

Using social network analysis to assess communications and develop networking tools among climate change professionals across the Pacific Islands region



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ABSTRACT

The climate science community of professionals in Hawai'i and the U.S.-Affiliated Pacific Islands is a vast interdisciplinary and international group, with the potential for spatial and sectoral barriers to communication and collaboration. This study sought to (1) assess the structural nature and expanse of climate-based communication between professionals across sectors in the Pacific Islands region; (2) identify key regional hubs and isolated groups both sectorally and spatially; and, (3) create a set of place-based tools that would increase and facilitate the connectedness of climate change resources (human, research, and adaptation). Social network analysis was chosen as a versatile method to assess the network and create free tools to facilitate future collaborations among stakeholders across spatial and disciplinary boundaries. Given the complexities of the large network, an innovative approach was used for data collection, blending a nominalist (researcher-created list of names) and realist (participant-created list in open fields) survey construction. Participants indicated frequency of communication to capture both active coworkers and periodic collaborators, consistent with the realities of the network. Survey participation was not confidential and was used to create region-wide and sub-regional maps that can be used by stakeholders to increase connectedness, in line with use-inspired science. Study results reveal a simultaneously diffuse and strongly connected network, with no isolated spatial or sectoral groups. The most central network members are those with a strong networking component to their professions. Gaps in communication were also revealed. Future research should evaluate the use and long term benefits of the created networking tools, and the specific nature of local and international communications within each sub-network.

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Uso del análisis de redes sociales para evaluar las comunicaciones y desarrollar herramientas de networking entre los profesionales del cambio climático en la región de las Islas del Pacífico

RESUMEN

La comunidad de profesionales del cambio climático en Hawai y las islas asociadas del Pacífico (Estados Unidos) es un grupo internacional amplio e interdisciplinario, que se enfrenta a posibles barreras espaciales y sectoriales de comunicación y colaboración. Este estudio trata de (1) evaluar la naturaleza estructural y la extensión de las comunicaciones centradas en el clima entre los profesionales de la región de las Islas del Pacífico; (2) identificar los ejes clave y los grupos aislados, tanto sectorial como

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espacialmente; y (3) crear un conjunto de herramientas locales que aumentarían y facilitarían la conexión entre los recursos contra el cambio climático (humanos, de investigación y de adaptación). El análisis de redes sociales se eligió como un método versátil para evaluar la red y crear herramientas gratuitas para facilitar futuras colaboraciones entre las partes interesadas. Dada la complejidad de la red, se siguió un enfoque innovador para la recolección de datos, combinando una estrategia nominalista (una lista de nombres creada por el investigador) y realista (una lista creada por los participantes en campos abiertos) en el diseño de la encuesta. Los participantes indicaron la frecuencia de comunicación para diferenciar a los compañeros de trabajo activos de los colaboradores periódicos, de acuerdo con la naturaleza de la red. La participación en la encuesta no fue confidencial y se utilizó para crear mapas de carácter regional y sub-regional que pudiesen ser utilizados por las partes interesadas para aumentar la conexión. Los resultados muestran una red difusa y fuertemente conectada, sin grupos aislados espacial o sectorialmente. Los más centrales fueron aquellos con un componente de networking importante en su ejercicio profesional. También se identificaron problemas de comunicación. Las investigaciones futuras deberían evaluar el uso y los beneficios a largo plazo de las herramientas de networking diseñadas, así como las subredes locales e internacionales específicas.

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Introduction

Communication among diverse environmental and climate science professionals (e.g., researchers, knowledge producers, and decision-makers) is complex. It is characterized by ongoing introduction of new information, reintroduction of previously established knowledge, and reconsideration of inputs and outcomes from the perspectives of multiple disciplines and sectors (Bidwell, Dietz, & Scavia, 2013; Frank, Maroulis, Belman, & Kaplowitz, 2011). Climate science communications in the Pacific Islands region adds spatial distances and international complexities to these interdisciplinary challenges. The Pacific Ocean covers one-third of the earth's surface, bordered by the west coast of the United States, the east coast of Japan, as far south as Antarctica and as far north as Alaska. The focal region in this paper includes Hawai'i and the U.S.-Affiliated Pacific Islands (USAPI): Federated States of Micronesia (FSM), American Sāmoa, Guam, Palau, Republic of the Marshall Islands (RMI), and Commonwealth of the Northern Mariana Islands (CNMI) (see Fig. 1).

The Pacific Islands region is largely composed of small, developing states that are resource poor in terms of human, infrastructure, land, economic, and political resources. The populations are small; land is scarce; modern (especially Westernized) infrastructure and development remain sparse; economies are small; and political power on a global scale is limited (Burns, 2003). Additionally, because of the large distances between islands and states, the region is home to many populated areas that are extremely remote with no or limited air travel, and very limited sea travel. This could potentially lead to a professional network featuring both homophily and segregation, with isolated spatial or disciplinary clusters that are not well integrated with the rest of the network (Bojanowski & Corten, 2014). However, spatial dispersion does not necessarily lead to sparse network ties (Doreian & Conti, 2012; Sailer & McCulloh, 2012), especially when there exists a tradition of mobility and long-distance ties (Viry, 2012), as in the Pacific.

Despite these resource limitations, there are many ways in which the region is at the forefront of climate change research and adaptation (Keener, Marra, Finucane, Spooner, & Smith, 2012). Many low-lying islands face the threat of future uninhabitability due to sea-level rise, other climatic changes, and associated socio-economic changes (Wong et al., 2014). Species and ecosystems that are highly integrated with indigenous ways of life are at risk of extinction (e.g., Lazrus, 2009). Coral bleaching, ocean acidification, erosion, and other threats to near-shore environments pose a direct risk to the livelihoods of coastal communities (Keener et al., 2012). Many of these risks and threats have already been made apparent by ocean, island, and weather changes over the past few decades.

In response, many Pacific Island communities have become leaders in research, education, advocacy, and adaptation (Farbotko & McGregor, 2010; Parks & Roberts, 2006).

The Pacific Regional Integrated Sciences and Assessments (Pacific RISA) program conducts interdisciplinary and international climate research to support local communities in the Pacific Islands region. Research and outputs are designed to meet targeted community needs for local projects and decision-making. The current study was developed by the Pacific RISA in response to a repeatedly stated need for tools to increase and facilitate the connectedness of climate change resources (human, research, and adaptation), as well as an assessment of the current extent to which Pacific Island climate change professionals are able to effectively communicate climate science across countries within Hawai'i and the USAPI.

As the number of organizations, international groups, academics, and governments devoting time and resources to facilitate climate adaptation-related research in the Pacific Islands region grows, both stakeholders and funders need better methods of communicating across diverse sectors and island settings about new and existing projects. Funding agencies are also interested in quantifying and increasing the strength of regional collaborations and reducing project and outreach redundancies (UNISDR & UNDP, 2012). To address these questions, the Pacific RISA developed this study utilizing innovative network analysis methodology and application specifically to: (1) assess the structural nature and expanse of climate-based communication between professionals across sectors in the Pacific Islands region; (2) identify key regional hubs and isolated groups both sectorally and spatially; and, (3) create a set of place-based tools that would increase and facilitate the connectedness of climate change resources (human, research, and adaptation). This study was reviewed and approved by the Institutional Review Board at the East-West Center in Honolulu, HI.

