Anchialine pools

Vulnerability to Climate Change in West Hawai‘i

Anchialine pools of West Hawai‘i

Anchialine pools, known locally as *wai ‘ōpae* or *loko ‘ōpae‘ula*, are landlocked bodies of water with a subterranean connection to the ocean (from Greek *ankhialos*, ‘near the sea’). Anchialine pools are unique coastal ecosystems that support West Hawai‘i biodiversity, fisheries, cultural activities, and tourism. Healthy anchialine pools filter run-off and provide habitat for the native shrimp *Halocaridina rubra* (*‘ōpae‘ula*) and *Metabetaeus lohena*, along with numerous other endemic species. Hawai‘i island has one of the highest concentrations of anchialine pools in the world. Anchialine pool ecosystems are gravely threatened by introduced fishes, changes in landuse that contribute to habitat loss, reductions or impairments of freshwater water quantity and quality, and rising sea levels.

NOAA’s Integrated Ecosystem Assessment

The National Oceanic and Atmospheric Administration’s (NOAA’s) West Hawai‘i Integrated Ecosystem Assessment (IEA) is a program that builds relationships with State and Federal agencies, universities, non-profits and community organizations to deliver science that meets management needs. Such working relationships are crucial to conserving anchialine ecosystems as the pools occur on federal, state, and private lands. Assessing the vulnerability of key ecosystems and species to climate change is a goal of the IEA. With this report, the University of Hawai‘i at Hilo (UH-Hilo), The Nature Conservancy (TNC), NOAA Habitat Blueprint and the NOAA IEA are communicating state-of-the-art climate science on anchialine pool futures, promoting and supporting pool restoration and conservation efforts, and helping raise awareness of the significant ecological and cultural value of anchialine pools.

Anchialine pool vulnerability to climate change

Anchialine pools are currently threatened by invasive vegetation and invasive fish. The non-native vegetation and fish increase sediment, blanketing pool bottoms that form the habitat for native shrimp and provide substrate for their food source. In the coming decades, these threats to pools are compounded by the threat of inundation from sea-level rise and flood events.

In 2018 surveys, 509 anchialine pools were recorded. Study projections estimate current pools will decline to only 100 by 2050. Some of the existent pools will submerge under rising sea levels and will be lost, while others will merge and grow in area. Over 1,000 new pools are projected to form in the decades ahead as rising seas in the subterranean porous basalt force groundwater to the surface in more areas. In 2050, 77% of the projected anchialine pools will have a high threat of inundation, meaning connection to the ocean is expected at least 1 to 2 times per month. In 2018, invasive fish were present in 31% of anchialine pools, representing 108,006 m^2 or 89% of total pool area. Pools with invasive fish will increase 2.5 times in total area by the year 2050, to 261,086 m^2, and the majority of these pools have a high threat of inundation. By 2080, there are projected to be 336 pools with and 406 pools without invasive fish along the West Hawai‘i coastline with a high threat of inundation. Today, many pools are actively being restored through vegetation, fish and sediment removal and these efforts will be essential in the coming decades to conserve these unique ecosystems.

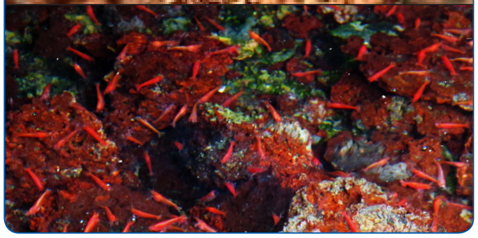
Anchialine pools are home to endemic shrimp and rare birds; these unique coastal ecosystems warrant greater research and conservation focus.

Anchialine pool ecology and threats

Features of healthy pools | Threats | Conservation efforts

Opae'ula

'Ōpae'ula: *Halocaridina rubra* are tiny red shrimp that are the dominant grazers in the anchialine pool system. They move between the groundwater and sunlit pools where they feed on the microbial films growing on rocky substrate. When introduced fish show up in a system, the shrimp disappear underground or may only come out at night. Without the constant grazing, pools can become full of algal mats and may become more eutrophic.



Invasive fish

Tilapia and poeciliids (*Gambusia* spp. and guppies) have been introduced to pools by humans for bait, food, and mosquito control. These have a significant impact on native pool biota and ecosystem ecology. *Tilapia* and poeciliids feed on *'ōpae'ula*, so these shrimp will often disappear from the pool completely or only emerge at night. Without the dominant grazer, algae begins to cover the pool substrate. The system may become eutrophic and filled with sediments. As sea levels rise, pools with introduced fishes may connect overland to other pools allowing the fishes to disperse into new habitat. Removing fish now will help prevent fish from invading other pools.

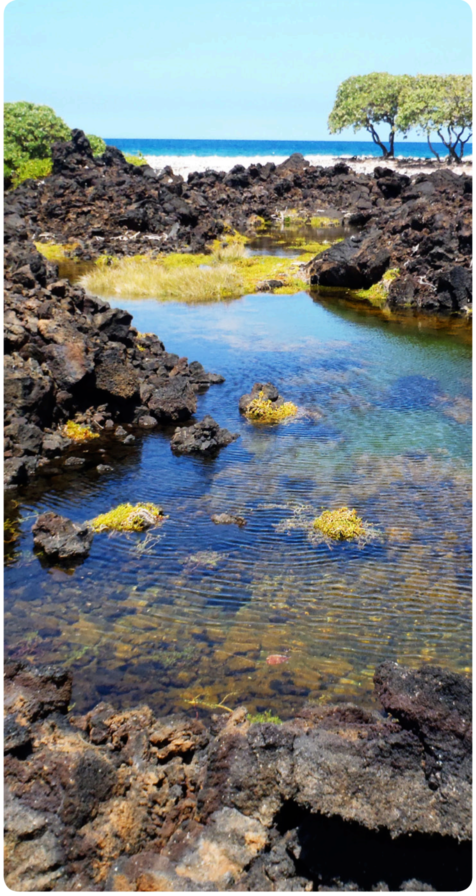
Introduced vegetation

Plants such as the *Kiawe* tree (*Prosopis pallida*), Christmas Berry (*Schinus terebinthifolius*), sourbush (*Pluchea* sp.), golf-course grass (*Paspalum* sp.) and pickleweed (*Salicornia* sp.) grow at the edges of anchialine pools. These introduced plants flourish due to the brackish groundwater at the surface of the arid Kona lava fields. These plants remove groundwater through their root systems and result in branches and leaf litter in the pools. These plants block access to pools, and increase sedimentation rates and infilling.

