>
<td>Inc./dec. flooding</td>
<td>Longer periods of drought</td>
<td>Saltwater intrusion</td>
<td>Inc. number/intensity of storms</td>
<td>Maladapted crop varieties</td>
</tr>
<tr>
<td></td>
<td>Inc. erosion, sedimentation</td>
<td>Habitat, biodiversity loss</td>
<td>Extreme water levels (SLR), high run up (storms)</td>
<td>Fish population shifts</td>
<td>Irrigation shortages</td>
</tr>
<tr>
<td></td>
<td>Drying of streambeds</td>
<td>Hotter temperatures</td>
<td>Vulnerable fish ponds</td>
<td>Reef erosion from acidification</td>
<td>Flooding of ag. lands</td>
</tr>
<tr>
<td></td>
<td>Reduced groundwater supply</td>
<td>Altered seasonal variation</td>
<td>Degraded infrastructure</td>
<td>Altered salinity</td>
<td>Saltwater intrusion</td>
</tr>
<tr>
<td></td>
<td>Decline in natives, inc. invasives</td>
<td>Inc. of disease and pests</td>
<td>Decrease in trade winds</td>
<td>Faster weed growth</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Organizations implementing current actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kohala Watershed Partnership Restoration (Pelekane Bay Watershed)</td>
</tr>
<tr>
<td>UH Sea Grant Waiulaula Restoration</td>
</tr>
<tr>
<td>Hui Malama Loko I‘a fishpond restoration</td>
</tr>
<tr>
<td>UH Hilo erosion modeling</td>
</tr>
<tr>
<td>Hawai‘i Wildfire Organization</td>
</tr>
<tr>
<td>Kohala Watershed Partnership Restoration (Pelekane Bay Watershed)</td>
</tr>
<tr>
<td>UH Sea Grant</td>
</tr>
<tr>
<td>USDA NRCS</td>
</tr>
<tr>
<td>Kailapa Community fencing and native vegetation project</td>
</tr>
<tr>
<td>Coral Reef Alliance cesspool</td>
</tr>
<tr>
<td>South Kohala Coastal Partnership</td>
</tr>
<tr>
<td>Hui Malama Loko I‘a fishpond restoration</td>
</tr>
<tr>
<td>Conservation International</td>
</tr>
<tr>
<td>TNC</td>
</tr>
<tr>
<td>USFS</td>
</tr>
<tr>
<td>US FWS</td>
</tr>
<tr>
<td>UH Hilo</td>
</tr>
<tr>
<td>NOAA Habitat Blueprint/West Hawai‘i Habitat Focus Area</td>
</tr>
<tr>
<td>NOAA Sentinel Site</td>
</tr>
<tr>
<td>NOAA NESDIS</td>
</tr>
</tbody>
</table>