Professional communications

The definitions of "climate change professional" and "climate change communication" were carefully constructed to fit the reality of the network (Emirbayer & Goodwin, 1994). Active climate change professionals include not only scientists and researchers, but also natural resource managers, teachers, activists, and private sector professionals whose primary roles overlap with climate change science (Pike, 2010; Prell, Hubacek, Quinn, & Reed, 2008). Additionally, the professionals in many extremely remote areas communicate seasonally or annually or even less frequently with professionals from other islands, often through regional workshops or conferences. Online and phone communication, newsletters,

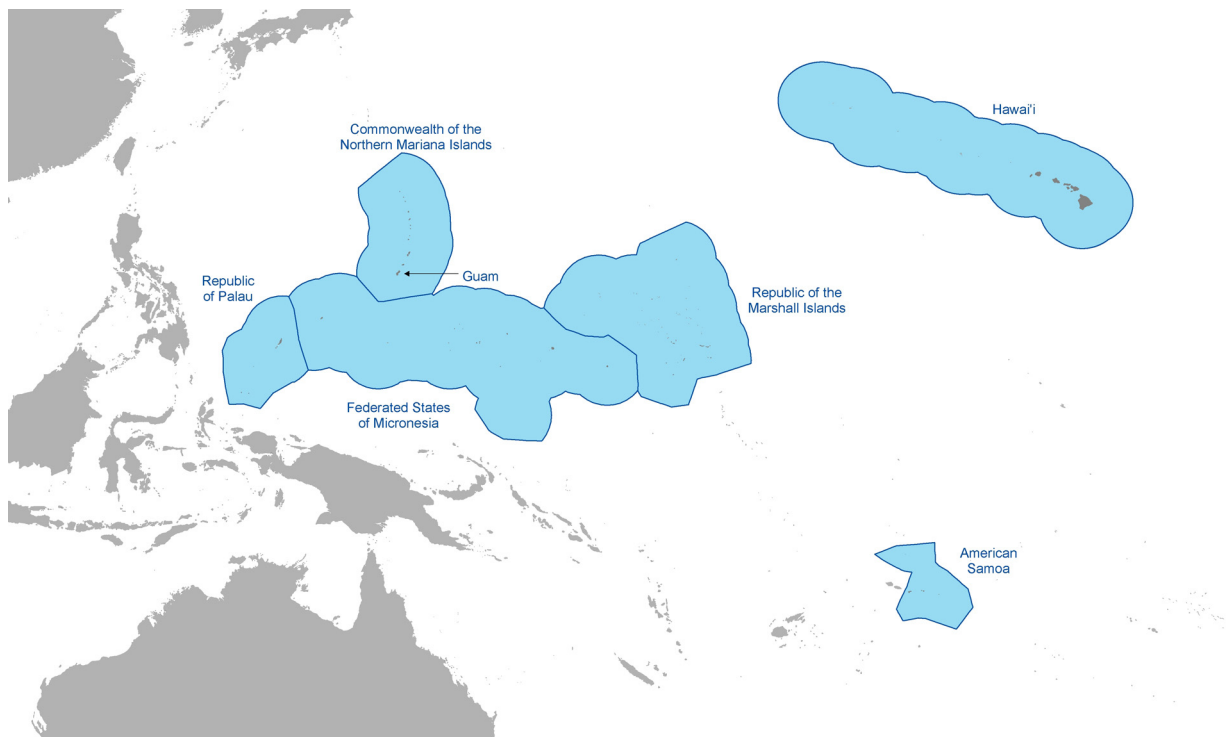


Fig. 1. Map of the Pacific Islands region (East-West Center, 2012). The focal subregion includes Hawai'i and the U.S.-Affiliated Pacific (USAPI): Federated States of Micronesia (FSM), American Sāmoa, Guam, Palau, Republic of the Marshall Islands (RMI), and Commonwealth of the Northern Mariana Islands (CNMI).

listservs, social media, and other remote and/or indirect avenues are also common and necessary in a multi-island network, and are extremely valuable tools for information sharing (Morales, Borondo, Losada, & Benito, 2014). As such, the definitions constructed for the sake of defining the network are:

Climate change professional: All professionals or community members who actively participate in research, planning, management, policy, or other activities related to weather and climate, ocean, environment, and natural systems affected by weather and climate events.

Communication: Emails, phone calls, face-to-face conversations, meetings, and other forms of dialog.

Innovative applications in network analysis

Since the purpose of this research included assessment, analysis, and the development of applied tools for use in the focal region, an innovative method was required. Due to its unique ability to statistically and graphically express patterns of connection in complex systems, social network analysis (SNA) was identified as an appropriate method to assess connectedness and to develop tools to facilitate future collaborations (Moreno, 1953; Scott, 2000; Wasserman & Faust, 1994). SNA has been used to assess information and resource exchange in rural settings in which factors other than spatial proximity may influence network centrality (Caudell, Rotolo, & Grima, 2015). Exploring multidisciplinary interactions across the complex systems with SNA can provide insight into the nature and impacts of information sharing and collaboration on the decisions, activities, and outcomes of professionals who work with the natural environment (Bodin & Prell, 2011).

Bounding the network (defining network membership) was a highly complicated issue due to the nebulous nature of international collaborations and sometimes high turnover rate for many positions across the region. Current collaborations are not necessarily indicative of past relationships and vice versa. Furthermore,

Pacific collaborations extend past the USAPI borders and so there must be a survey mechanism to capture these broader Pacific and global connections for an accurate (if cumbersome) reflection of actual communications.

Even within the focal region, the preliminary list of potential participants included 1359 people. Taking a nominalist approach to bounding the network, with researchers listing all identified professionals in the survey for participants to review (Lauman, Marsden, & Prensky, 1989; Marsden, 1990), would create an unwieldy document that no one could expect to complete within a reasonable timeframe. However, using a realist approach, with participants listing strongest professional connections in open fields (ibid), would certainly lead to a disjointed map with major gaps and isolates, given the infrequency and multiple modalities of communication inherent in the network. Finally, mapping apparent connections via documented co-attendance at conferences, co-membership in listservs or organizations, or co-authorships (e.g., Boyack, Klavans, & Borner, 2005; Harris, Luke, Burke, & Mueller, 2008) could isolate professionals who communicate in-person rather than through documented connections, or cause other falsely inflated or underreported connections in the resulting map. These deficiencies would cause difficulties measuring centrality, network density, and cross-spatial/sectoral connections (Leavitt, 1951; Wasserman & Faust, 1994).

To address these issues, the survey was designed using a blended approach. A limit was applied of up to 20 climate change professionals from each of the seven sub-regions in the USAPI were selected based on apparent high activity within multiple communication networks to be listed by name in the survey along with communication frequency. An additional open field section was included in which participants could list other connections they considered to be noteworthy within textboxes of assigned frequency. By structuring the survey to begin with a selection of active professionals listed by country, we sought to spur participants to consider international as well as local connections when entering names in the

open fields. In this way, each participant created a personal network (McCarty, 2002) with a realist approach to be attached to the created preferential attachment network with a nominalist approach.

Participation in this network analysis was not confidential. This is fairly unique to this study, but was essential to the later development of useful network tools. The Pacific RISA's core mission is to drive use-inspired science within the region. Indeed, one major factor contributing to participant support for the study was the creation of network tools that would be useful across the region, as opposed to "research for the sake of research." All participants consented within the survey to have their names and professions listed in the resultant network tools. The lack of confidentiality was highlighted in the survey tool, and participants were informed about the intended use of their names and network connections to develop tools that would be disseminated for free for the purpose of supporting the development of future communications and collaborations. The study team spent 6 months attempting to contact non-participants who were listed in open fields to attain permission to list their names as well. Among those for whom current contact information was available, all but three consented to have their names listed in the tools (two of whom had since changed professions, and one who had moved to another country). The remaining network members identified in the study are listed to the best of our abilities according to their profession and sub-region alone.