Rare and endangered species

Numerous other endemic species rely on this habitat including the endangered shrimp *Procaris hawaiana* and *Vetericaris chaceorum*, several uncommon snails, and the rare brackish water eel *Xenoconger fryeri*. Other endangered species that use the habitat are the Hawaiian damselfly *Megalagrion xanthomelas* and birds such as the Hawaiian stilt *Ae'o – Himantopus mexicanus knudseni*.

Photo: Troy Sakihara



Sedimentation

Sedimentation from decomposing plant or algae material, fish excrement, and human modification can cause pools to fill in and even disappear. Fine sediment layers may block passageways for shrimp and other organisms that need to move between the subterranean and surface groundwater. Sediment may stop fresh groundwater from flushing pools on a regular basis. The excess sediment can be suctioned off the bottom with pumps (see photo).

Native vegetation

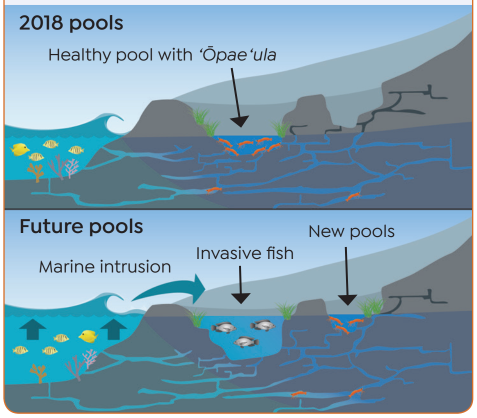
The coastline of West Hawai'i is arid with no perennial streams. Anchialine pools provide places where plants with shallow roots can access water. Native wetland plants along with several trees introduced by Polynesians may be found at the edges of anchialine pools including endemic species such as *aka'akai – Schoenoplectella tabernae-montani*. This vegetation provides habitat for a number of insect species and food sources for seabirds.

Conservation and restoration

Protecting and restoring pool habitats ensures these ecosystems will continue to provide the important services they deliver. Restoration actions are focused on removing introduced fish, cutting back or removing introduced plants, and removing fine sediment. Pool conservation includes advocating that developments do not encroach onto or over pools. This includes ensuring that groundwater moving from upslope areas is plentiful and clean and does not contain high amounts of nutrients or toxins from septic systems, cesspools, and runoff. Finally, as sea levels rise, new pools will emerge in low lying areas and limiting development around environments that contain these future pool habitats is critical.

Rising sea levels

Pools will become connected to the ocean more frequently in the coming decades. Daily or near daily connection to the ocean means the pools disappear; their ecology changes entirely. If pools connect to the ocean during big storms, pools will flush and retain their brackish nature. However, large storm waves and connection of pools can cause invasive fishes to spread into new habitat. High sea levels also push groundwater higher and ~1000 new pools are projected to emerge in low lying areas by 2050.



Project methods

Our approach included using a geographic information system (GIS) to map currently existing pools, and to visualize and quantify future status of pools for 2030, 2040, 2050, and 2080. Projections were developed for water levels, changes to 2018 pools through time, formation of new pools, and the presence/absence of invasive fish as new pools form and existing pools merge.

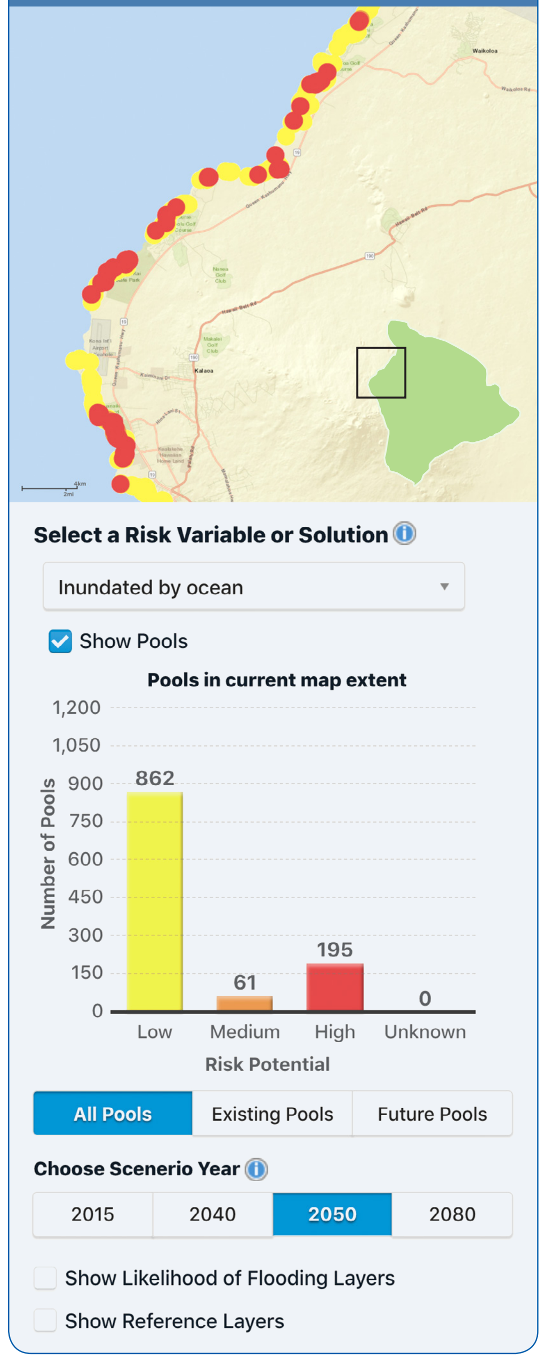
During surveys conducted between 2011 and 2018, existing pools were mapped and the presence/absence of introduced fishes were recorded (Marrack *et al.*, 2015). We then created maps to visualize potential impacts to anchialine pools due to coastal flooding that could occur during 2030, 2040, 2050, and 2080 time periods. Together with in-situ measurements of local groundwater levels (collected at 12 sites over a year) and high resolution LiDAR-based topographic data, these visualizations were derived from a scenario-based analysis of various contributions to high water levels including local tides and storm surge, regional patterns of atmospheric and oceanic circulation, and regional patterns of vertical land motion, as well as global changes in absolute sea level (Marra and Genz, 2018).