| Hawai‘i Humpback Whale National Marine Sanctuary |
| NOAA Sentinel site |
| NOAA Habitat Blueprint/West Hawai‘i Focus Area |
| South Kohala Coastal Partnership |
| Hui Malama Loko I‘a fishpond restoration |
| TNC and Jeff Maynard coral resilience study |
| DLNR/DAR coral reef fish monitoring |
Table 2 Common issues across the landscape and possible modifications to current efforts to enhance resilience.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Potential modifications to current actions</th>
<th>Current findings</th>
<th>Example plans/actions</th>
</tr>
</thead>
</table>
| Invasive species       | - Outreach & education: invasive species management info. to be included in all public awareness programs in relation to CC  
                         - Reduce existing invasive species threats to increase the capacity of native species & ecosystems to adapt to CC (e.g. fencing if not doing it already)  
                         - Re-examine plans that aim to restore past conditions or maintain current species assemblages/distributions. Describe and embrace new configurations and species, mixes that will thrive in new conditions.  
                         - Increased monitoring-scope, range, occurrence  
                         - Conduct risk assessment of any potential plant introductions (good practice)  
                         - Anticipate (using climate models/VA) and prevent range expansion of invasive plants  
                         - Advertise benefit of planting natives over ornamental species | * Vorsino et al. 2014\(^{11}\)  
                         * Somers and Asner 2012\(^{12}\)  
                         * Hawai'i and Pacific Islands National Climate Assessment\(^{13}\) | * McNeely et al. 2001\(^{14}\)  
                         * Kriticos et al. 2010\(^{15}\)  
                         * Burgiel and Hall 2014\(^{16}\) |
| Habitat shift/loss     | - Consider assisted colonization/experimental relocation using species distribution models  
                         - Protection or conservation of remnant ecosystems through covenants or nature reserves  
                         - Captive breeding  
                         - Species reintroductions  
                         - Control invasives in future habitat  
                         - Control invasives and manage development in future habitat  
                         - Model habitat movement | * Corlett and Westcott 2013\(^{17}\)  
                         * Fortini et al. 2013\(^{18}\)  
                         * Price et al. 2007\(^{19}\) | * 2009 California Climate Adaptation Strategy (CAS)\(^{20}\) |
| Drought, stream flow, water availability | - Create drought exercises to properly train relevant stakeholders and to offer a forum for information exchange (e.g. suggestions for improving the drought-planning process)  
                         - Community-based stream groups that take care of the streams  
                         - Prepare for overdraft subsidence, decreased water quality/pollution  
                         - Increased outreach to educate and prepare the public  
                         - Stand-Alone Drought Plans, actions taken by individuals, industry, government, before drought occurs to reduce or mitigate impacts and conflicts arising from drought | * Timm et al. 2014\(^{21}\)  
                         * Zhang et al. 2012\(^{22}\)  
                         * Kundewicz et al. 2013\(^{23}\) | * Colorado Drought Mitigation and Response Plan (2013)\(^{24}\) |
| Wildfire               | - Remote (plane, satellite) operational monitoring of forests  
                         - Plant drought tolerant plants/trees  
                         - Monitor climate effects on forest health and the effectiveness of management actions  
                         - Prohibit campfires in parks, beaches, camping grounds  
                         - Provide training on how to prevent and fight forest fires | * Trauernicht et al. 2015\(^{25}\)  
                         * Ellsworth et al. 2014\(^{26}\) | * CAL FIRE Adaptation to Climate Change\(^{27}\)  
                         * Williams et al. 2009\(^{28}\) |
Table 2 continued  Common issues across the landscape and possible modifications to current efforts to enhance resilience.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Potential modifications to current actions</th>
<th>Current findings</th>
<th>Example plans/actions</th>
</tr>
</thead>
</table>
| Sea level rise         | -Plan for shoreline change/estuary retreat (needs modeling) and infrastructure flooding/inundation  
-Plan for less reef protection of shoreline over time (as coral reefs “sink”)  
-Urge sewer infrastructure to replace cesspools/septic systems (onsite wastewater systems) vulnerable to rising water table  
-Plan for lack of drainage of ponds near SL (i.e. aquaculture ponds, fishponds, maybe raise bottom and sides)  
-Plan for decreased storm water drainage  
 -Create living shorelines with wetlands that absorb floods, slow erosion, and provide habitat  
-Promote increased coastal setbacks-a prescribed distance to a coastal feature such as the line of permanent vegetation | ♦ Anderson et al. 2015\textsuperscript{29}  
♦ Fletcher et al. 2012\textsuperscript{30}  
♦ Fletcher et al. 2002\textsuperscript{31}  
♦ Fletcher et al. 2010\textsuperscript{32}  
♦ Reynolds et al. 2012\textsuperscript{33} | ♦ Sea Level Rise Hawaii\textsuperscript{34}  
♦ Surging Seas: Sea level rise analysis by Climate Central\textsuperscript{35}  
♦ Sea Level Rise Adaptation Strategy for San Diego Bay January 2012\textsuperscript{36}  
♦ 2009 California Climate Adaptation Strategy\textsuperscript{20} |
| Coral health           | -Expand marine protected areas around reefs  
-Proactively tailor activities addressing land-based pollution (e.g. sediment and nutrient delivery to nearshore waters) to consider climate change predictions/uncertainties  
-Integrate CC predictions and uncertainties into Hawai‘i’s comprehensive planning laws and procedures  
-Decrease the likelihood of negative fishing, diving, and other reef use impacts to key habitats and important functional groups of plants and animals (e.g. herbivores) by increasing law enforcement presence and regulatory compliance  
-Promote minimum impact reef use activities (e.g. appropriate fishing gear, catch-and-release fishing) and voluntary avoidance of bleached, diseased or otherwise stressed coral reefs  
-Identify and protect transition/alternative habitats that will provide for range shifts in distribution and abundance of species and habitats affected by CC  
-Determine and map areas of high and low resilience to CC in order to identify refugia and prioritize management efforts  
-Partner with stakeholder groups, such as the tourism industry, to understand CC implications, reduce climate footprint, and prepare adaptation plans  
-Reduce land-based sources of pollution through erosion control and re-vegetation; identify erosion hotspots | ♦ Kittinger et al. 2011\textsuperscript{37}  
♦ Munday et al. 2009\textsuperscript{38}  
♦ Keller et al. 2009\textsuperscript{39}  
♦ van Hooidonk et al. 2015\textsuperscript{5} | ♦ Bentivoglio 2003\textsuperscript{40}  
♦ Climate Change Action Plan for the Florida Reef System 2010-2015\textsuperscript{41}  
♦ Great Barrier Reef Climate Change Action Plan 2012-2017\textsuperscript{42}  
♦ EPA’s Pacific Southwest Strategic Plan for Coral Reefs\textsuperscript{43} |
| Fisheries & Agriculture| -Reduce land-based sources of pollution and destructive fishing practices  
-Reduce destructive fishing practices, increase best fishing practices  
-Change fishing rules to protect reef-critical species  
-Implement temporary MPAs (‘try wait’ program) for other areas  
-Change timing or locations of fishing as species arrive earlier/later, or shift to new areas  
-Water supply and irrigation systems: retrofit and modify existing systems (Ag.)  
-Contemplate forest restoration of former agricultural lands where current/future conditions preclude productive agriculture  
-Use/create different crop variety/species (Ag.) based on climatic factors and inundation | ♦ Howell et al. 2012\textsuperscript{44}  
♦ McIlgorm et al. 2010\textsuperscript{45}  
♦ Bell et al. 2011\textsuperscript{46} | ♦ Shelton 2014\textsuperscript{47}  
♦ Sriskanthan and Funge-Smith 2011\textsuperscript{48} |
Figure 1 All identified resilience activities have been mapped, and are delineated into five categories: 1) Restoration of native species/habitat; 2) Controlling processes such as fire, erosion, and pollution; 3) Restoring agriculture/aquaculture systems; 4) Conducting research/monitoring; and 5) Organizing/carrying out community education.
References