The direction of communications, i.e., information suppliers and receivers, was beyond the scope of the study because as collaborative relationships progress through a series of activities or interventions, each actor will play different directional roles at different times – at times supplying, receiving, or co-creating knowledge (Harary & Schwenk, 1974; Hawe, Shiell, & Riley, 2009; Iacobucci & Wasserman, 1990). Similarly, the type of communication between professionals was not captured by the survey; however, the frequency of communications was (weekly, monthly, seasonally, yearly, at least once ever). In this way, periodic sharing of information at regional gatherings was more likely to be captured, but some level of differentiation would exist between those who have active ongoing communication versus those who periodically communicate or collaborate.

Multiple centrality measures are used to reflect the weighted (frequency) nature of communications in the network (Opsahl, Agnessens, & Skvoretz, 2010). The connections, or edges, between network members, or nodes, can be explored graphically and statistically with SNA. A path length is the most direct route for information to be passed between any pair of nodes through connections between. The average path length is the mean of all path lengths between all node pairs. The geodesic distance is the shortest path length in the network (Brandes, 2001; Wasserman & Faust, 1994). Degree centrality calculations report the number of connections regardless of frequency. Eigenvector centrality uses an algorithm incorporating the centrality of adjacent nodes; a professional in an extremely remote location who periodically connects with very central figures will therefore have a higher eigenvector centrality than a professional only connected to peripheral figures. Closeness centrality is the reciprocal of farness, or the sum of the shortest distance to all other nodes. Closeness reflects the number of "hops" one must make to give or receive information to all other network members (Brandes, 2001).

Materials and methods

Participants

Participant recruitment also proceeded using a blended approach (Scott, 2000). Employees of agencies that explicitly work with climate change in the focal region were identified. In

addition, potential participants were identified by compiling names, professions, and contact information from a variety of professional, academic, scientific, environmental, community, and political participant and attendee lists, mailing lists, and listservs that are related to research, planning, management, policy, or other activities related to weather and climate, ocean, environment, and natural systems affected by weather and climate events (Prell, Reed, & Hubacek, 2011). Because "climate change professionals" in the region come from a variety of disciplines and backgrounds and their primary employment may be entirely unrelated to fields traditionally associated with climate change, recorded involvement in professional climate activities was used to identify "climate change professionals" (Krause, 2012). A high-level of recorded involvement was used to identify the professionals that would be listed in the survey within each sub-region.

Though this process was largely a success in identifying a large number of people from multiple backgrounds who are involved in climate change in the region, there were inherent difficulties and unexpected problems that resulted from this approach. Contact information for many was not current or proved impossible to find for some (137, or about 10%, of the 1359 identified professionals had no contact information or invitation emails were kicked back because they were no longer in service). Nearly a thousand others did not respond in any way to email invitations (though we cannot be sure if the contact information was not current, or if the lead author's lack of direct network connection to these professionals led them to dismiss the invitation as irrelevant or email spam).

Despite these recruitment issues, 331 climate change professionals participated in the network survey. Including participants, those listed on the survey, and the additional people listed in the open fields, the Full Network created by this study included 967 people from across the Pacific and world (see Table 1). As is apparent in Table 1, the Full Network contains proportionally more members from outside of the focal region than participants themselves. This was in part due to the launch of the surveys at regional conferences, but is also reflective of the many people in the mainland United States and across the greater Pacific Islands region who actively collaborate with, generate research for, or utilize research generated within the focal Hawai'i-USAPI region. However, while it is necessary to reflect these international connections as an inherent aspect of the network, the study also wanted to create a narrower Core Network focusing on professionals from the USAPI and their direct connections. The Core Network has a more proportionally similar construction to the participant list.

Data collection

The survey was administered online through surveygizmo.com; email invitations were sent to the preliminary list of 1359 climate change professionals. In the email invitation, participants were encouraged to forward the invitation to others in their office or network to ensure maximum reach. Additionally, paper copies of the survey were distributed at three regional conferences, including the survey launch at the Pacific Islands Regional Climate Assessment (PIRCA) forum in Honolulu, HI in December, 2012; the Pacific Islands Climate Services Forum (PICSF) in Suva, Fiji in January, 2013; and the Pacific Risk Management 'Ohana (PRiMO) annual meeting in Honolulu, HI in March, 2013. Only a few paper surveys were completed; a vast majority were completed online. Distribution at the regional conferences primarily served to increase awareness and support for the survey and study. Up to four follow-up email invitations were sent approximately once a month during the data collection period. Additionally, the survey invitations were distributed via snowballing email chains and through partner listservs and social media. The multiple invitation modalities makes

Table 1

Survey participants, Full Network members (including all non-participants who were listed in survey open fields by participants), and Core Network members (including only network members with two degrees centrality or greater, and those with a direct connection to network members in the focal region) by sub-region *n* (%).

Sub-region	<i>n</i> (% of total) survey participants	<i>n</i> (% of total) Full Network members	<i>n</i> (% of total) Core Network members
Hawai'i	137 (41%)	278 (29%)	177 (39%)
Federated States of Micronesia	39 (12%)	91 (9%)	52 (12%)
American Sāmoa	21 (6%)	54 (6%)	33 (7%)
Guam	21 (6%)	48 (5%)	28 (6%)
Palau	16 (5%)	42 (4%)	33 (7%)
Republic of the Marshall Islands	20 (6%)	41 (4%)	31 (7%)
Commonwealth of the Northern Mariana Islands	17 (5%)	39 (4%)	28 (6%)
Total Hawai'i USAPI focal region	279 (84%)	593 (61%)	382 (85%)
Other Pacific Islands	33 (10%)	193 (20%)	34 (8%)
Mainland United States	21 (6%)	139 (14%)	29 (6%)
Australia/New Zealand	3 (1%)	24 (2%)	4 (1%)
Other international	3 (1%)	18 (2%)	3 (1%)
Total	331 (100%)	967 (100%)	452 (100%)

calculating an exact response rate impossible. The survey was closed in May, 2013.

Tools development and dissemination

In addition to conducting a baseline assessment of the current level of network connectedness across the region, a primary purpose of this study was to create free tools for use by climate change professionals in the region to facilitate future collaborations. This would require locating both professional and spatial connections in the region (Adams, Faust, & Lovasi, 2012; Daraganova et al., 2012; Doreian & Conti, 2012; Hipp, Faris, & Boessen, 2012; Cardazone, Sy, Chik, & Corlew, 2014). Network maps for the full region, core region, and each sub-region were created using Gephi software, an open-source network analysis and visualization software (Bastian, Heymann, & Jacomy, 2009).

The nodes in all maps below are sized according to eigenvector centrality; the higher the centrality, the larger the node. Thicker edges denote more frequent communications. The layout of the maps was constructed using Force Atlas 2 layout algorithm in Gephi. All centrality measures reported below were calculated using Gephi unless explicitly stated otherwise.

The tools were launched in January, 2014 on the Pacific RISA website, with free low to high-resolution images available for download through the Pacific RISA Flickr account (<https://www.flickr.com/photos/pacificrisa/>). Throughout the study period, participants, conference attendees (see "Data Collection" section, above), and other interested parties signed up to be notified by email when the tools became available. Additional publicity for the network tools release continued through February, 2014 via the Pacific RISA mailing list, partner agency mailing lists, and through Pacific RISA and partner agency social media. This wide range of publicity reached thousands of people. Through Pacific RISA's facebook page alone, over 2000 people were notified of the tool release due to the many "shares" and post "likes." Google analytics for the network analysis tools pages showed 641 page views between February 1, 2014 and April 14, 2014, with pageviews averaging 1–6 min per visit (note: this does not include Flickr views or downloads, the analytics of which are not available).