This analysis of changes in flood frequency and magnitude at different time periods and their connection to changes in local groundwater levels enabled us to determine when current pools could be inundated by the ocean and where future pools could appear. A new pool was defined as meeting these three criteria: 1) a previously dry natural area that begins to flood more than 182 days a year, 2) does not fall within the 13-m shoreline buffer expected at that time period, and 3) does not intersect with water bodies (fishpond, wetland) that connect overland to the ocean. At each time period, pools were classified as unlikely or likely to have invasive fish based on extent of groundwater flooding. Additionally, the threat of inundation was rated as low (connection to the ocean less than once per year), medium (connection to ocean 1-2 times per year), or high (connection to the ocean at least 1-2 times per month).

An **interactive tool** was developed by The Nature Conservancy (TNC), in partnership with NOAA and local stakeholders; the online application (app) is called ***Ecological Effects of Sea Level Change*** (available at http://maps.coastalresilience.org/hawaii/). The app helps planners and resource/land managers understand the potential future risk of sea level rise to anchialine pool ecosystems. Users can explore the risk of inundation for anchialine pools for 2015 and for 2040, 2050, and 2080. The user interface updates a graph showing the numbers of pools in each risk category in the current map extent as users zoom in and out of areas of interest.

The example to the right is for all of West Hawai'i in 2050 for all pools. Users can follow pools in 2018 through time, can look at all pools, or can look at projected future pools. The app will continually be updated and improved by TNC and partners as new science becomes available and in response to feedback from managers.

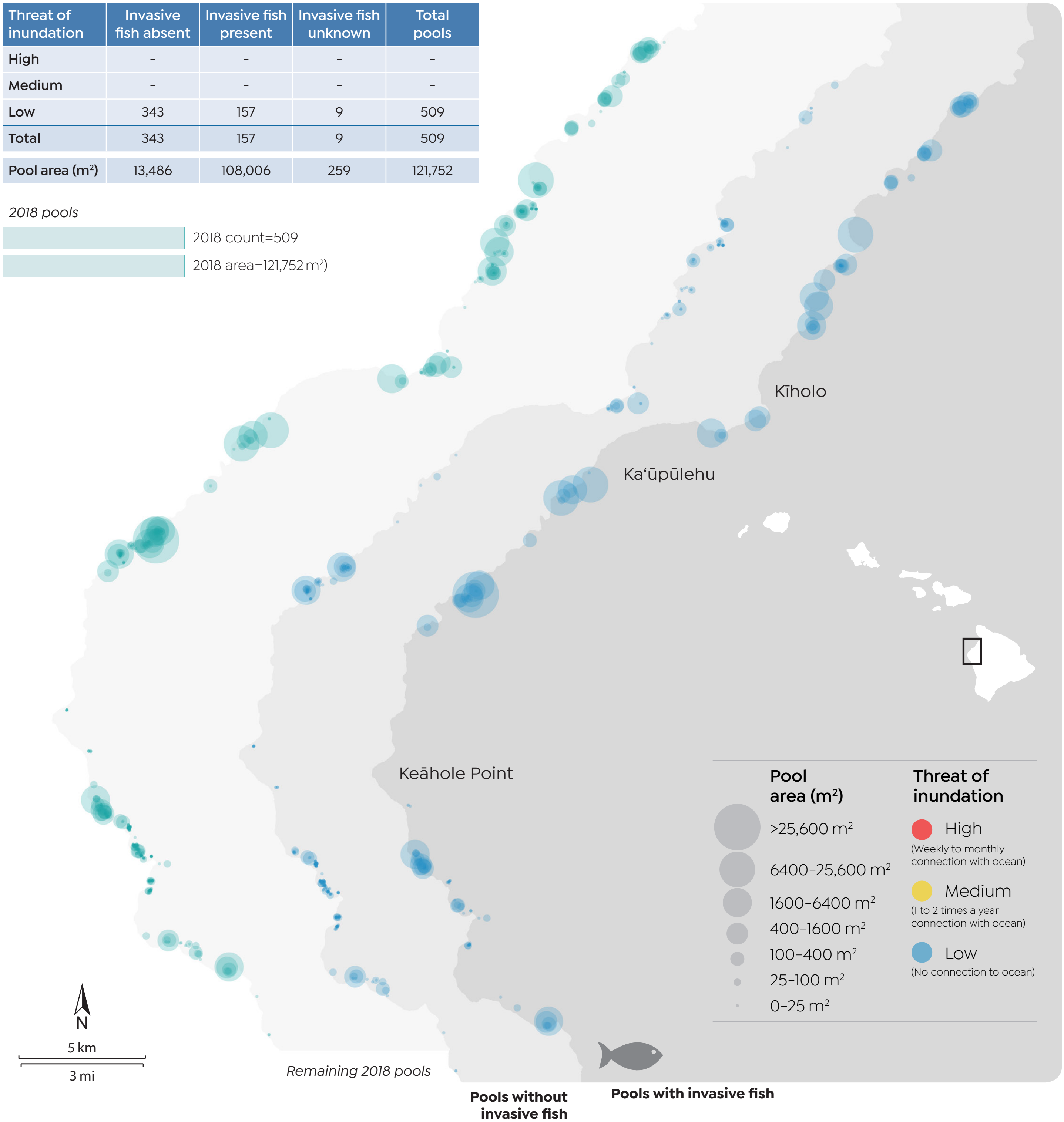
Interactive tool



Users of the interactive tool see this map and bar graph on the left side of the computer screen. These data update as users zoom in and out of areas of interest.

