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ORIGINAL ARTICLE

The future is behind us: traditional ecological knowledge and resilience over time on Hawai‘i Island

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Abstract Local and traditional ecological knowledge (TEK) systems are thought to be particularly valuable for fostering adaptation and resilience to environmental and climate change. This paper investigates the role of TEK in adaptation to social–ecological change at the community level. It is unique because it takes a longitudinal perspective and draws on historical and contemporary data. We focus on a case study from Hawai‘i where TEK, cultural identity, and their relationships to environmental stewardship are locally seen as the basis for social resilience. We describe how coping strategies and indicators of social resilience have changed over time; the role of TEK in resilience; and the implications for climate change adaptation. Our results show the relative contributions of some strategies to cope with social–ecological change have decreased (e.g., forecasting, storage, and mobility), while others have maintained but adapted (e.g., livelihood diversification, knowledge transmission and storage, communal pooling, and cultural identity), underscoring the importance of considering multiple strategies together to promote community resilience. The article argues that understanding how people responded in the past can suggest relevant and culturally appropriate ways—through specific language, values, reference points, and indicators expressed in narratives, proverbs, and songs—of situating climate change and framing adaptation planning. This research also shows that TEK is vital for adaptation to environmental change broadly and climate change in particular, for subsistence-based, indigenous, rural communities, as well as place-based communities living in mixed economies. Thus, it is relevant for the larger Pacific Islands region and other areas that represent a continuum from rural-to-urban and traditional-to-global economies and lifeways.

Keywords Social resilience · Adaptation · Pacific Islands · Traditional ecological knowledge · Climate change

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Introduction

I ka wā ma mua, i ka wā ma hope.

This Hawaiian proverb translates to “in the time in front, in the time in back,” meaning the future is behind us, because wisdom from the past is before us.

Understanding the ways societies have responded to climate and environmental change is a critical issue worldwide (Adger et al. 2005). Local and traditional ecological knowledge systems (TEK) (Berkes 2012) are thought to be particularly valuable for fostering resilience to environmental and climate change (Gómez-Baggethun and Reyes-García 2013; Pearce et al. 2015; Nakashima et al. 2012). These customary knowledge–practice–belief

systems center on the relationships of living beings with one another and with their environment, emerge through adaptive processes, and are culturally transmitted over generations (Berkes 2012).

TEK systems can buffer against disturbances (McMillen et al. 2014) by distributing risk, facilitating learning (Turner and Berkes 2006), and promoting social cohesion (Gómez-Baggethun et al. 2012). For example, they include strategies for fostering agrobiodiversity (Thaman 2009), managing water resources (Republic of Vanuatu 2011), predicting weather (Lefale 2010), and forecasting the onset of periodic climatic events (Strauss and Orlove 2003). Such knowledge and practices are embedded in social institutions that maintain collective long-term memory of adaptations (Gómez-Baggethun et al. 2012) and reinforce the cultural values and worldviews that undergird societies.

The ability to learn from past experiences and share knowledge is critical for resilience (Adger et al. 2005) and inspiring "new and transformative futures" (Fazey et al. 2015). The concept of resilience, the capacity to absorb shocks, maintain function, self-organize, learn, and adapt (Carpenter and Brock 2008), has been broadly applied across a continuum from ecological to social systems. While we recognize ecological and social resilience are inherently interrelated, here we focus on the social characteristics of resilience to environmental and social change in order to inform a discussion of climate change adaptation. Research suggests social resilience "may be more influential than environmental resilience in determining the outcome of a collapse and recovery scenario" (Maher and Baum 2013:1470) and that the "capacities for human (rather than environmental) transformation that lie at the heard of adaptation" (Tanner et al. 2015:23). Identifying and understanding the factors that support social resilience is then paramount to planning and supporting adaptation to social–ecological change. While sociocultural systems affect adaptive capacity, they are dynamic themselves. They integrate and adapt new knowledge and practices, both from within and beyond. A community's capacity to adapt to climate change may largely be determined by the manner in which traditional and other belief systems can coexist (Murphy et al. 2015), complement, and positively influence each other. Applied at the level of a community, resilience is the "existence, development and engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability and surprise" (Magis 2010:401).

This paper is a community-centered, rather than problem-centered (cf Bennett et al. 2015), investigation. Our preliminary research in this community revealed that other drivers of change (e.g., development and socioeconomic–demographic shifts) are seen as more critical than climate change. To reflect this perspective, our research considers multiple, interacting drivers of environmental change in order to inform our discussion of climate change adaptation. This research is unique because it takes a longitudinal perspective and draws on historical and contemporary data to understand themes in the process of adaptation. We focus on a case study of Ka'ūpūlehu (North Kona District, Hawai'i Island, USA), a community that is locally recognized for its strong social resilience and Hawaiian cultural identity, despite remarkable social–ecological changes. Our goal is to contribute to evidence-based decision-making and planning processes that incorporate local perspectives and values (cf Bennett et al. 2015). We address the following questions: How have strategies to cope with environmental variability and change and indicators of social resilience adapted over time? What are the factors that allow for social resilience at the community level today? What is the role of TEK in resilience? What does this teach us about strategies for adaptation to climate change?

Background: Ka'ūpūlehu as a social–ecological system

Ka'ūpūlehu Ahupua'a (ahupua'a are traditional Hawaiian biogeographic land units) is in the North Kona District on the leeward side of Hawai'i Island (hereafter Ka'ūpūlehu) (Fig. 1). Its area of 104 km^2 extends from Hainoa, the summit of Hualālai (a dormant shield volcano), into the nearshore environment. From mid- to low elevation, about one-third of the surface area is covered by sparsely vegetated lava fields, and a notable portion of what was traditionally the agricultural zone is now Hualalai cattle ranch (28 km^2). An adjacent dryland forest restoration project maintains remnant native forest.