Results

Pacific Islands region: both highly connected and diffuse

Despite the inherent barriers to communication in the region discussed in the "Introduction" and "Materials and Methods" sections, study results indicate a high degree of connectedness across

the sub-regions and across professional clusters. The number of participants from each sub-region varied greatly (see Table 1), but no sub-region within the focal region was isolated or disconnected from the others. In fact, a process of systematically removing hubs to determine the existence of bridges to isolated clusters showed that nearly half of all network members had to be removed to produce any isolated spatially or sectorally defined groups. No meaningful bridges existed, and no sub-region was in danger of being cut off from the larger climate change professional community in the region. Within the Full Network, the spectrum of degree centrality, eigenvector centrality, and closeness centrality scores (Brandes, 2001) across the sub-regions are all comparable (see Table 2). Despite the variety of communication contexts apparent across the region, the only apparent difference in communication rate had to do with number of actors but not with situational constraints (Webster, Freeman, & Aufderberg, 2001).

An excellent example of the consistently high connectivity across sub-regions despite vastly different social and communication contexts is the comparison between Hawai'i and Palau. Hawai'i professionals make up more than 28% of the Full Network members (*n* = 278). Palau professionals make up under 5% of the Full Network (*n* = 42). Hawai'i is "rich" in terms of human, economic, political, development, and research resources, whereas Palau is a comparatively small, remote, and sparsely populated developing state. Despite these contextual differences, measures of centrality in Hawai'i are only reasonably higher than Palau. There are apparent centrality differences; in the Full Network, the Palauan professionals with the highest degree centrality and lowest closeness centrality are less central than the fifth most central Hawaiian professional. It is surprising, however, that Palauan professionals are so central within this wide network given the contextual barriers to connectedness across the region.

It should be noted that the limitations in data collection have created limitations in results interpretation. The comparison of sub-regional measures of centrality as well as assessment of cross-regional connections have strong usefulness in this project's goals of assessing the structure of connections and identifying isolated groups. However, statistical measures of the network, including the centrality measures, have limited usefulness as standalone data. For example, despite the high degree of connectedness across sub-regions, the Full Network density is relatively low (0.019). The largest geodesic distance between any pair of nodes was 7; the average path length between any two pair of nodes was 3.25; there were 918,754 shortest paths (distance of 1) between node pairs in the network (Brandes, 2001; Wasserman & Faust, 1994). The seeming paradox of high connectedness but low density is likely a result of the mixed survey methodology. The nominalist portion captured strong connections across the sub-regions,

Table 2

Degree centrality, eigenvector centrality, and closeness centrality of the five most central people in the Full Network and from each sub-region.

Country	Degree centrality	Eigenvector centrality	Closeness centrality
Full Network	Deanna Spooner (218) Maxine Burkett (199) Reggie White (193) Fran Castro (182) Peter Houk (182)	Maxine Burkett (1) Peter Houk (0.997) Raymond Tanabe (0.976) Reggie White (0.972) Laura Biggs (0.969)	Deanna Spooner (2.03) Maxine Burkett (2.05) Reggie White (2.07) Raymond Tanabe (2.08) John Marra (2.11)
Hawai'i	Deanna Spooner (218) Maxine Burkett (199) Raymond Tanabe (176) Bill Ward (164) John Marra (163)	Maxine Burkett (1) Raymond Tanabe (0.976) Bill Ward (0.957) Deanna Spooner (0.779) John Marra (0.730)	Deanna Spooner (2.03) Maxine Burkett (2.05) Raymond Tanabe (2.08) John Marra (2.11) Chip Fletcher (2.15)
Federated States of Micronesia	Ricky Carl (172) Douglas Kusto (114) Curtis Graham (110) Simpson Abraham (104) Johannes Berdon (95)	Ricky Carl (0.958) Curtis Graham (0.680) Douglas Kusto (0.673) Simpson Abraham (0.653) Johannes Berdon (0.562)	Ricky Carl (2.17) Andrew R. Yatilman (2.33) Johannes Berdon (2.35) Douglas Kusto (2.36) Wisney Nakayama (2.37)
American Sāmoa	Hans Malala (158) Douglas Fenner (115) Lelei Peau (112) Tepa Suaesi (110) Christianera Tuitele (101)	Hans Malala (0.943) Lelei Peau (0.679) Abe Utu Malae (0.631) Christianera Tuitele (0.618) Douglas Fenner (0.610)	Hans Malala (2.20) Fatima Sauafea-Le'au (2.27) Douglas Fenner (2.28) Tepa Suaesi (2.36) Lelei Peau (2.36)
Guam	Peter Houk (182) Laura Biggs (170) Trina Leberer (151) Chip Guard (149) Mark Lander (123)	Peter Houk (0.997) Laura Biggs (0.969) Chip Guard (0.730) Trina Liberer (0.716) John Calvo (0.689)	Peter Houk (2.13) Laura Biggs (2.17) Chip Guard (2.21) Trina Liberer (2.22) Mark Lander (2.30)
Palau	Sebastian R. Marino (154) Yimnang Golbuu (109) Maria Ngemaes (95) Carol Emaurois (88) Wayne Andrew (86)	Sebastian R. Marino (0.935) Yimnang Golbuu (0.584) Maria Ngemaes (0.578) Carol Emaurois (0.513) Wayne Andrew (0.496)	Sebastian R. Marino (2.19) Carol Emaurois (2.33) Maria Ngemaes (2.34) Wayne Andrew (2.34) Yimnang Golbuu (2.35)
Republic of the Marshall Islands	Reggie White (193) Candice M. Guavis (162) Emma Kabua (157) Olai Uludong (92) Mark Stege (91)	Reggie White (0.972) Candice M. Guavis (0.942) Emma Kabua (0.927) Mark Stege (0.589) Olai Uludong (0.570)	Reggie White (2.07) Candice M. Guavis (2.20) Emma Kabua (2.20) Olai Uludong (2.31) Dean Jacobson (2.35)
Commonwealth of the Northern Mariana Islands	Fran Castro (182) Jose M. Kaipat (105) Dana Okano (90) Steve McKagan (89) Greg Moretti (82)	Fran Castro (0.927) Jose M. Kaipat (0.674) Dana Okano (0.546) Greg Moretti (0.511) Steve McKagan (0.509)	Fran Castro (2.14) Jose M. Kaipat (2.38) Dana Okano (2.39) Steve McKagan (2.42) Michael Tenorio (2.42)

while the open fields better captured the scope of membership. Only about a third of network members were survey participants, which likely led to a high degree of false negative edges (Prell et al., 2008; Wang, Shi, McFarland, & Leskovec, 2012). Many connections may exist in reality between professionals who were listed in the open fields but who did not themselves participate in the study to list their connections. Network density on its own is therefore not a strong measure of connectedness for this innovative mixed data collection process. Multiple centrality measures (eigenvector, closeness centrality, and degree centrality) were chosen for use in this study precisely because the recorded network is inherently diffuse (Opsahl et al., 2010).

This is not to say that the discussed communication barriers have no practical impact on communications in this extremely vast network. We were informed during the study that a number of people in the participant list (including several who were selected to be named in the survey) had passed away in the months or even years preceding the study. It should be noted that before the deceased persons were removed from the survey, multiple participants had noted them as active contacts. When communications occur via distance communications (mailing lists, etc.) or periodic conference attendance, some time can pass before one becomes aware that communication has ceased. An unexpected finding of this study was that there is no systematic mechanism for spreading news of death, promotions, retirement, or turnover across disciplines, agencies, or countries. A close colleague of the lead author heard of one participant's death during the study period; however despite

near-daily communication on other professional topics, this news was not relayed for 3 months.