42. EPA’s Pacific Southwest Strategic Plan for Coral Reefs, https://www3.epa.gov/region9/strategicplan/islans.html


Climate Impacts

The West Maui Resilient Lands and Waters site is located on the northwestern portion of Maui. Climate change (CC) is currently affecting this area and these impacts will increase in the future. Climate change stresses for Hawai‘i include increasing air and sea temperatures, changing ocean chemistry, rising sea levels, changes in precipitation, and increased risks from hurricanes. Hawai‘i’s ecosystems are responding to these changes in complex ways.

Air and sea temperature
Globally, 15 of the 16 warmest years on record have occurred since 2000, with 2015 topping the chart as the warmest year on record by 20%. Hawai‘i is growing warmer, with high temperatures in the ocean leading to two consecutive years of coral bleaching in 2014 and 2015. High summer temperatures are projected to create severe bleaching conditions every year by about 2040, which is likely to substantially change the character of coastal ecosystems. Changing ocean chemistry (ocean acidification) will slow coral growth and may weaken reef structure.

Sea level
The rate of global mean seal level rise is approximately 3.4 mm/yr, and is predicted to accelerate. Models project sea levels in Hawai‘i to be a foot higher than current levels, and climbing, by 2050.

Rainfall and storms
In Hawai‘i, measurements show that the dry season has grown longer and drier. Considerable disagreement currently exists between climate models in terms of future rainfall, but any shift in rainfall patterns would result in stream flows varying from present day values. Potential issues arising from altered rainfall patterns include flooding, decreased fresh water availability, drought and consequent irrigation shortages, decline of native aquatic species and increased populations of invasive aquatic species. Changes in rainfall will interact with increasing temperatures in ways that could stress crops and lead to changes in upland forests. Storm frequency and intensity have also been changing throughout the Pacific region.
Eighteen named storms were recorded in the Central Pacific in 2015, over three times the annual average. Rainfall and wind speeds associated with hurricanes are increasing; meanwhile, storm tracks are shifting northward, putting Hawai‘i at greater risk.