Ka'ūpūlehu is part of Kekaha, the traditional name for this region that receives little rainfall and has no surface waterflow. Despite the challenges of living in an environment characterized by limited farmable land, high environmental variability, volcanic eruptions, drought, tsunamis, and earthquakes, small coastal settlements were established by the mid-thirteenth century (Rieth et al. 2011). They encountered a protected bay; abundant coastal and open ocean fisheries; edible seaweeds; anchialine ponds; natural salt pans; subsurface springs; and dryland forest resources (cf Kumu Pono Associates 1998a). These attracted and sustained a population of Hawaiians (circa 1300–1800s).

Under the traditional land management system established throughout Hawai'i (circa 1400s), chiefs governed ahupua'a and headmen managed land and fishing rights for chiefs (Handy et al. 1991). Commoners had rights to access resources and cultivate within their ahupua'a of residence

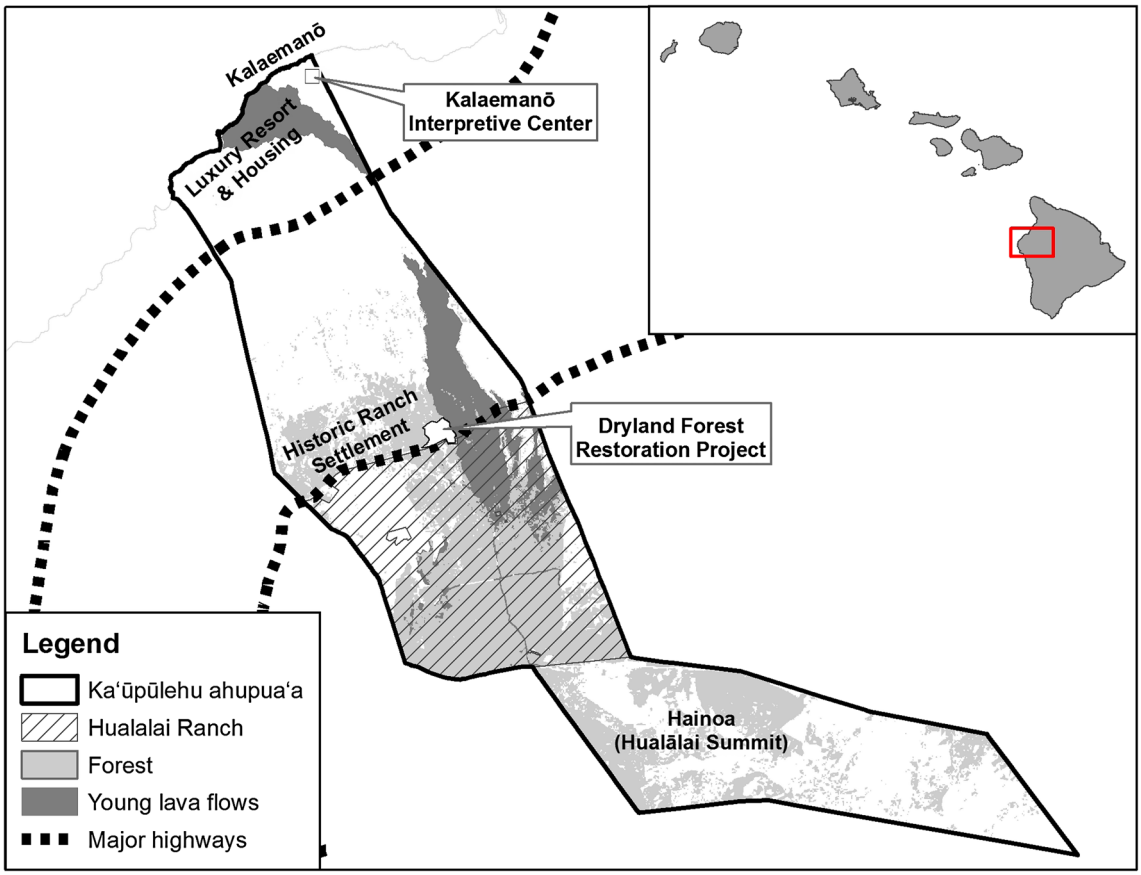

Fig. 1 Map of Ka'ūpūlehu Ahupua'a, Hawai'i Island

(Kamakau 1992). European contact (1778) eventually led to decimation of much of the Hawaiian population due to infectious disease, the abandonment of the Hawaiian religious and resource management systems, and the redistribution of lands and land rights (Bushnell 1993).

Chronic drivers of environmental change over the past two centuries are diverse (e.g., environmental, economic, climate, demographic, and political), occurring at different scales and speeds, and interacting with each other. They include introduced, invasive plants; grazing by domestic and feral ungulates; fire; and drought. Since the 1960s, significant shifts in the socioeconomic landscape have also occurred. Unlike other areas of Hawai'i Island, Ka'ūpūlehu's rugged, lava-dominated landscape, absence of streams, and scarcity of arable land kept plantations, their foreign owners, and significant shifts in the local lifeways at bay. Before the development of a luxury resort at the shoreline (1962) and the opening of a major highway (1975) the small, rural community of Ka'ūpūlehu can be described as a kīpuka (McGregor 1995), a place where Hawaiians maintained a close relationship to the land and continued cultural practices including subsistence, even though massive change was occurring all around them.

While most of Ka'ūpūlehu continues to be rural and sparsely populated because areas available for habitation are limited by lava fields and by the management of the private landowner,[1] it has changed. The historical ranch settlement at mid-elevation (Fig. 1) with about 12 dwellings continues its rural character. The newer luxury development at the shoreline with a population of about 55 (US Census Bureau 2011) and the additional temporary residents who occupy the 243 rooms at the adjacent luxury resort, built on the grounds of an historical fishing village, have a strong tourist, exclusive character.