Network tools capture connectedness across and within the region

Network map tools were created to explore connections graphically. In addition to being identified by location, all network members were sorted into 20 professional sectors to facilitate use of the created network tools as a search instrument for potential collaborations. Professional identifiers were problematic among participants and non-participants alike. Another unexpected finding of the study is that most if not all "climate change professionals" wear multiple hats. To the best of our ability (sometimes including extensive conversations with the participants themselves), a "primary" professional category was ascribed. However, it should be noted that the professional title or category of all network members should be considered non-exhaustive of the diversity of work they actually do.

Because of the large size of the Full and Core Networks (967 and 452 members, respectively), they are cumbersome for use in exploring personal connections and identifying potential collaborators for future projects. To address this issue, sub-regional maps were created focusing on Hawai'i and each of the USAPI. Each sub-regional map focused narrowly on members from that sub-region and those directly connected to them. With far fewer members in each sub-regional map, the nodes appear larger and connections are easier to explore. Two maps were created for each region,

partitioned (colored) by spatial location and by primary professional sector respectively. Included in this paper are representative examples from Hawai'i, American Sāmoa, and Commonwealth of the Northern Mariana Islands.

Professionals can use the sub-region map tools to search out new connections by sector or location. For example, “Pua” from Hawai'i is interested in working collaboratively with Palauan conservation professionals (see Fig. 2). She may either search the Palau Sectoral map in which participants are colored according to their professional sector (left) to identify professionals who work in conservation-related fields, or she may search the Palau Location map in which participants are colored according to their location. Because Pua is from Hawai'i, she will search the light blue nodes (Hawaiian professionals) for names of colleagues who may be able to provide networking opportunities in Palau.

Full Network

The Full and Core Networks are useful for exploring region-wide patterns of connection among professions and sub-regions. The Full Network map includes all participants and all climate change professionals who were entered into open fields (see Fig. 3). This map and the accompanying centrality data (see Table 2) capture connections to the wider Pacific Islands region and to the world.

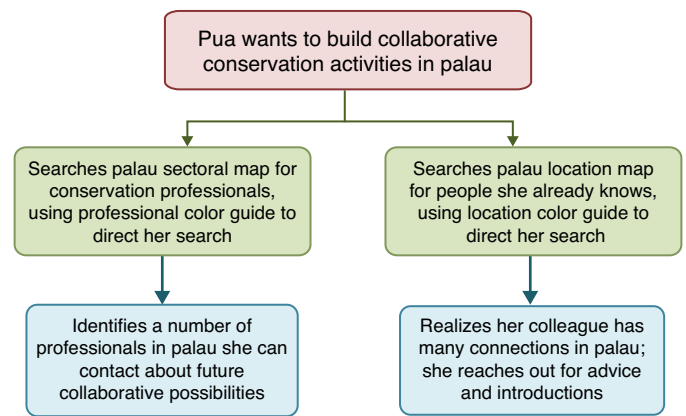


Fig. 2. Flowchart for using the network tools to develop collaborations.

The names listed on the survey were bounded to the focal region (Hawai'i and the USAPI) and participants were largely recruited from this area. However, professionals who work with/within the focal region but are based beyond its borders were allowed to join as participants. The Full Network therefore also includes member

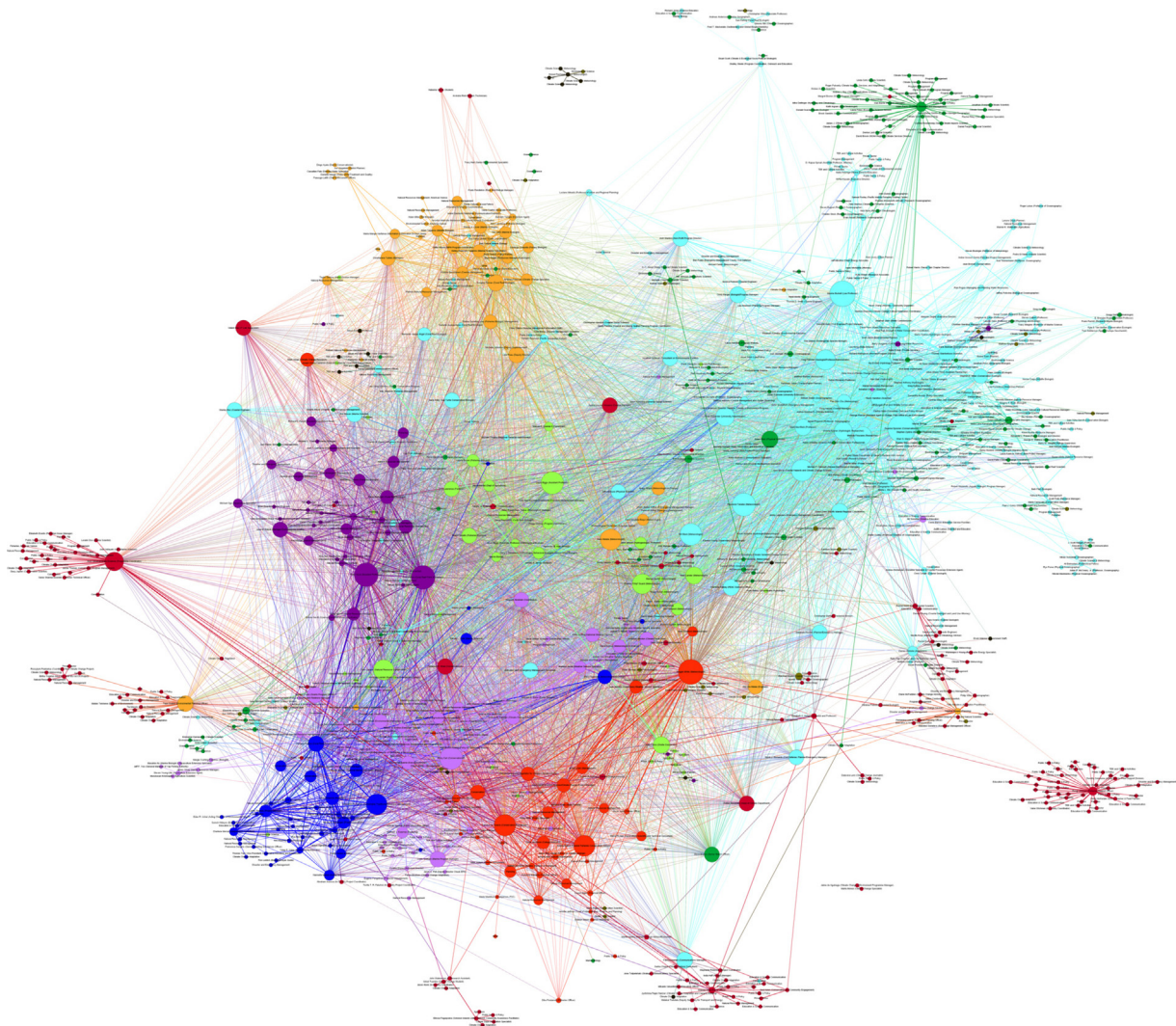


Fig. 3. Full Network map, partitioned by region: Hawai'i (light blue); Federated States of Micronesia (light purple); American Sāmoa (orange); Guam (light green); Palau (dark blue); Republic of the Marshall Islands (red); Commonwealth of the Northern Mariana Islands (purple); mainland United States (dark green); other Pacific Islands (dark red); Australia/New Zealand (brown); other international (black).