Community responses
Due to human-caused warming of the global system, the climate in Hawai‘i will transform in the coming decades to a new and changing state, different from the recent past. Those working to conserve and enhance our environment should consider the range of possible impacts of climate change, examine their current efforts, and consider or devise reasonable modifications to current efforts that will achieve greater resilience to climate change.
Current Efforts & Potential Modifications

Table 1 provides a detailed account of climate related impacts in West Maui and which organizations are currently addressing these issues. Table 2 lays out issues caused or enhanced by climate change along with suggested modifications to create more resilient landscapes.

<table>
<thead>
<tr>
<th>Area</th>
<th>Climate change impacts</th>
<th>Organizations implementing current actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>West Maui Ridge2Reef</td>
</tr>
<tr>
<td></td>
<td></td>
<td>West Maui Mountains Watershed Partnership</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DAR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOAA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USGS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Freshwater: Terrestrial water systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Terrestrial</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coastal &amp; low lying areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ocean systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agriculture</td>
</tr>
<tr>
<td></td>
<td>• Inc./dec. streamflow</td>
<td>• More, larger wildfires</td>
</tr>
<tr>
<td></td>
<td>• Inc./dec. flooding risk</td>
<td>• Longer periods of drought</td>
</tr>
<tr>
<td></td>
<td>• Incr. erosion, sedimentation</td>
<td>• Habitat, biodiversity loss</td>
</tr>
<tr>
<td></td>
<td>• Drying of streambeds</td>
<td>• Hotter temperatures</td>
</tr>
<tr>
<td></td>
<td>• Reduced groundwater supply</td>
<td>• Altered seasonal variation</td>
</tr>
<tr>
<td></td>
<td>• Decline in natives, inc. invasives</td>
<td>• Inc. of disease and pests</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Inc. erosion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Damaged cultural sites</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2  Common issues across the landscape and possible modifications to current efforts to enhance resilience.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Potential modifications to current actions</th>
<th>Current findings</th>
<th>Example plans/actions</th>
</tr>
</thead>
</table>
| Invasive species           | - Outreach & education: invasive species management info. to be included in all public awareness programs in relation to CC  
- Reduce existing invasive species threats to increase the capacity of native species & ecosystems to adapt to CC (e.g. fencing if not doing it already)  
- Re-examine plans that aim to restore past conditions or maintain current species assemblages/distributions. Describe and embrace new configurations and species, mixes that will thrive in new conditions.  
- Increased monitoring: scope, range, occurrence (for detection and elimination)  
- Conduct risk assessment of any potential plant introductions (good practice)  
- Anticipate (using climate models/VA) and prevent range expansion of invasive plants | ✷ Vorsino et al. 2014  
✦ Somers and Asner 2012  
✦ Hawaiʻi and Pacific Islands National Climate Assessment  
✦ McNeely et al. 2001  
✦ Kriticos et al. 2010  
✦ Burgiel and Hall 2014 | ✷ Vorsino et al. 2014  
✦ Somers and Asner 2012  
✦ Hawaiʻi and Pacific Islands National Climate Assessment  
✦ McNeely et al. 2001  
✦ Kriticos et al. 2010  
✦ Burgiel and Hall 2014 |
| Habitat shift/loss         | - Consider assisted colonization/experimental relocation using species distribution models  
- Protection or conservation of remnant ecosystems through covenants or nature reserves  
- Implement captive breeding  
- Species reintroductions  
- Control invasives in future habitat  
- Consider forest restoration where climate conditions preclude current/former uses (e.g. ag) | ✷ Corlett and Westcott 2013  
✦ Fortini et al. 2013  
✦ Price et al. 2007 | ✷ 2009 California Climate Adaptation Strategy (CAS) |
| Drought, stream flow, water availability | - Create drought exercises to properly train relevant stakeholders and to offer a forum for information exchange (e.g. suggestions for improving the drought-planning process)  
- Community-based stream groups that take care of the streams  
- Prepare for overdraft subsidence, decreased water quality/pollution  
- Increased outreach to educate and prepare the public  
- Stand-Alone Drought Plans, actions taken by individuals, industry, government, before drought occurs to reduce or mitigate impacts and conflicts arising from drought | ✷ Timm et al. 2014  
✦ Zhang et al. 2012  
| Wildfire                   | - Remote (plane, satellite) operational monitoring of forests  
- Plant drought tolerant plants/trees  
- Monitor climate effects on forest health and the effectiveness of management actions  
- Prohibit campfires in parks, beaches, camping grounds  
- Provide training on how to prevent and fight forest fires (fire prevention plans) | ✷ Trauernicht et al. 2015  