Ka'ūpūlehu is at once a dispersed and a place-based community. Some lineal descendants (i.e., those who trace their genealogy to the pre-Contact era before 1778) still live there, while others live in neighboring ahupua'a. These core community members maintain social bonds to each other and to the 'āina (usually land but can also be ocean, literally that which feeds) by engaging with its natural–cultural resources and storied landscape. Yet, Ka'ūpūlehu

[1] Ka'ūpūlehu is owned by Kamehameha Schools (KS), the largest private landowner in Hawai'i, and the largest charitable trust in the USA (King and Roth 2006). KS was established in 1887, following the death of Princess Bernice Pauahi Bishop, the last surviving heir of Kamehameha I. All her lands were deeded to a trust that became KS.

is valued by a wider range of people who relate to it for its cultural, historical, biological, and personal significance. In this case, the "community" that participated in the research includes those who have ancestral ties to the area and those who are active in Ka'ūpūlehu's stewardship.

The pressures of growing populations (residents and tourists), intensified marine resource use, increasing drought, fires, the spread of invasive species, declines in native species, and expanding real estate development are among the most pressing concerns identified by community members. Although climate change is not a chief concern among community members at this time, it is projected to have significant effects in the future and to magnify current drivers of change. Across the Pacific Islands including Hawai'i, the trends for increased air temperatures and drought are expected to increase fire risk, threaten the viability of some narrowly distributed endemic plant species, and potentially accelerate the expansion of invasive plant species (Keener et al. 2012). The marine environment is projected to be affected by sea-level rise and coral reef bleaching, which will affect the biota that rely on those ecosystems, including people.

Methods

This research engaged a process of prior informed consent and multiple discussions about intellectual property rights and the protection of familial and cultural knowledge. We followed ethical protocols from the International Society of Ethnobiology, and we also followed cultural protocols. These included asking the ancestors for permission to proceed with the project and engaging in acts of reciprocity with participants who shared their knowledge and time. For example, we gifted tokens of appreciation such as local fruits and flowers; we contributed to community-led fieldwork projects; and we adapted and shared research findings for this community—from climate change predictions to TEK from other place-based communities. To strengthen our relationship with the community and to expand the benefits of the research more broadly, we hired local research assistants, and we built upon existing community work, research projects, and tools. We worked closely with community leaders to incorporate findings into the design of educational and monitoring tools that would both be useful in meeting local priorities as well as inform climate change adaptation planning.

One of the tools we created is a time line of adaptation for Ka'ūpūlehu. It identifies indicators of resilience and strategies for coping with environmental variability and change, and it details how these have changed over time as the social–ecological context has changed. The time line highlights the role of TEK as a critical factor that allows for social resilience today. Taking a historical perspective for understanding change over time (rather than measuring change against current or recent conditions) is often a more meaningful for indigenous and place-based communities (Turner et al. 2008). Historical time lines have been used as tools with place-based communities, for example in Alaska (Kofinas et al. 2010) and Micronesia (Gombos et al. 2013), to understand local responses to disturbances and to guide future resource management under climate change. In a theoretical context, they have also been used to retrospectively understand the role of severe drought in the collapse of social systems (Abel et al. 2006; Bunce et al. 2009).

To create the time line, we used mixed methods (interviews, focus groups, workshops, participation, and observation) and we triangulated and contextualized our findings with biological, historical, and ethnographic secondary data. We began with secondary data. Ethnographic sources include the unpublished works on the people of North Kona (Kumu Pono Associates 1998a, b, 2006); the texts of Kamakau (1992), Malo (1951), and Kelly (1996) among others, as well as Hawaiian language newspaper articles, legal documents, and journals kept by missionaries and explorers. Next, we incorporated traditional accounts with guidance from community advisors. Then, we integrated data from semi-structured interviews. Using purposeful sampling and a process of prior informed consent, we consulted 21 individuals alone and in groups. This included 15 men and 6 women, ages 25–72. Because this is a small community, participants were few, but easily identifiable. Participants were recommended by community advisors based on their in-depth and long-term relationships to Kekaha (e.g., as lineal descendants, resource managers, cultural practitioners, outreach specialists, educators, cowboys, and fishers) and because they are knowledgeable.

The interviews were exploratory and iterative. Most were conducted at participants' homes or workplaces. All were conducted in English and integrated Hawaiian words and concepts. Participants were asked about social, ecological, and meteorological changes and how people have responded. Detailed notes were taken during all interviews and returned to participants for review, corrections, and approval. Key themes, salient events, processes, and responses were incorporated into the time line. When known, the years corresponding with events were added, but when they were not well defined or known (e.g., related to traditional accounts or slow trends), they were approximated. In line with a community-based approach, community participants (including coauthor HKS) engaged in a process of multiple, collaborative reviews to determine which events to include in the time line and how to describe them. The process also helped refine, cross-check, and give depth to the content. Finally, we used an open-

source software program to integrate the text with imagery (http://hbmpweb.pbrc.hawaii.edu/kaupulehu/timeline). A version of the digital time line was adapted for children, and both versions were printed as books for the Kalaemanō Interpretive Center (Fig. 1).

Thirteenth century–1779 characterized by Polynesian settlement of the Kona coast; creation of state religion; expansion of agriculture; population increase; Kekaulike of Maui attacking the region; and Captain Cook landing in Kona.

To frame our characterization of Ka‘ūpūlehu (Table 1), we used the indicators of social resilience and the relevant strategies for coping with environmental variability and change (Agrawal 2008; Gómez-Baggethun et al. 2012; Berkes and Ross 2013). To evaluate change over time, we summarized and grouped major events from the time line into four periods.

1780–1840 characterized by influx of European explorers, American missionaries; decline in the indigenous religion and code of conduct (kapu system); introduction of grazing animals and the resulting decline in native habitats; drought; famine; epidemics; volcanic eruptions; and tsunami.

1841–1959 characterized by the institutionalization of private property in 1848; goat and cattle ranching; the illegal overthrow of the Hawaiian government and establishment as a state of the USA; the conversion from native to invasive, alien-dominated habitats; earthquake; and tsunami.

1960–present characterized by real estate and tourism development; changing sociodemographics; construction of a major highway; a renaissance of Hawaiian language and culture; further declines in native habitat due to invasive plants and animals, fire, and increasing drought; and tsunami.