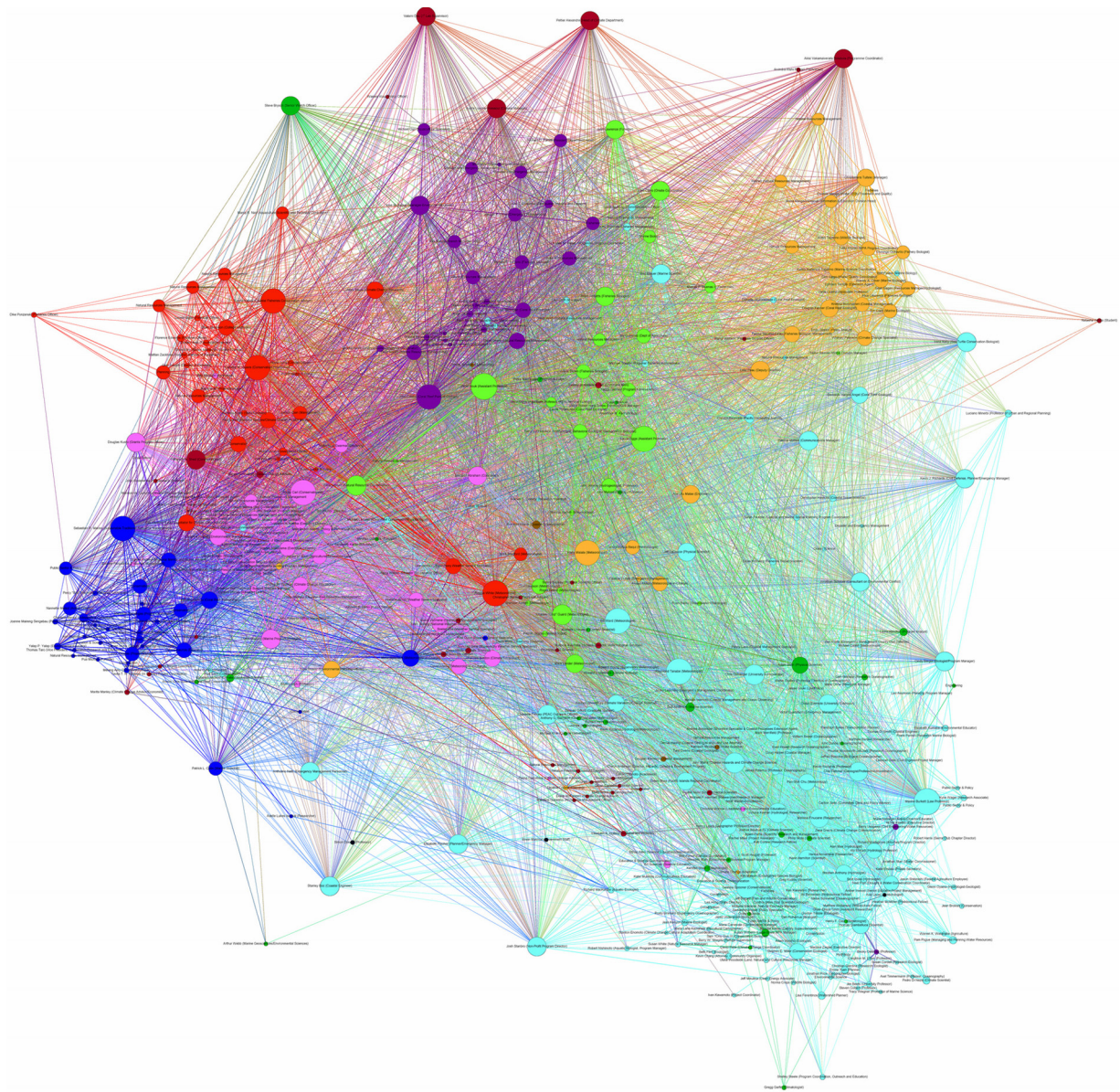


Fig. 4. Core Network map, partitioned by region: Hawai'i (light blue); Federated States of Micronesia (light purple); American Samoa (orange); Guam (light green); Palau (dark blue); Republic of the Marshall Islands (red); Commonwealth of the Northern Mariana Islands (purple); mainland United States (dark green); other Pacific Islands (dark red); Australia/New Zealand (brown); other international (black).

clusters from sub-regions outside of the focal area (e.g., the dark red clusters of other Pacific Island members to the left, right, and bottom of the map, and the dark green cluster of mainland United States members at the top right of the map). In each case the central node in the cluster is connected directly to members of the focal region, but is also well-connected to contexts outside of the focal region. Note also that the Full Network map includes two disconnected components (top center and lower right); this was a result of forum attendees who were new to the network desiring to participate in the study. These disconnected components are reflective of the nebulous structure of the network, in which new members are constantly being introduced from all over the Pacific and globe.

Core Network

To further explore Hawai'i and the USAPI, a Core Network map was created by removing (a) those outside the focal region who are not directly connected to a member of the focal region, and

(b) those with a degree centrality of less than 2. Again, lower degree centrality does not necessarily reflect a network member's lack of connectedness, but rather indicates that person was a non-participant in the survey who was important enough to the network to be listed by name by survey participants. While direction was not captured by the data collection methods, no participants were excluded by these criteria; non-participants who were noted by three or more participants were also not excluded. The resultant Core Network is denser and focuses more precisely on the standards of cross-island communication and collaboration within the focal region (see Fig. 4).

Similarly to the Full Network map above, the Core Network map reveals sub-regional clusters that are nevertheless highly connected to other regional clusters. The high level of overlap among these spatial partitions graphically supports the strong degree of regional cohesion, and more specifically the absolute lack of sub-regional isolation regardless of actual geographic distances between any two of these sub-regions.