2018 Pools

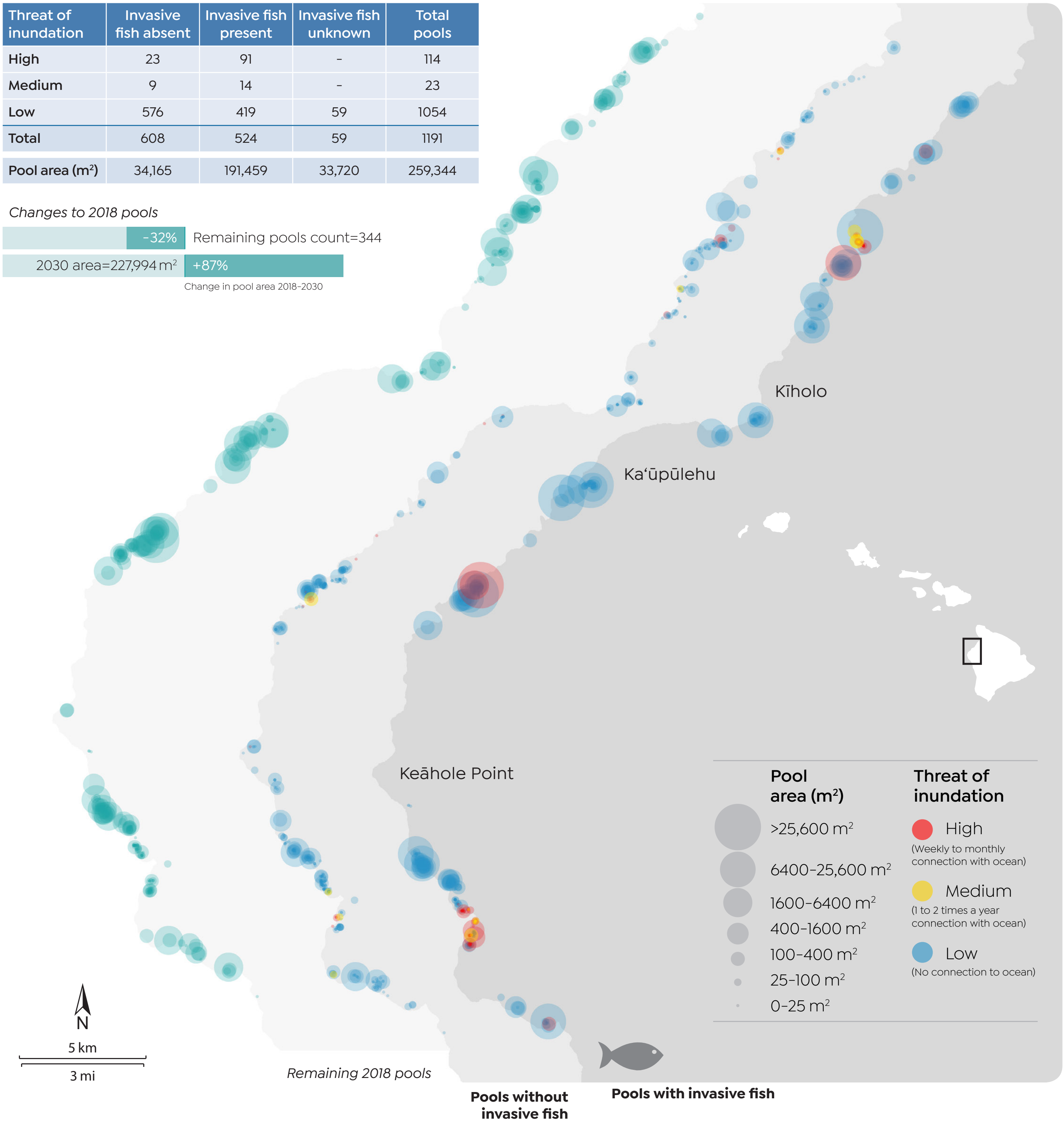
Threat of inundation	Invasive fish absent	Invasive fish present	Invasive fish unknown	Total pools
High	–	–	–	–
Medium	–	–	–	–
Low	343	157	9	509
Total	343	157	9	509
Pool area (m²)	13,486	108,006	259	121,752



Current status of anchialine pools (2018): During this study, we recorded 509 pools, representing 121,752 m² of habitat. Invasive fish are present in less than one third of the current pools (157 of 509); however, these pools are typically much larger than the pools where fish are absent. The area of anchialine pools where invasive fish are present represents ~90% of the current pool habitat (108,006 of 121,752 m²). In 2018, the risk of inundation is low for all pools. In the coming decades, current threats become compounded by the threat of inundation as current 2018 pools are lost to the sea and merge, new pools form, and the total pool area with invasive fish present greatly increases.