To understand shifts in the relative contributions of strategies to cope with change over time, we grouped them by decreasing contribution to resilience; increasing contribution to resilience; and ongoing importance to resilience (Table 1; Fig. 2).

Results and discussion

How have strategies to cope with environmental variability and change and indicators of social resilience adapted over time?

Although forecasting, selection, storage, and mobility were critical to coping with variability in the past, their relative contributions to community resilience in Ka‘ūpūlehu have decreased over time, in large part due to market access (Table 1; Fig. 2). As other studies have found, traditional forecasting is now challenged by changing weather (Kronik and Verner 2010; Murphy et al. 2015) and phenological cycles, but in Ka‘ūpūlehu reliance upon it has also been greatly reduced with modern weather forecasts and less reliance on subsistence-based lifestyles. As is the case throughout Hawai‘i, traditional Hawaiian moon calendars are now used more for educational than prescriptive purposes; however, perspectives about the applications of this kind of TEK may be starting to change. For example, through this project, we cocreated a seasonal calendar that builds upon TEK and integrates other knowledge (http://hbmpweb.pbrc.hawaii.edu/kaupulehu/seasonal%20calendar). It includes the TEK related to forecasting (i.e., knowledge of cycles with wind, rains, currents, astronomy, and phenological cycles of plants and animals) that guided the timing of fishing, planting, harvesting, ocean travel, and relocation in the past, knowledge that is now recognized for its potential to inform an understanding of how cycles are changing and to inform the management of natural–cultural resources today.

Increased access to and reliance on markets, along with improved water catchment systems, means that the selection of crop varieties, knowledge of famine foods, and the ability to drink brackish water are no longer critical for biological survival. Seasonal mobility is no longer practiced or practical today given the sedentary lifestyle. Our findings contrast with other studies that center on rural, subsistence-based communities that have emphasized the continued importance of mobility, selection, and storage (Agrawal 2008, Gómez-Baggethun et al. 2012) for livelihoods. Market exchange is the only factor we found to have increased its contributions to community resilience over time in Ka‘ūpūlehu (Table 1; Fig. 2). Agrawal (2008) explains that market exchange-based adaptation practices can take the place of other adaptations to environmental variability. In Kekaha, nearby markets expand access to resources (e.g., dried and frozen foods); however, intense reliance on them can increase vulnerability if importation ceases. The practices, knowledge, and coping skills described above (much still held by elders) would then be critical. For example, knowledge of and experience with the selection of traditional crop varieties that were best suited to the dry climate of Ka‘ūpūlehu could inform the discussions about revitalizing local cultivation, practices that are seen as having potential to both strengthen cultural traditions and connections to the land while also bolstering food security in the face of climate change. Similarly, if traditional practices of food preservation and storage (e.g., through drying) become more common, their contributions to resilience could also increase. The trends shown in Fig. 2 are not fixed; they have the potential to change.

Table 1 Indicators of resilience and strategies to cope with environmental variability and change over time in Kaʻūpūlehu, Hawaiʻi

	13th Century – 1779	1780 -1840	1841-1959	1960-2016
Decreasing contribution to resilience				
Forecasting Meteorological and biological indicators forecast cycles	Knowledge of cycles with weather (wind, rains, currents) and astronomy indicated times for fishing, planting, harvest, ocean travel, and relocation.		Decreasing	Greatly reduced, moon calendars still used by some. Innovative seasonal calendar created that builds on TEK and integrates other knowledges.
Selection of species, varieties, settlement planning	Planting dryland taro, sweet potato, other drought-tolerant crops;		Decreasing	Very little
		Planting pumpkin and watermelon.	Decreasing	Very little
			Planting introduced fruits and vegetables.	Much less cultivation now.
	Few if any permanent residence sites near shoreline, only in uplands.			Not adaptive: areas for residences decided by landowner, including luxury development at shoreline.
Storage food, water	Dried fish and meat			Much less now
	Fishponds			
	Paʻiʻai (mashed taro)		Less common	Poi (paʻiʻai with water) is more common but spoils faster.
	Traditional vessels for water		Less common; replaced by buckets and tanks.	Water catchment tanks, bottled water.
Mobility	Seasonal movement based on precipitation and disturbance.		Declined post-land privatization (1848) and ceased (1940s).	
Increasing contribution to resilience				
Market exchange	Little to none	With ranches cashless exchanges turned into trading local resources for store goods. The introduction of goats encouraged a cash economy.	Purchasing from stores (e.g., dried goods) increasingly common. Mixed economy with market and subsistence.	Dominant market-based economy with wide access to global products (e.g., dried/frozen foods).
Consistent contribution to resilience				
Diversification subsistence strategies, livelihoods, economy	Freshwater harvesting from plants, caves, under rocks, ocean springs; consumption of brackish water.			
			Water catchment	
				Water hauling
	Diverse fishing strategies and collection of invertebrates, seaweeds, salt.			Fishing at night to protect locations from new fishers.
	Small scale polycultural cultivation			Little cultivation, but continues to buffer against hard times.
	Wild harvested forest resources			Much less, includes non-native species, especially pigs.
	Animal husbandry (pigs, fish, chicken, dogs)			Few if any pigs, sheep, goats; chickens, fish only at resort (mostly gone since 2011 tsunami).
			Goat herding thrives	
		Horses introduced	Cattle ranching	Ranching dwindling
		Commercial fish sale (following decline in indigenous religious system and introduction of capitalism)	Increased commercial sale of fish	Tourism Conservation Education/ Outreach Related to marine environment