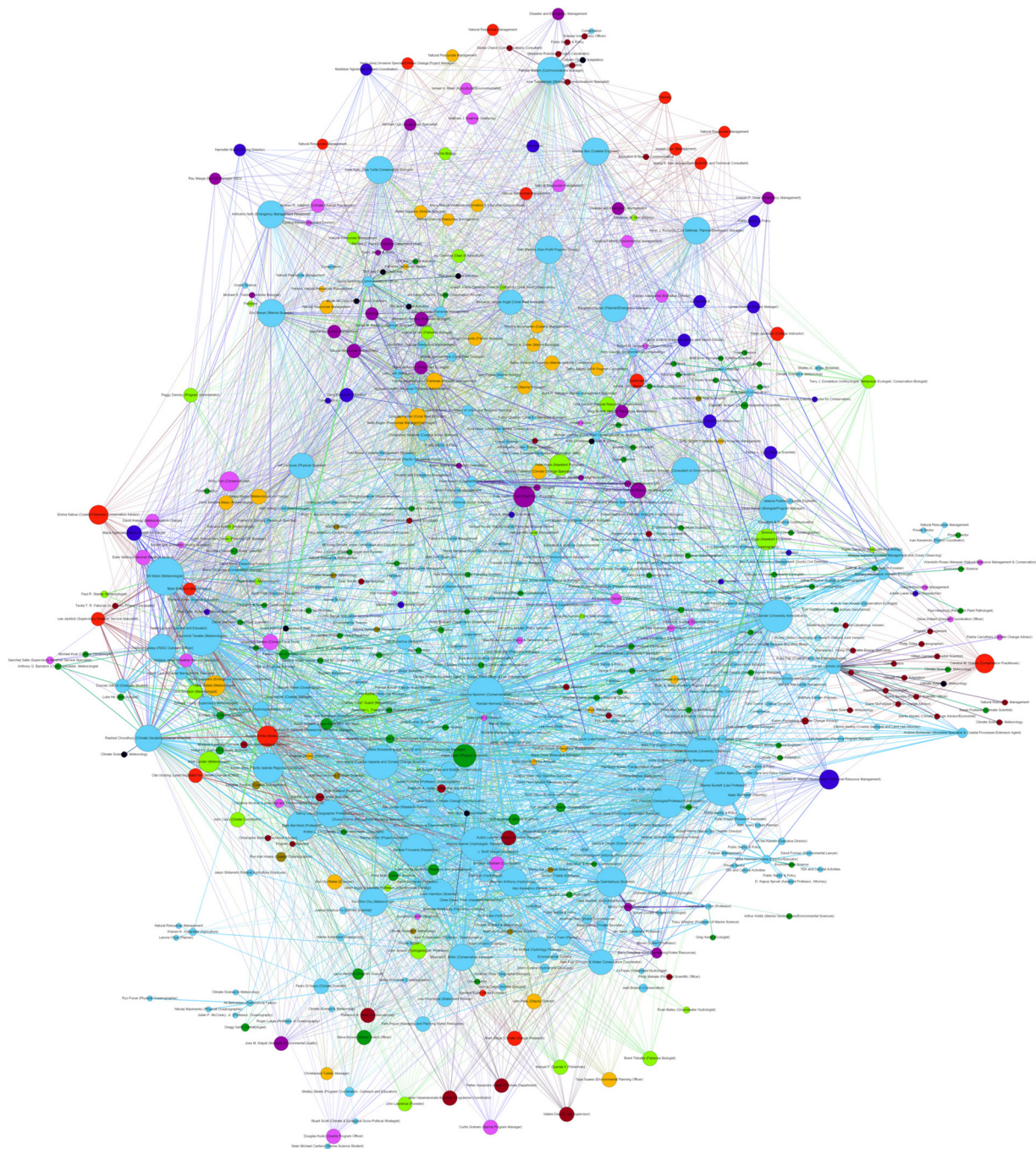


Fig. 5. Hawai'i Network map, partitioned by region: Hawai'i (light blue); Federated States of Micronesia (light purple); American Samoa (orange); Guam (light green); Palau (dark blue); Republic of the Marshall Islands (red); Commonwealth of the Northern Mariana Islands (purple); mainland United States (dark green); other Pacific Islands (dark red); Australia/New Zealand (brown); other international (black).

Hawai'i

The Hawai'i sub-regional network ($n=571$) is by far the largest in the region. Two hundred seventy-eight of the total 967 climate changes professionals identified in this study are based in Hawai'i. Of all areas in the focal region, Hawai'i has by far the largest population and the greatest amount of economic and scientific resources available for climate change related research and activities. Many professionals based in Hawai'i conduct active research across the Pacific Islands region. It is therefore not surprising that the Hawai'i sub-regional map partitioned by spatial location reveals a densely connected map with many international professions

scattered throughout and closely connected to the professionals based in Hawai'i (Fig. 5).

The Hawai'i map tool partitioned by professional sector reveals major clusters from Climate Sciences and Meteorology (bright red) and Marine Biology (blue), which are well-connected to other sectors. There are no apparent professional clusters that are isolated from other professional sectors. This reveals a strong interdisciplinary network of communication. Two of the most connected network hubs are in Conservation, olive green, and Public Sector and Policy, tan. These specific individuals have jobs which require and facilitate communications and collaborations internationally

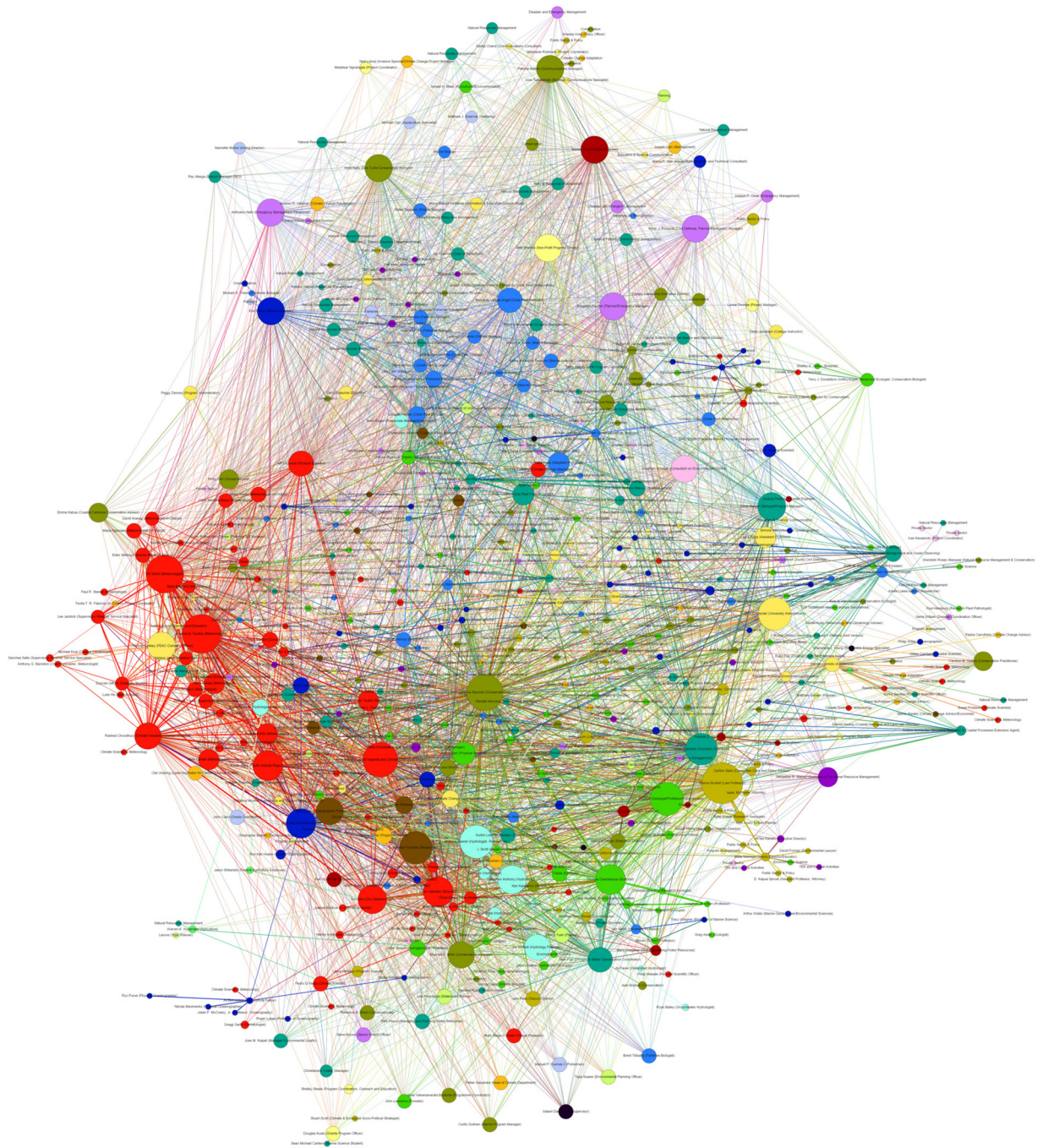


Fig. 6. Hawai'i Network map, partitioned by professional sector: Engineering (dark red); climate science and meteorology (bright red); climate change adaptation (orange); education and science communication (yellow-orange); program management (yellow); public sector and policy (tan); social science (brown); conservation (olive green); planning (yellow-green); agriculture (light green); environmental science (kelly green); natural resources management (blue-green); marine biology (blue); ocean science (dark blue); fisheries (blue-gray); hydrology (light blue); disaster and emergency management (light purple); traditional ecological knowledge and cultural activities (purple); private sector (pink); other (black).

and across professional sectors. Both of these professionals work in a capacity that requires a high degree of professional networking within their sub-region as well as internationally. Referring back to Table 2, it is important to note that these are the two most central people in the entire network, positions well supported by their professions (Fig. 6).