2030 Projections

Threat of inundation	Invasive fish absent	Invasive fish present	Invasive fish unknown	Total pools
High	23	91	-	114
Medium	9	14	-	23
Low	576	419	59	1054
Total	608	524	59	1191
Pool area (m²)	34,165	191,459	33,720	259,344



Projections indicate that by 2030, pool numbers will more than double, from 509 in 2018 to 1,191. During that time, 165 pools will be lost (32%); many of these pools will merge and expand, resulting in an 87% increase in the area of pools that existed in 2018 (from 121,752 to 227,994 m²). In 2030, there will still be more pools without invasive fish than with invasive fish (608 versus 524). The percentage of the total pool area with invasive fish is projected to have fallen from ~90% in 2018 to ~73% (191,459 of 259,344 m²). Only 13% of the total pool area is projected to not have any invasive fish. Whether invasive fish will occur in the remaining 14% of total pool area in 2030 is unknown. The threat of inundation is projected to be medium (1 to 2 times per year) or high (1 to 2 times per month) for ~5% of the pools projected to not have any invasive fish. In contrast, 20% of pools projected to have invasive fish will have a medium (14 of 524) or high (91 of 524) threat of inundation — these are south of Keāhole Point, between Keāhole Point and Kaʻūpūlehu and north of Kīholo.

2040 Projections

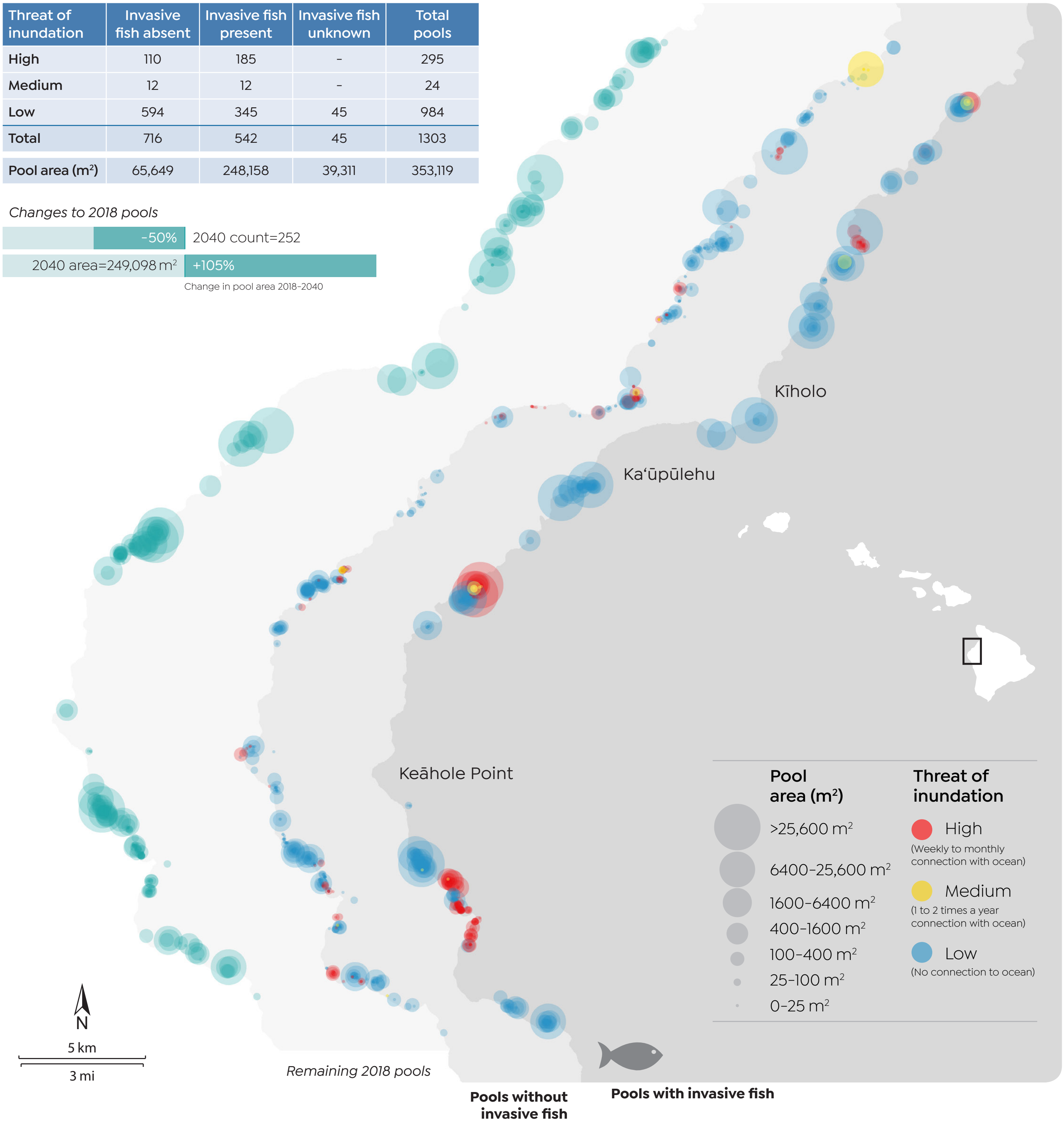
Threat of inundation	Invasive fish absent	Invasive fish present	Invasive fish unknown	Total pools
High	110	185	-	295
Medium	12	12	-	24
Low	594	345	45	984
Total	716	542	45	1303
Pool area (m²)	65,649	248,158	39,311	353,119