✦ Ellsworth et al. 2014 | ✷ CAL FIRE Adaptation to Climate Change  
✦ Williams et al. 2009 |
Table 2 continued Common issues across the landscape and possible modifications to current efforts to enhance resilience.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Potential modifications to current actions</th>
<th>Current findings</th>
<th>Global example plans/actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea level rise</td>
<td>- Plan for shoreline change/estuary retreat (needs modeling) and infrastructure flooding/inundation</td>
<td>• Anderson et al. 2015^29 &lt;br&gt; • Fletcher et al. 2012^30 &lt;br&gt; • Fletcher et al. 2002^31</td>
<td>• Sea Level Rise Hawaii^24 &lt;br&gt; • Surging Seas: Sea level rise analysis by Climate Central^25</td>
</tr>
<tr>
<td></td>
<td>- Plan for less reef protection of shoreline over time (as coral reefs &quot;sink&quot;)</td>
<td>• Fletcher et al. 2010^32 &lt;br&gt; • Reynolds et al. 2012^33</td>
<td>• Sea Level Rise Adaptation Strategy for San Diego Bay January 2012^36 &lt;br&gt; • 2009 California Climate Adaptation Strategy^20</td>
</tr>
<tr>
<td></td>
<td>- Urge sewer infrastructure to replace cesspools/septic systems (onsite wastewater systems) vulnerable to rising water table</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Plan for lack of drainage of ponds near SL (i.e. aquaculture ponds, maybe raise bottom and sides)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Plan for decreased storm water drainage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Create living shorelines with wetlands that absorb floods, slow erosion, and provide habitat</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Promote increased coastal setbacks—a prescribed distance to a coastal feature such as the line of permanent vegetation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Proactively tailor activities addressing land-based pollution (e.g. sediment and nutrient delivery to nearshore waters) to consider climate change predictions/uncertainties</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Decrease the likelihood of negative fishing, diving, and other reef use impacts to key habitats and important functional groups of plants and animals (e.g. herbivores) by increasing law enforcement presence and regulatory compliance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Promote minimum impact reef use activities (e.g. appropriate fishing gear, catch-and-release fishing) and voluntary avoidance of bleached, diseased or otherwise stressed coral reefs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Identify and protect transition/alternative habitats that will provide for range shifts in distribution and abundance of species and habitats affected by CC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Determine and map areas of high and low resilience to CC in order to identify refugia and prioritize management efforts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Partner with stakeholder groups, such as the tourism industry, to understand CC implications, reduce climate footprint, and prepare adaptation plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fisheries &amp; Agriculture</td>
<td>- Reduce land-based sources of pollution and destructive fishing practices</td>
<td>• Howell et al. 2012^44 &lt;br&gt; • McIlgorm et al. 2010^45 &lt;br&gt; • Bell et al. 2011^46</td>
<td>• Shelton 2014^47 &lt;br&gt; • Sriskanthan and Funge-Smith 2011^48</td>
</tr>
<tr>
<td></td>
<td>- Change fishing rules to protect reef-critical species</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Implement temporary MPAs ('try wait' program) for other areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Change timing or locations of fishing as species arrive earlier/later, or shift to new areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Water supply and irrigation systems: retrofit and modify existing systems (Ag.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Contemplate forest restoration of former agricultural lands where current/future conditions preclude productive agriculture</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Use/create different crop variety/species (Ag.) based on climatic factors and inundation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
All identified resilience activities have been mapped, and are delineated into five categories: 1) Restoration of native species/habitat; 2) Controlling processes such as fire, erosion, and pollution; 3) Restoring agriculture/aquaculture systems; 4) Conducting research/monitoring; and 5) Organizing/carrying out community education.
References


43. EPA’s Pacific Southwest Strategic Plan for Coral Reefs, https://www3.epa.gov/region9/strategicplan/islands.html


Climate Impacts

The He‘eia Resilient Lands and Waters site is located on the windward side of O‘ahu. Climate change (CC) is currently affecting this area and these impacts will increase in the future. Climate change stresses for Hawai‘i include increasing air and sea temperatures, changing ocean chemistry, rising sea levels, changes in precipitation, and increased risks from hurricanes. Hawai‘i’s ecosystems are responding to these changes in complex ways.