Table 1 continued

Knowledge storage and transmission traditional and non-traditional knowledge systems	Proverbs, oral histories, place names, hula, chant, song. Lessons for surviving drought encoded.			Traditional proverbs, oral histories, place names, hula, chant, song endure. New proverbs created to reflect changed environment.
	Hawaiian is primary language.	English introduced and increasingly integrated.	After 1896 ban, Hawaiian is taught and perpetuated outside schools. Hawaiian newspapers continue to publish. English is increasingly spoken.	English is primary language, but Hawaiian is revitalized, including in some schools.
	Knowledge is protected and shared within communities, families, according to traditional protocols.		Decreased and changed due to population declines, foreign culture and politics.	Knowledge is shared with unfamiliar people and in formal settings to protect places and maintain access to resources.
			Integration of "Western" knowledge and skills through formal education with traditional knowledge.	Formal education based on "Western" knowledge and skills. Outreach/formal education programs based on traditional perspectives, knowledge, and practices.
	Traditional "ways of knowing" (e.g., proverbs, song) that encode knowledge are created and transmitted			
				Reinvigoration of traditional "ways of knowing" (e.g., proverbs) created to reflect current conditions, not just teaching of traditional wording.
Community pooling and exchange labor and resources	Cooperative labor for constructing dwellings, canoes, fishponds; cultivation; fishing.			Decreased but ongoing, often for educational purposes.
				Recent examples of pooling include repairing fishpond walls; cattle branding; restoration and conservation efforts; political/legal support.
			Goat herding	Goat hunting
			Cattle ranching, branding	
	Sharing fish through cooperative fishing, feasts.			Decreased but ongoing in some place-based families
				Cooperative fishing for scientific and educational purposes.
	Resource exchanges. Social relationships promoted food security.		Greatly declined after land privatization but continues among native families in area.	Exchange of traditional foods, other resources maintain social relationships; reinvigorated by poor economy.
People-place relationships	Completely place-based lifestyle with subsistence activities; travel on foot and canoe; ocean recreation; rituals and cultural practices.		Hunting; cowboy living; fishing; ocean transportation and recreation; rituals and cultural practices.	
				Fewer opportunities to reside and work in Kaʻūpūlehu. Maintaining relationships with place is intentional. Private ownership limits access, but relationships are maintained through oral accounts, place names, and proverbs; subsistence and other cultural practices; stewardship; and education.
Social networks and institutions	Indigenous religion is norm	Missionaries introduce, spread Christianity	Christianity is norm	
	Konohiki (traditional managers of ahupuaʻa system)		Decreased, but continued in some areas into the 20th century	
	Family institutions			
	Mauka-makai (ridge to reef) exchange networks		Expand beyond ahupuaʻa boundaries	Based on traditional families of area. Community-research-landowner partnerships; cultural-ecological conservation/restoration partnerships
Values and beliefs	Indigenous religion		Continues but declines and transformed from institutionalized to internalized beliefs and practices.	
	ʻĀina as ʻohana (land as family), Aloha ʻāina (love of the land), Mālama ʻāina (stewardship of the land), Aloha kekahi i kekahi (love one another), Take only what you need, Nature is revered, not controlled			

Table 1 continued

Cultural identity	?		Hawaiian	Hawaiian renaissance reinvigorates pride in Hawaiian identity, knowledge, practices and language.
	?		Integration with diverse cultures brought to plantations and ranches; and those who came as business people and missionaries. Cowboy culture is strong.	Hawaiian cultural identity is strongest and unifying factor.
	Not enough information to detect trend			
Positive outlook	**?**			Faith in ongoing ability to adapt as ancestors did; new generations; prayer.
Social solidarity	Chiefdom, ahupua'a, and indigenous religious systems (?)			Church
	?		Culture	
	?		Ancestry descent	
	?		Reinforced through cooperative traditional resource management (e.g., maintaining trails, fishponds) and culture-environmental education.	
	Indigenous religion			Declined but continues
Self-organizing			People signed onto the anti-annexation Petitions	
	Konohiki (Headman of an ahupua'a)		Greatly decreased	
	?		Fire fighting (place-based)	Replaced by top-down fire fighting
				Legal action for preservation, and ongoing access to land/resources.
				"Try Wait" Campaign – a community-based initiative proposing a ten year 'resting period' for nearshore marine resources. Driven by Hawaiian cultural values and customary practices.
	Resource use restrictions based on gender and status are prescribed by religious institutions of kapu system.			Changes after 1819 with decline of kapu system
Rationing	Social institutions and norms reflected a conservation ethic and water rationing; ridge to reef relationships enshrined in proverbs; moon calendars reflected sanctioned timing of harvest	Continues but likely decreased and adapted due to population declines and to foreign culture and politics.	Decline continues	
				Ban on aquarium fish collection. Culture and science-motivated marine conservation initiatives, including "Try Wait" campaign.
	Chiefdom and religious system governed. At the individual and community levels, it is unclear how leadership and governance worked.			Power of traditional priests and religious system declines.
Engaged governance and leadership			Petitions against annexation and for lands exhibit leadership and engagement with government.	
				Non-profit educational, cultural organizations; Collaborative partnerships with managers, residents, resource users, government, and conservation organizations; Cultural advisory boards consult on development and conservation.

Cells with "?" mean there is not enough information available. Blank cells mean the indicator is not present. Although examples are interrelated, for clarity we list each in one category only