Changes to 2018 pools

-50% 2040 count=252

2040 area=249,098 m² +105%

Change in pool area 2018-2040

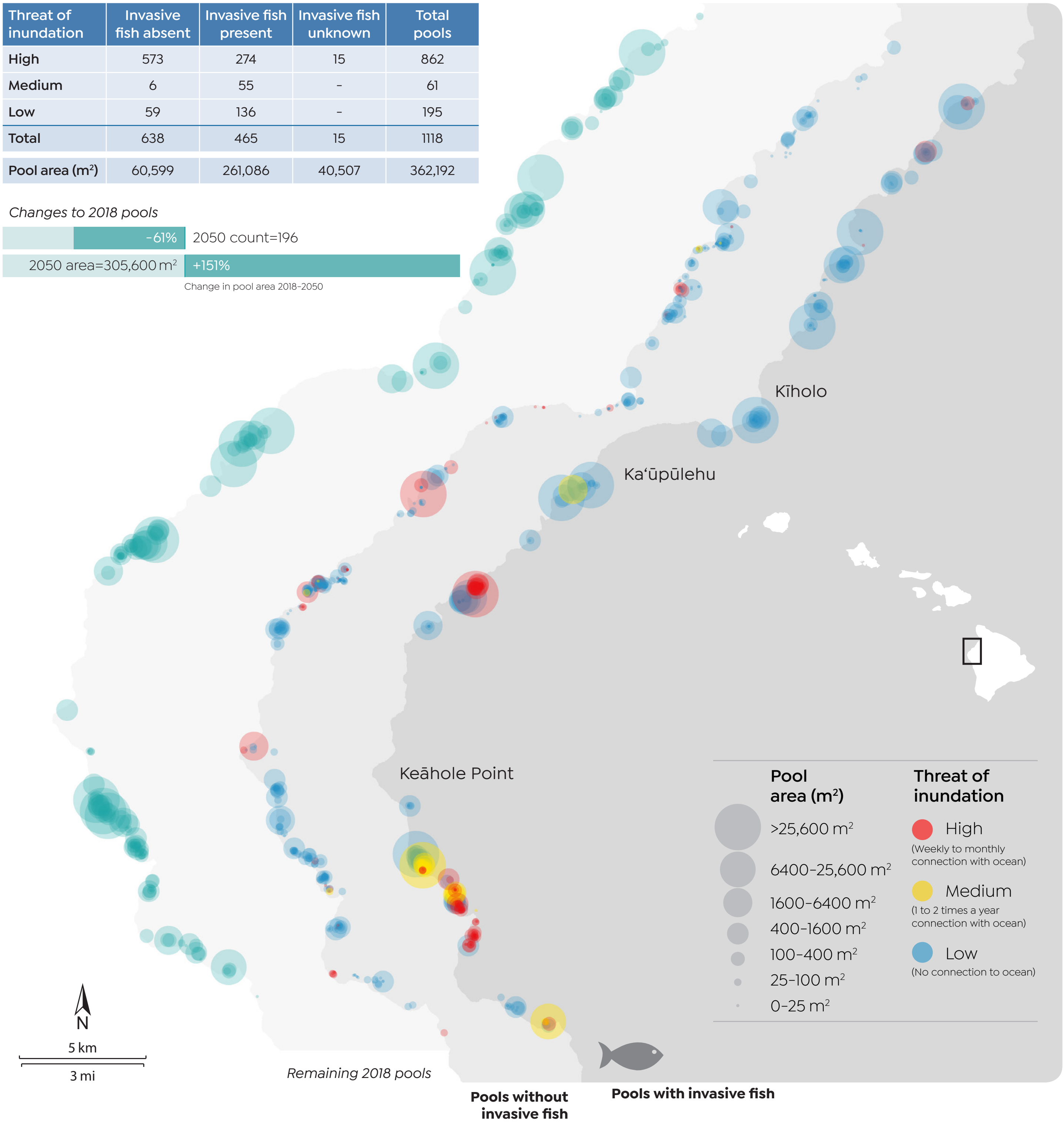


Projections indicate that between 2030 and 2040, pool numbers will increase from 1,191 to 1,303. Changes to 2018 pools include that 257 of the current pools will be lost (50%); many of these pools will merge and expand resulting in a 105% increase in the area of pools that existed in 2018 (from 121,752 to 249,098 m²). In 2040, there will still be more pools without invasive fish than with invasive fish (716 versus 542). The percentage of the total pool area with invasive fish is projected to fall from ~90% in 2018 to ~70% (248,158 of 353,119 m²). Only 18% of the total pool area is projected to not have any invasive fish. Whether invasive fish will occur in the remaining 12% of total pool area in 2040 is unknown. The threat of inundation will be medium (1 to 2 times per year) or high (1 to 2 times per month) for ~18% of the pools projected to not have any invasive fish (up from 5% in 2030). In contrast, 36% of pools projected to have invasive fish will have a medium (12 of 542) or high (185 of 542) threat of inundation (up from 20% in 2030) – these are in the same locations as in 2030: south of Keāhole Point, between Keāhole Point and Ka'ūpūlehu and north of Kīholo. In 2040, twice as many pools with invasive fish will have a high threat of inundation than was the case in 2030 (185 versus 91 pools).

2050 Projections

Threat of inundation	Invasive fish absent	Invasive fish present	Invasive fish unknown	Total pools
High	573	274	15	862
Medium	6	55	–	61
Low	59	136	–	195
Total	638	465	15	1118
Pool area (m²)	60,599	261,086	40,507	362,192