Air and sea temperature
Globally, 15 of the 16 warmest years on record have occurred since 2000, with 2015 topping the chart as the warmest year on record by 20%2. Hawai‘i is growing warmer3, with high temperatures in the ocean leading to two consecutive years of coral bleaching in 2014 and 20154. High summer temperatures are projected to create severe bleaching conditions every year by about 2040, which is likely to substantially change the character of coastal ecosystems5. Changing ocean chemistry (ocean acidification) will slow coral growth and may weaken reef structure5.

Sea level
The rate of global mean seal level rise is approximately 3.4 mm/yr6, and is predicted to accelerate7. Models project sea levels in Hawai‘i to be a foot higher than current levels, and climbing, by 20508.

Rainfall and storms
In Hawai‘i, measurements show that the dry season has grown longer and drier9. Considerable disagreement currently exists between climate models in terms of future rainfall, but any shift in rainfall patterns would result in stream flows varying from present day values. Potential issues arising from altered rainfall patterns include flooding, decreased fresh water availability, drought and consequent irrigation shortages, decline of native aquatic species and increased populations of invasive aquatic species5. Changes in rainfall will interact with increasing temperatures in ways that could stress crops and lead to changes in upland forests. Storm frequency and intensity have also been changing throughout the Pacific region10. Eighteen named storms were recorded in the Central Pacific in 2015, over three times the annual average2. Rainfall and wind speeds associated with hurricanes are increasing; meanwhile, storm tracks are shifting northward, putting Hawai‘i at greater risk10.

Community responses
Due to human-caused warming of the global system, the climate in Hawai‘i will transform in the coming decades to a new and changing state, different from the recent past. Those working to conserve and enhance our environment should consider the range of possible impacts of climate change, examine their current efforts, and consider or devise reasonable modifications to current efforts that will achieve greater resilience to climate change.
# Current Efforts & Potential Modifications

Table 1 provides a detailed account of climate related impacts in He`eia and which organizations are currently addressing these issues. Table 2 lays out issues caused or enhanced by climate change along with suggested modifications to create more resilient landscapes.

---

### Table 1 Potential climate change impacts across the He`eia landscape and the groups currently incorporating these impacts in their efforts.

<table>
<thead>
<tr>
<th>Area</th>
<th>Freshwater: Terrestrial water systems</th>
<th>Terrestrial</th>
<th>Coastal &amp; low lying areas</th>
<th>Ocean systems</th>
<th>Agriculture</th>
</tr>
</thead>
</table>
| Climate change impacts | • Inc./dec. streamflow  
• Inc./dec. flooding risk  
• Inc. erosion, sedimentation  
• Drying of streambeds  
• Reduced groundwater supply  
• Decline in natives, inc. invasives | • Longer periods of drought  
• Habitat, biodiversity loss  
• Hotter temperatures  
• Altered seasonal variation  
• Inc. of disease and pests  
• Inc. erosion  
• Damaged cultural sites | • Flooding and erosion  
• Saltwater intrusion  
• Extreme water levels (SLR), high run up (storms)  
• Inc. natural disasters (intensity, frequency, impact from winds and rain)  
• Vulnerable fish ponds  
• Degraded infrastructure | • Coral bleaching, disease outbreaks  
• Inc. number/intensity of storms  
• Fish population shifts  
• Reef erosion from acidification  
• Changing circulation patterns  
• Altered salinity  
• Decrease in trade winds | • Dec. crop productivity  
• Maladapted crop varieties  
• Irrigation issues  
• Flooding of ag. lands  
• Saltwater intrusion  
• Faster weed growth |