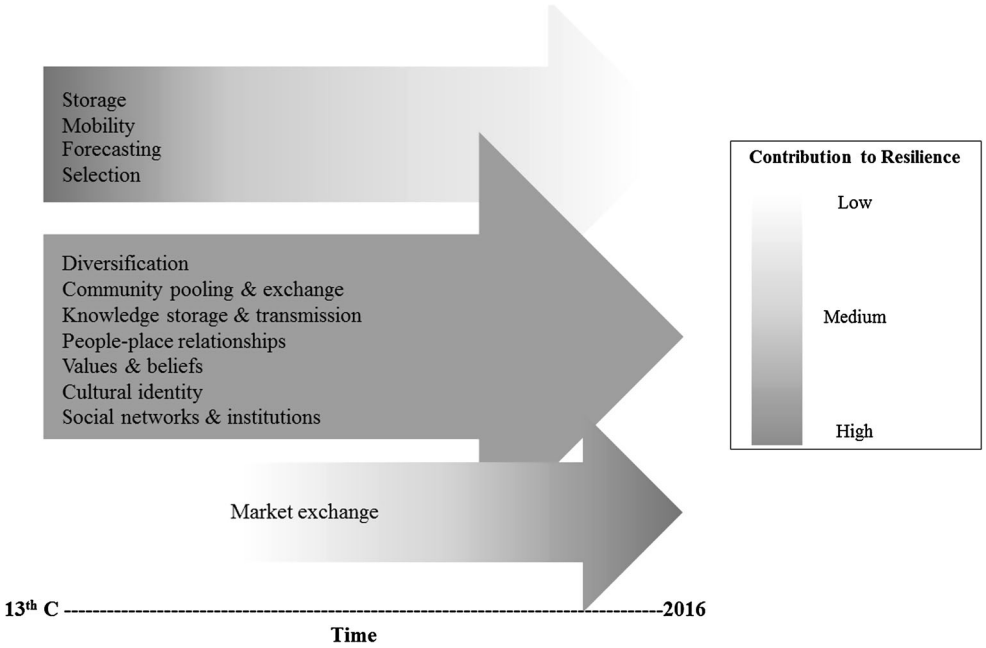

Fig. 2 Shifts in relative contributions to community resilience to environmental variability and change over time in Ka‘ūpūlehu, Hawai‘i. *Darker shading* represents a higher contribution to resilience at a given time relative to another time. *Lighter shading* represents a lower contribution to resilience. The *top arrow* shows the four strategies that have decreasing contribution to resilience over time. The *bottom arrow* shows that market exchange has had an increasing contribution to resilience over time since it became more prevalent in the 1800s. The *middle arrow* shows seven strategies/indicators that were and have maintained a high contribution to overall resilience

The importance of most coping strategies and indicators of social resilience that we identified have been maintained over time, although their nature has adapted (Table 1; Fig. 2). For example, diversification of livelihoods remains a key strategy for resilience. Although the presence of markets has meant that diverse subsistence practices (fishing, ranching, cultivation) are no longer critical for biological survival (they remain critical for cultural identity and social networks), today community members' livelihoods are based on a diversity of activities that contribute to maintaining and restoring Ka‘ūpūlehu's natural and cultural resources, including education, consulting, resource management, conservation, fishing, ranching, research, and stewardship. Tourism and construction provide other opportunities to remain in the region.

Knowledge storage and transmission

TEK is a strong factor determining how this community identifies as resilient and adaptive. The main threads in participants' conversations about environmental variability and change (past, present, and future) and how to be resilient are traditional Hawaiian knowledge, cultural identity, and their relationships to environmental stewardship, all of which are integral to TEK. Within the community itself, TEK describes practice-based knowledge of terrestrial, marine, and atmospheric systems and the associated values, beliefs, and skills to live together in the systems. Foundational concepts are rooted in traditional Hawaiian worldviews based on kin-centric ecology and reciprocal, mutually beneficial relationships among people and their environments (see Online Resource). Traditionally, these guided subsistence livelihood practices (fishing, cultivation, cattle, and gathering). Today, they also influence people's relationships through environmental stewardship, resource management, and educational activities. Participants described TEK as an embedded part of culture that continues to be transmitted within families from older to younger generations through observation and apprenticeship of subsistence and stewardship activities, and orally through narratives, proverbs, and songs. In addition, participants demonstrated, through their own work and volunteer activities, how place-based and culture-based educational settings outside of the family context are additional pathways for transmitting TEK.

Ecological, genealogical, survival, spiritual, and other knowledge has been stored and continues to be transmitted through song, chant, dance, place names, historical accounts, and proverbs (Table 1; Fig. 2). For example, proverbs encode information on the timing of seasonal plant and animal cycles, and historical accounts from Hawaiian language newspapers (circa late 1800s–early 1900s) and oral traditions convey a range of information on surviving drought, sourcing and conserving freshwater, and how to care for the land and each other (see Online

Resource). Participants described how these themes were interwoven with religious beliefs and worldviews that represent a social memory about how to endure hardship, and bonded people together through shared knowledge, practices, values, and beliefs. Shared systems of beliefs and values are critical for fostering collective action (Gómez-Baggethun et al. 2012) and social cohesion in the face of disturbance. Because these factors support social–ecological resilience broadly, they are also relevant for thinking about climate change adaptation planning in the future.

While knowledge storage and transmission continue to be an important for supporting resilience (Adger et al. 2005), the specific details of what knowledge is stored and how it is transmitted in Ka‘ūpūlehu have changed. Traditional "ways of knowing" (e.g., proverbs) are being adapted to reflect current conditions. For example, as native tree populations have decreased, today people look to widely distributed introduced species to signal the appropriate times to harvest sea urchins. Participants emphasized the importance of not getting caught up on the proverbs' words and instead focusing on the wisdom behind the words—wisdom based on observation and deep understanding. Although the literature is thick with cases documenting the loss of TEK around the world (Zent 2001; Reyes-García et al. 2010; Hanazaki et al. 2013), other research has focused on the dynamic nature of TEK systems, and astutely emphasized the larger importance of process and innovation (Thornton and Manasfi 2010) in generating, transforming, transmitting, and applying TEK (Gómez-Baggethun and Reyes-García 2013). We see this innovative, adaptive process in Ka‘ūpūlehu where knowledge transmission remains critical for social resilience.

In Kekaha, community members have adapted knowledge transmission to suit the current context where the immediate threats to resources are development and degradation. Traditional protocols for knowledge transmission required personal relationships, lengthy time commitments, and emphasized learning through doing and observing rather than direct questioning; however, participants described how, in the 1990s, these practices were adapted to include sharing beyond one's family and culture in order to protect places, practices, maintain access to resources, and recognition of rights. Personal knowledge of the locations of natural–cultural resources and family connections to them is now made public through the court system, environmental impact assessments (EIA), scientific research, and conservation work. This has affected how resources are identified as well as the assessment of potential adverse affects upon them at the Federal and State levels.