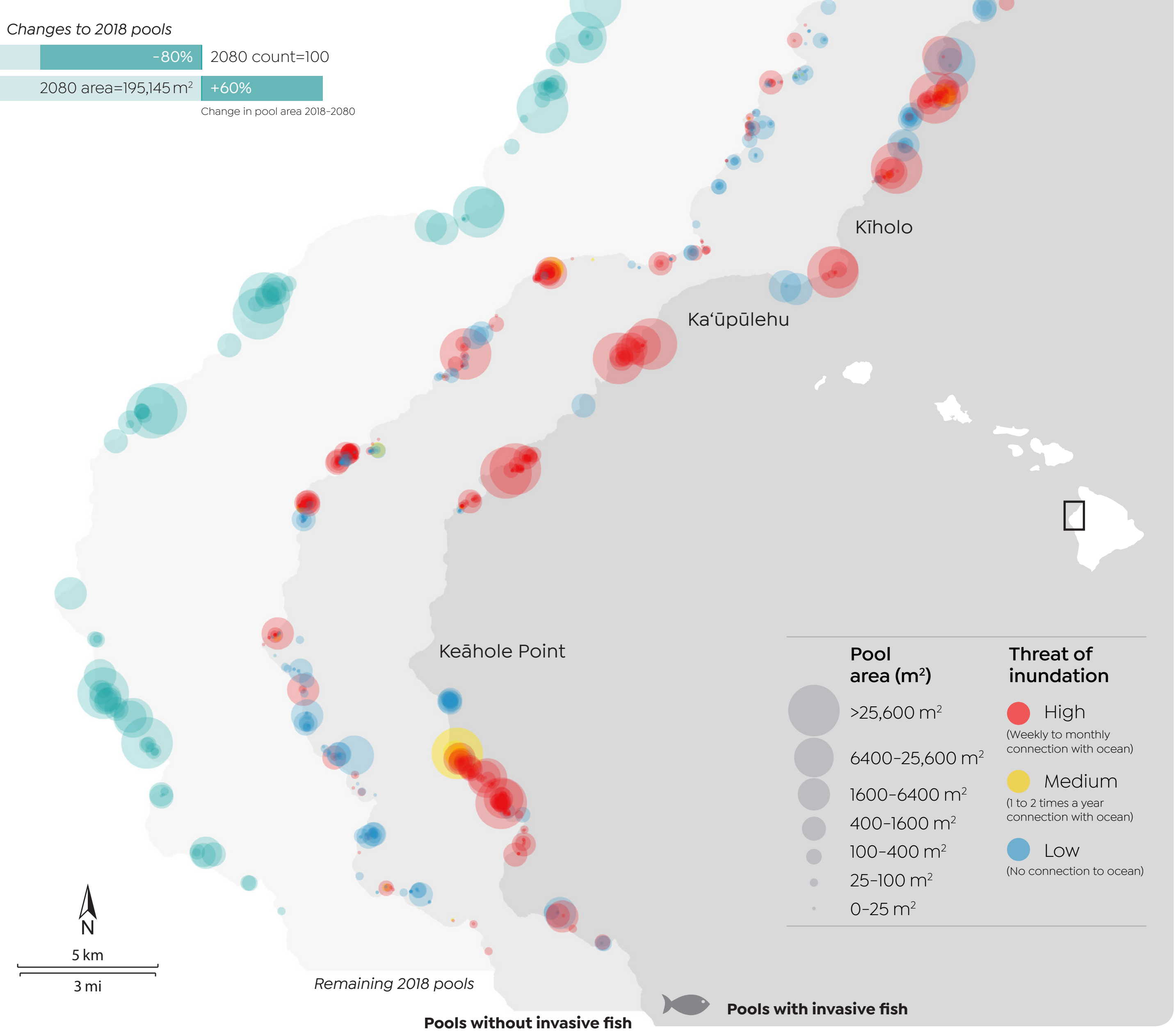
Changes to 2018 pools



Projections indicate that between 2040 and 2050, pool numbers will decrease from 1,303 to 1,118. Changes to 2018 pools include that 313 of the current pools will be lost (61%); many of these pools merge and expand resulting in a 151% increase in the area of pools that existed in 2018 (from 121,752 to 305,600 m²). In 2050, there will still be more pools without invasive fish than with invasive fish (638 versus 465). The percentage of the total pool area with invasive fish will have fallen from ~90% in 2018 to ~72% (261,086 of 362,192 m²). Only 16% of the total pool area is projected to not have any invasive fish. Whether invasive fish will occur in the remaining 12% of total pool area in 2050 is unknown. The threat of inundation will be medium (1 to 2 times per year) or high (1 to 2 times per month) for ~90% of the pools projected to not have any invasive fish (up from 16% in 2040). Of the pools projected to have invasive fish, 70% have a medium (55 of 465) or high (274 of 465) threat of inundation (up from 36% in 2040) — these will be in the same locations as in 2040: south of Keāhole Point, between Keāhole Point and Ka'ūpūlehu and north of Kīholo. Between 2040 and 2050, there will be a 50% increase in the number of pools with invasive fish that have a high threat of inundation (185 in 2040 versus 274 in 2050).

2080 Projections

Threat of inundation	Invasive fish absent	Invasive fish present	Invasive fish unknown	Total pools
High	336	406	4	746
Medium	33	72	-	105
Low	264	100	-	364
Total	633	578	4	1215
Pool area (m^2)	63,983	273,950	6,853	344,785



Projections indicate that between 2050 and 2080, pool numbers will increase from 1,118 to 1,215. Changes to 2018 pools include that 400 of the current pools will be lost (80%); many of these pools will merge and expand resulting in a 60% increase in the area of pools that existed in 2018 (from 121,752 to 195,145 m^2, ~30% loss in pool area from a 2050 high of 305,600 m^2). In 2040, there will still be more pools without than with invasive fish (633 versus 578), but the percentage of total pool area with invasive fish will increase from 72% in 2050 to 79% in 2080 (273,950 of 344,785 m^2). Only 18% of the total pool area is projected to not have any invasive fish. The threat of inundation will be medium or high for ~58% of the pools projected to not have any invasive fish (down from 90% in 2050 – many pools with high threat of inundation in 2050 will be submerged by 2080). Of the pools projected to have invasive fish, 70% will have a medium (72 of 578) or high (406 of 578) threat of inundation (up from 36% in 2040). By 2080, there will be pools all along the West Hawai'i coastline with and without invasive fish that have a high threat of inundation. Between 2050 and 2080, there will be a 50% increase in the number of pools with invasive fish that have a high threat of inundation (274 in 2050 to 406 in 2080).