| Organizations implementing current actions | He`eia Stream Restoration Project  
Kako‘o ‘Oiwi wetland restoration  
Lower He`eia Stream Restoration Project  
Papahana Kuaola native forestry and stream restoration  
Water to Watch: Lower He`eia Stream  
DOFAW | Hawai‘i Wildfire Organization  
He`eia State Park-Kama‘aina Kids  
He`eia Stream Restoration Project  
Kako‘o ‘Oiwi wetland restoration  
Lower He`eia Stream Restoration Project  
Papahana Kuaola native forestry  
Water to Watch: Lower He`eia Stream | He`eia State Park-Kama‘aina Kids  
He`eia Stream Restoration Project  
Kako‘o ‘Oiwi wetland restoration  
Lower He`eia Stream Restoration Project  
Papahana Kuaola  
Water to Watch: Lower He`eia Stream  
Paepae o He`eia | Hawaiian Islands Sentinel Site Program  
Paepae o He`eia fishpond restoration  
Super Sucker Reef Restoration  
HIMB  
He`eia Coastal Ocean Observing System  
CO2 Monitoring buoys | Kako‘o ‘Oiwi kalo lo‘i  
Lower He`eia Stream Restoration Project  
Papahana Kuaola kalo lo‘i and agriforestry |
Table 2 Common issues across the landscape and possible modifications to current efforts to enhance resilience.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Potential modifications to current actions</th>
<th>Current findings</th>
<th>Example plans/actions</th>
</tr>
</thead>
</table>
| **Invasive species**   | - Outreach & education: invasive species management info. to be included in all public awareness programs in relation to CC  
                        - Reduce existing invasive species threats to increase the capacity of native species & ecosystems to adapt to CC (e.g. fencing if not doing it already)  
                        - Re-examine plans that aim to restore past conditions or maintain current species assemblages/distributions. Describe and embrace new configurations and species, mixes that will thrive in new conditions.  
                        - Increased monitoring: scope, range, occurrence  
                        - Conduct risk assessment of any potential plant introductions (good practice)  
                        - Anticipate (using climate models/VA) and prevent range expansion of invasive plants  
                        - Advertise benefit of planting natives over ornamental species | - Vorsino et al. 2014\textsuperscript{11}  
                        - Somers and Asner 2012\textsuperscript{12}  
                        - Hawai'i and Pacific Islands National Climate Assessment\textsuperscript{13} | - McNeely et al. 2001\textsuperscript{14}  
                        - Kriticos et al. 2010\textsuperscript{15}  
                        - Burgiel and Hall 2014\textsuperscript{16} |
| **Habitat shift/loss** | - Consider assisted colonization/experimental relocation using species distribution models  
                        - Protection or conservation of remnant ecosystems through covenants or nature reserves  
                        - Captive breeding  
                        - Species reintroductions  
                        - Control invasives and manage development in future habitat  
                        - Model habitat movement   | - Corlett and Westcott 2013\textsuperscript{17}  
                        - Fortini et al. 2013\textsuperscript{18}  
                        - Price et al. 2007\textsuperscript{19} | - 2009 California Climate Adaptation Strategy (CAS)\textsuperscript{20} |
| **Drought, stream flow, water availability** | - Create drought exercises to properly train relevant stakeholders and to offer a forum for information exchange (e.g. suggestions for improving the drought-planning process)  
                        - Community-based stream groups that take care of the streams  
                        - Prepare for overdraft subsidence, decreased water quality/pollution  
                        - Increased outreach to educate and prepare the public  
                        - Stand-Alone Drought Plans, actions taken by individuals, industry, government, before drought occurs to reduce or mitigate impacts and conflicts arising from drought | - Timm et al. 2014\textsuperscript{21}  
                        - Zhang et al. 2012\textsuperscript{22}  
                        - Kundewicz et al. 2013\textsuperscript{23} | - Colorado Drought Mitigation and Response Plan (2013)\textsuperscript{24} |
| **Wildfire**           | - Plant drought tolerant plants/trees  
                        - Monitor climate effects on forest health and the effectiveness of management actions  
                        - Provide training on how to prevent and fight forest fires  
                        - Plans for wildfire containment | - Trauernicht et al. 2015\textsuperscript{25}  
                        - Ellsworth et al. 2014\textsuperscript{26} | - CAL FIRE Adaptation to Climate Change\textsuperscript{27}  
                        - Williams et al. 2009\textsuperscript{28} |
### Table 2 continued