For example, in the 1990s, when a developer applied for permit to dredge the shoreline of Ka‘ūpūlehu, community members responded by establishing a legal precedent that recognizes biological resources as cultural resources of importance, making them eligible for protection (see Online Resource). This has become an essential strategy for protecting and maintaining access to resources in Hawai‘i and beyond. Adapting the way TEK is transmitted has been critical for community resilience in this place-based community, and it continues to be invoked in legal, educational, and economic contexts. Other studies show a decrease in TEK intergenerationally (Hanazaki et al. 2013), but in Ka‘ūpūlehu, TEK is being reclaimed and regenerated. This is evidenced by community leaders who are members of the younger generation.

Access to and reliance upon land and local resources for livelihoods has been identified as vital for TEK to evolve (Gómez-Baggethun and Reyes-García 2013) and as a structural condition for adaptation (Adger 2003). In this case, maintaining access to natural–cultural resources is also critical for the Hawaiian culture and resource management systems in Ka‘ūpūlehu to be resilient. To that end, some community members position TEK as an essential part of conservation, resource management, and formal education. They also suggest its potential to decrease reliance on outside markets and promote food security, themes in resilience to climate change worldwide. This points to the political nature of TEK. Traditional practices and memories (personal and collective) are invoked to maintain access to and relationships with the land (cf Brosius 2006).

Community pooling and social networks

As elsewhere in the Pacific (McMillen et al. 2014), community pooling and social networks continue to contribute to resilience in Ka‘ūpūlehu; however, they have adapted, too. Previously, these were critical for expanding the availability and diversity of food and other resources across time and space, enabling buffering against hard times when resources were less available due to drought, tsunami, or other disturbance. These exchanges also served to reinforce social networks that could be activated in other times of need. Today, access to food is less impacted by environmental disturbances due to global markets; however, people maintain social networks through exchange of plant materials for garlands and fallen hardwood for creating digging sticks, sluice gates for fishponds, outrigger canoe floats, and barkcloth beaters; and food continues to be exchanged as well. Participants explained that in the 2000s, when the national economy declined, local families that are multigenerational and multi-occupational responded by resuming resourcefulness, including cultivating the land, and exchanging upland resources (locally cultivated fruits and vegetables, locally harvested meat) and ocean

resources (locally harvested fish and salt). In the process, social connections were reinforced. Other contemporary examples of pooling include feasts for baby's first luau and graduations, which are important markers of Hawaiian identity. A woman in her late 60s described the importance of exchanges in past and suggested their relevance for the future:

> Sharing food was a living practice. It is a tradition to have neighborly sharing with each other. For example, squash, whatever you had, you shared…It was natural. That's why everyone survives. The people who share will be the foundation, the pillars.

The traditions of reciprocity and pooling of labor (physical and cognitive) have also been adapted for new concerns. This is demonstrated among community members across Kekaha who support and engage in each other's efforts to protect and maintain access to resources. Educational groups across the region benefit from these collaborations that advance TEK, support stewardship from coastal to upland habitats, and provide opportunities for exposure and access to land and resources. This is an example of pooling efforts to use and protect commonly held resources—a key factor for adaptation (Ruiz-Mallén et al. 2015). Similarly, after damaging storms and tsunami, pooled (volunteer) labor has been an important part of restoring historical fishpond walls, clearing roads, and fighting fires. Repeated exposure to disturbances and the resulting accumulation of collective memories play a vital role in this process. Participants described the resettlements and repairs after the volcanic eruption of 1800, and after the tidal waves of 1946, 1960, and 2011, experiences they see as contributing to their adaptive nature. "We're always in the condition of responding, and that is a part of resilience" (woman in her early 60s). "We're not just waiting for something to happen and then we will react" (woman in her early 40s).

A notable example of pooling knowledge and efforts is the "Try Wait" campaign, an ongoing, community-driven initiative "shaped by the observation, understanding, and wisdom of kūpuna [elders] and the kamʻāiana fishermen, families, and community of Kaʻūpūlehu" to rest the fishery for 10 years in order to "restore marine resources and ensure that traditional, subsistence, and cultural fishing practices are sustained" (KMLAC 2016). Scientific research conducted by universities and international conservation organizations complements and supplements observations based on TEK, but the drive to implement the policy comes from the community itself. This and other research from Hawaiʻi highlights that pooling and exchanging resources remain critical to indigenous communities for maintaining social networks and institutions even in mixed economies (e.g., Vaughan and Vitousek 2013). As community resilience depends on social networks based on reciprocity and trust (Adger 2003; Adger et al. 2005), existing social networks should then be incorporated into climate change adaptation planning. These networks could effectively disseminate and promote the exchange of information and resources needed to respond to increasing drought, fire, and severity of storms.

People–place relationships, beliefs, and cultural identity—as expressed through cultural values, knowledge, and practices—were expressed by participants as the foundation for community resilience, both past and present. These are also integral parts of TEK systems. Values determine priorities for preservation, and these underlie perspectives of what the goals of adaptation should be (O'Brien and Wolf 2010). In the past, subsistence-based livelihoods and place of residence would have been central to people–place relationships. Today, relationships are reinforced and maintained through livelihoods outside of subsistence activities and beyond one's residence—for example, through stewardship and educational activities. At the same time, community members emphasize the importance of subsistence practices and being on the land and in the sea as ways to continue engaging in reciprocal relationships with each other and with their environment.

For many participants, there is no separation between the people and their place, as expressed by one woman in her early 40s:

> We are the stories. We are this land. We are the kama [native people], the kupa [citizens], we are the ʻopihi [limpets that are native species and prized traditional foods] of Kaʻūpūlehu. That has been so solidifying for us to say 'this is our home' …

One woman in her early 60s described how developers attempted to create conflict within the community, but did not succeed. "Never did the families waver from the form of aloha kekahi i kekahi [love one another], and that's a form of resiliency…we have not lost the aloha for one another and for the lands. That's always where we operate from." Other values such as: ʻāina as ʻohana, aloha ʻāina, and mālama ʻāina relate to loving and caring for the land as a family member remain foundational to local worldviews today (Table 1).