Conservation and restoration

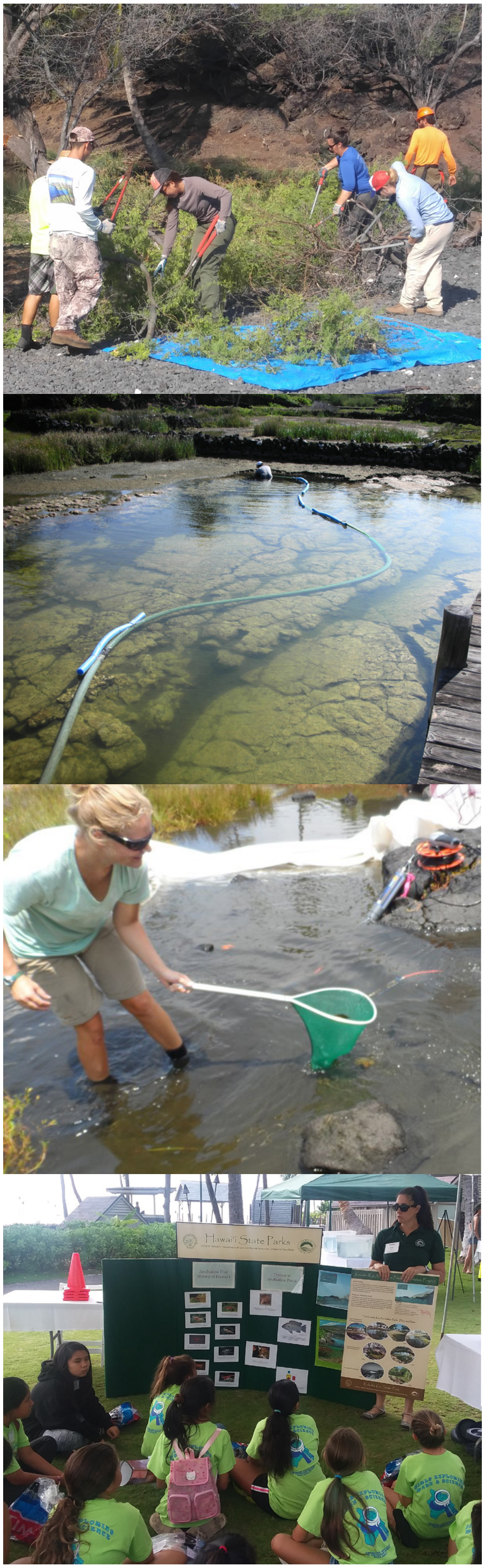
Hui Loko or 'pond group' is an informal network of 24 organizations that collaborate to protect traditional fish ponds and anchialine pool ecosystems through restoration and education. Network participants include federal and state resource managers, resource manager resort staff, conservation non-profit staff, private landowners, scientists, community members, and cultural practitioners. *Hui Loko* is based in West Hawai'i and is a subset of the statewide fishpond network called *Hui Malama Loko I'a* (group to care for fishponds). *Hui Loko* meets quarterly to share resources and knowledge and as needed to assist each other with restoration (vegetation, sediment, and fish removal) and education and outreach efforts. Leaders of ongoing restoration efforts are all very inclusive – there are many opportunities for people to get involved in conserving and restoring anchialine pools.

Vegetation removal can help prevent the build-up of sediment in the pools. Introduced tree species, as well as pickleweed, California grass, and other grasses used in resort and golf course areas, all negatively impact anchialine pools. The grasses grow very quickly – nearly all *Hui Loko* network participants face the challenge of removing invasive grasses or slowing down their growth. Manual removal of non-native vegetation is effective if completed regularly.

Sediment removal is another technique to maintain pool ecology where invasive fish and introduced vegetation species cause sediment (e.g., leaf litter and excrement) to cover the pool bottom. The excess sediment can be suctioned off the bottom with pumps and barrier features can be added near pools to prevent sediment build-up.

Fish removal is important for restoring pools to their natural ecology as the introduced guppies, mosquito fish, and tilapia all compete with other native invertebrates. Fish excrement adds sediment to pools and reduces available oxygen. Total fish removal requires a combination of methods, such as lowering the pH using carbon dioxide, hand netting, and using certain traditional plants to stun and collect invasive fish. Fish need to be removed regularly as they reproduce frequently and can quickly proliferate in the pools, even if left in small numbers.

Education and outreach efforts at resorts and in schools are raising awareness of anchialine pool ecosystem ecology and the need for conservation and restoration. Many resorts have land managers on staff that take visitors to see and learn about the pools. *Hui Loko* network participants have also developed a curriculum for elementary and high school students with educational activities related to anchialine pools and fish ponds.



Participants in the Hui Loko network restore and conserve pools through vegetation, sediment, and fish removal, and outreach and education.

ʻUla ka loko kāheka i ka ʻula o loko.

— Danny Akaka

Sacred is the red pond where the red shrimp dwell within.

ʻŌpaeʻula have a role in traditional sustainable fishing practices in Hawaiʻi. *ʻŌpaeʻula* were harvested from the pools to be used as bait for *ʻōpelu*, a coastal pelagic mackerel found close to shore. The *ʻōpaeʻula* were collected and mixed with red dirt or cinder to deploy from a canoe. The dark color of the bait attracts the *ʻōpelu*, who mainly rely on visual cues for food, while not drawing in predators like sharks that rely on smell. *ʻŌpelu* fishing was highly seasonal. Harvesting *ʻōpelu* from February to June was *kapu* (forbidden) as they grew and spawned. During this time many fishers would feed the *ʻōpelu* schools from their canoes using the *ʻōpaeʻula* mixture. After caring for the *ʻōpelu* schools during the closed season, the Hawaiians would harvest the *ʻōpelu* from July to January. Such open-ocean farming is one of the traditions that made Hawaiians prosperous. Some families cared for the *ʻōpelu koʻa* (areas where *ʻōpelu* would aggregate) for generations, a practice that is still carried on in some areas of West Hawaiʻi today.

Mahalo Nui Loa *To everyone working to collect data and restore and conserve anchialine pool ecosystems.*

For Additional Information: *Contact Dr. Lisa Marrack at lisamarrack@gmail.com for additional information on the sea level rise scenarios and anchialine pool maps and projections presented on pages 4-8, and contact Dr. Jamison Gove at jamison.gove@noaa.gov or visit https://www.integratedecosystemassessment.noaa.gov/regions/hawaii for additional information on the NOAA IEA.*

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References:

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