Common issues across the landscape and possible modifications to current efforts to enhance resilience.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Potential modifications to current actions</th>
<th>Current findings</th>
<th>Global example plans/actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sea level rise</strong></td>
<td>- Plan for coastal change/estuary retreat (needs modeling) and infrastructure flooding/inundation</td>
<td>- Anderson et al. 201529</td>
<td>- Sea Level Rise Hawaii34</td>
</tr>
<tr>
<td></td>
<td>- Plan for less reef protection of shoreline over time (as coral reefs “sink”)</td>
<td>- Fletcher et al. 201230</td>
<td>- Surging Seas: Sea level rise analysis by Climate Central35</td>
</tr>
<tr>
<td></td>
<td>- Urge sewer infrastructure to replace cesspools/septic systems (onsite wastewater systems) vulnerable to rising water table</td>
<td>- Fletcher et al. 200231</td>
<td>- Sea Level Rise Adaptation Strategy for San Diego Bay January 201236</td>
</tr>
<tr>
<td></td>
<td>- Plan for lack of drainage of ponds near SL (i.e. aquaculture ponds, maybe raise bottom and sides)</td>
<td>- Fletcher et al. 201032</td>
<td>- 2009 California Climate Adaptation Strategy20</td>
</tr>
<tr>
<td></td>
<td>- Plan for decreased storm water drainage</td>
<td>- Reynolds et al. 201233</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Create living shorelines with wetlands that absorb floods, slow erosion, and provide habitat</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Promote increased coastal setbacks-a prescribed distance to a coastal feature such as the line of permanent vegetation</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coral health</strong></td>
<td>- Expand marine protected areas around reefs</td>
<td>- Kittinger et al. 201137</td>
<td>- Bentivoglio 200340</td>
</tr>
<tr>
<td></td>
<td>- Identify drivers degrading reefs (e.g. sedimentation, heavy metals, etc.)</td>
<td>- Munday et al. 200938</td>
<td>- Climate Change Action Plan for the Florida Reef System 2010-201541</td>
</tr>
<tr>
<td></td>
<td>- Proactively tailor activities addressing land-based pollution (e.g. sediment and nutrient delivery to nearshore waters) to consider climate change predictions/uncertainties</td>
<td>- Keller et al. 200939</td>
<td>- Great Barrier Reef Climate Change Action Plan 2012-201742</td>
</tr>
<tr>
<td></td>
<td>- Integrate CC predictions and uncertainties into Hawai’i’s comprehensive planning laws and procedures</td>
<td>- van Hooidonk et al. 20155</td>
<td>- EPA’s Pacific Southwest Strategic Plan for Coral Reefs43</td>
</tr>
<tr>
<td></td>
<td>- Decrease the likelihood of negative fishing, diving, and other reef use impacts to key habitats and important functional groups of plants and animals (e.g. herbivores) by increasing law enforcement presence and regulatory compliance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Promote minimum impact reef use activities (e.g. appropriate fishing gear, catch-and-release fishing) and voluntary avoidance of bleached, diseased or otherwise stressed coral reefs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Identify and protect transition/alternative habitats that will provide for range shifts in distribution and abundance of species and habitats affected by CC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Determine and map areas of high and low resilience to CC in order to identify refugia and prioritize management efforts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Partner with stakeholder groups, such as the tourism industry, to understand CC implications, reduce climate footprint, and prepare adaptation plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fisheries &amp; Agriculture</strong></td>
<td>- Reduce land-based sources of pollution and destructive fishing practices</td>
<td>- Howell et al. 201244</td>
<td>- Shelton 201447</td>
</tr>
<tr>
<td></td>
<td>- Change fishing rules to protect reef-critical species</td>
<td>- McIlgorm et al. 201045</td>
<td>- Sriskanthan and Funge-Smith 201148</td>
</tr>
<tr>
<td></td>
<td>- Implement temporary MPAs (‘try wait’ program) for other areas</td>
<td>- Bell et al. 201146</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Change timing or locations of fishing as species arrive earlier/later</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Water supply and irrigation systems: retrofit and modify existing systems (Ag.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Contemplate forest restoration of former agricultural lands where current/future conditions preclude productive agriculture</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Use/create different variety/species (Ag.) based on climatic factors and inundation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1 All identified resilience activities have been mapped, and are delineated into five categories: 1) Restoration of native species/habitat; 2) Controlling processes such as fire, erosion, and pollution; 3) Restoring agriculture/aquaculture systems; 4) Conducting research/monitoring; and 5) Organizing/carrying out community education.
References


42. EPA’s Pacific Southwest Strategic Plan for Coral Reefs, https://www3.epa.gov/region9/strategicplan/islands.html