We did not have sufficient information from the early periods to detect trends over time for other factors reported to increase resilience, including engaged governance and leadership, positive outlook, social solidarity, and capacity to self-organize (Table 1); however, participants strongly expressed those factors as critical for maintaining cultural identity and social resilience today. Participants also demonstrate leadership and self-organization through initiating and engaging with culturally based organizations that perpetuate Hawaiian practices; and through playing advisory roles in real estate development and community-

based conservation with international nonprofit organizations. Participants maintain elements of traditional resource management and stewardship through those channels.

Despite the challenges the community faces, participants generally have a positive outlook for the future. A woman in her late 60s shared her vision for the areas in Kekaha where her family has lived for generations:

> Our ancestors had a system that will make us thrive. We have our characteristics and our system to show what this land has. We're not lost… The ground hasn't forgotten. We'll see the younger generations coming back to produce this system with the knowledge they've had…Because they have the book learning, they know the short cuts.

Her thoughts represent how TEK and other knowledge systems coexist and complement each other, a factor that strongly determines a community's capacity to adapt to climate change (Murphy et al. 2015).

What is the role of TEK in resilience?

More than anything, participants' discussions about coping with changes in the past and the present and adapting to environmental and climate change in the future centered on the importance of the preservation and stewardship of traditional and local knowledge and practices (cf Murphy et al. 2015; Ruiz-Mallén et al. 2015). Participants see cultural identity as the basis for communal pooling and exchange, people–place relationships, social networks and institutions, values and beliefs, and social solidarity. With the understanding that TEK is part of a system where knowledge is nested in practices, institutions, and worldviews (Berkes 2012), TEK is a manifestation of cultural identity, and its maintenance and evolution play strong roles in social resilience. As seen in Ka'ūpūlehu, TEK promotes innovation and flexibility; facilitates and structures knowledge storage and transmission; and serves as a collective resource for shaping future adaptations. As illustrated in the use of TEK in courtcases to protect places and resources from development, TEK is also a tool for political positioning to maintain access to, and ensure management of resources that allows for their perpetuity.

Part of this place-based identity and the role of TEK in Kekaha includes being adaptive or nimble. When reflecting on the collaborative process of creating the time line of adaptation and the conversations it inspired, a lineal descendant explained:

> During our time here, we've seen ali'i [royalty] come and go, we've seen an island nation born and die before its time. We've seen elected appointed officials come and go. We've seen our occupations change from fisher folk, gardeners, goat herders, cattle herders, to independent consultants, but we remain.
>
> During those times of all those generations that we're talking about, we've had to respond to a variety of circumstances, the political circumstances, the economic circumstances, the philosophical and religious circumstances, from one generation to the next, the occupational circumstances that we discussed as well, and I think if we looked at the compressed timeline, over which we have moved from being the … people that we were [upon first arrival in Hawai'i], to the citizens of the 21st century that we are, there's been some degree of nimbleness in our families and our people's adaptation to the changes around them. Some of them are fundamental and have been occurring over time as long as we've been on the land, whether it be to tsunami, whether it be in terms of big surf events that might be seasonal, volcanic events, times of drought, wide sweeping wild fires. Here we remain. We've been able to adapt to the conditions of the day, and here we stay.

Over time, repeatedly responding to environmental variability (e.g., drought), unpredictability (e.g., tsunami), and change (e.g., conversion to nonnative habitats; political and economic transformations) contributed to adaptive capacity of this community. Zooming out to look over the past two centuries, repeated use of coping mechanisms can be seen as steps toward developing a way of being in the world that is innovative and nimble. Are those not at the heart of what it means to be adaptive? We believe the experiences, knowledge, and approach to dealing with social–ecological change in Kekaha are strong assets that can inform climate change adaptation planning.

Conclusions: lessons for adaptation to climate change?

Through describing shifts in diverse coping strategies over time, we have shown that they work in concert and that they change in content, practice, and in their relative contributions to resilience over time. Specific strategies both adapt and contribute differently to resilience over time as the social–ecological context changes. Importantly, the trends illustrated in Table 1 are not fixed. Some strategies that are shown to have decreased contributions (e.g., knowledge of forecasting or selecting of traditional crop varieties) may play important roles in

future adaptation planning as they contribute to cultural identity, place attachment, and food security. Some of the evidence in Table 1 has clearer applications for climate change adaptation (TEK associated with weather and phenological cycles; selection of locally adapted crop varieties), while other evidence exemplifies community resilience more broadly (e.g., pooling, exchange, and social networks). Thus, in the context of planning for climate change adaptation, we argue it is important to consider multiple strategies together as a means to promote community resilience. Our research shows that TEK is vital for adaptation in a place-based community living in a mixed economy. Thus, the findings are relevant for the larger Pacific Islands region and other areas that represent a continuum from rural-to-urban and traditional-to-global economies and lifeways (cf Pearce et al. 2015).

Finally, we want to emphasize the participatory nature of our work, which represents research for change rather than research about change (Fazey et al. 2015). Through providing evidence of coping in the past and descriptions of how those strategies themselves adapted, we hope this work can guide research and contribute to decision-making processes that incorporate local perspectives, knowledge, and values. This study from Hawai‘i complements the growing body of work that deepens our understanding of TEK as an element of adaptive capacity and indicator of resilience in the Pacific (McMillen et al. 2014; Nunn et al. 2016), in the Arctic (e.g., Pearce et al. 2015; Berkes and Jolly 2001), and worldwide (Nakashima et al. 2012). Our findings underscore the need for continued research on the role of TEK in adaptation across a range of cultural and geographic settings that are variously affected by environmental and climate change among other socioeconomic changes. How are communities, across urban–rural and coastal–montane, independent–colonial–postcolonial gradients adapting TEK to promote community resilience, especially in light of future climate change projections? Answering that question requires longitudinal, in-depth, comparative studies and it requires community-based approaches that are designed to respond to community priorities (cf Keeney 1992). These approaches require investing additional effort and time, but are necessary to design meaningful adaptation strategies that can address local priorities and well-being.

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