American Sāmoa

The American Sāmoa network map includes 304 members (55 from American Sāmoa, and 249 who have direct connections to people from American Sāmoa). The first network map tool (see

Fig. 7) is partitioned according to spatial location of each network member; the second network map tool (see Fig. 8) is comprised of the same shape and structure of the first, but can be used to explore cross-disciplinary connections, clusters, and isolates. The American Sāmoa network, like many other sub-regional networks in the focal region, has a large bright-red cluster denoting "Climate Science & Meteorology." This is unsurprising in the Pacific because of the active networking done by meteorologists and climate scientists (such as a monthly international conference call with the Pacific ENSO Applications Climate [PEAC] Center). Additionally, this map shows a large cluster of closely related disciplines such as

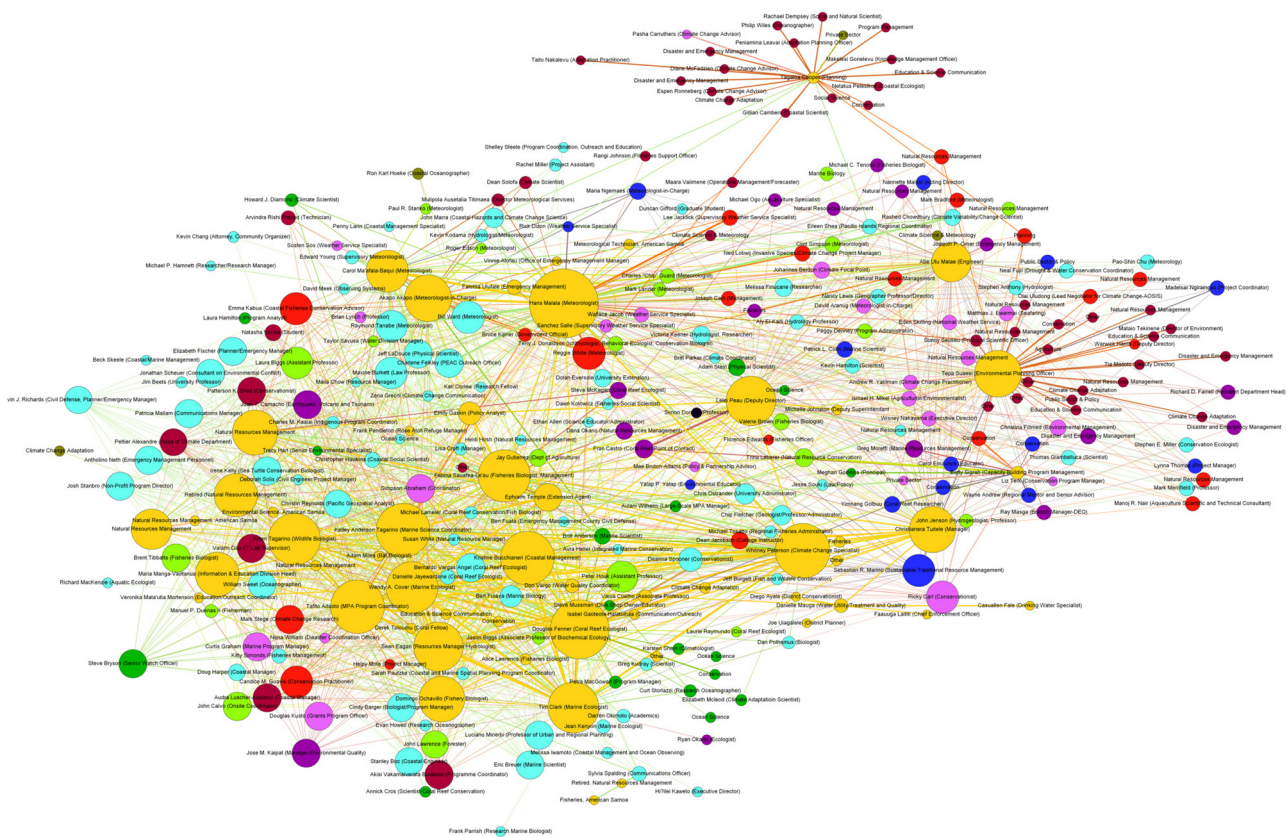


Fig. 7. American Samoa Network map, partitioned by region: Hawai'i (light blue); Federated States of Micronesia (light purple); American Samoa (orange); Guam (light green); Palau (dark blue); Republic of the Marshall Islands (red); Commonwealth of the Northern Mariana Islands (purple); mainland United States (dark green); other Pacific Islands (dark red); Australia/New Zealand (brown); other international (black).

Marine Biology, Ocean Science, Fisheries, and Natural Resource Management. The sectoral map therefore reflects reality, as American Samoa is home to the National Marine Sanctuary of American Samoa. A great deal of resources and professions are connected to the ocean and near-shore environments in American Samoa in conjunction to the work done by the sanctuary and sister agencies.

Commonwealth of the Northern Mariana Islands

CNMI is one of the least populated sub-regions, with a total population of 53,883. Survey participants included 17 people from CNMI; survey respondents identified a total of 39 climate change professionals in CNMI (see Fig. 9). Again, it is not surprising that the study yielded so few participants and the identification of so few professionals. What is interesting is that this very small sub-regional network is so connected internationally. The sub-regional network map includes the 39 professionals from CNMI identified in the study, as well as 206 from other countries to whom they are directly connected.

The web tools developed for each sub-region include a centrality table corresponding to the sub-regional network. The Full Network and Core Network centrality table include centrality measures based on region-wide connectedness; each sub-regional centrality table reports the ten most connected members of that sub-region. Members who are well connected locally but less connected internationally will be well represented within the sub-regional network tools. CNMI is unique among the sub-regional networks in this study in that one of the most connected professionals does not live in CNMI (see Table 3). Peter Houk is currently based in Guam, but was recently based in Saipan and continues his high degree of connectivity through a Saipan-based non-profit organization. For this reason, the centrality table tool for CNMI includes the 11 rather than 10 most central professionals. While it is an exception that this one hub is based in another country, it is very common in the Pacific Islands region for networks to extend internationally due to out-of-country job transfers. The potential power of the fluid network membership is revealed with

Table 3
Sub-regional centrality table for Commonwealth of the Northern Mariana Islands.

Country	Degree centrality	Eigenvector centrality	Closeness centrality
Commonwealth of the Northern Mariana Islands	Fran Castro (182)	Peter Houk (1)	Fran Castro (1.28)
	Peter Houk (182)	Fran Castro (0.969)	Peter Houk (1.29)
	Jose M. Kaipat (105)	Steve McKagan (0.685)	Jose M. Kaipat (1.65)
	Dana Okano (90)	Dana Okano (0.669)	Dana Okano (1.68)
	Steve McKagan (89)	Greg Moretti (0.649)	Steve McKagan (1.68)
	Greg Moretti (82)	Michael C. Tenorio (0.618)	Greg Moretti (1.71)
	Michael C. Tenorio (75)	Jose M. Kaipat (0.585)	Michael C. Tenorio (1.74)
	Joaquin P. Omar (66)	Joaquin P. Omar (0.573)	Ray Masga (1.83)
	Richard D. Farrell (55)	Ray Masga (0.537)	Richard D. Farrell (1.84)
	Ray Masga (55)	Richard D. Farrell (0.521)	Joaquin P. Omar (1.84)

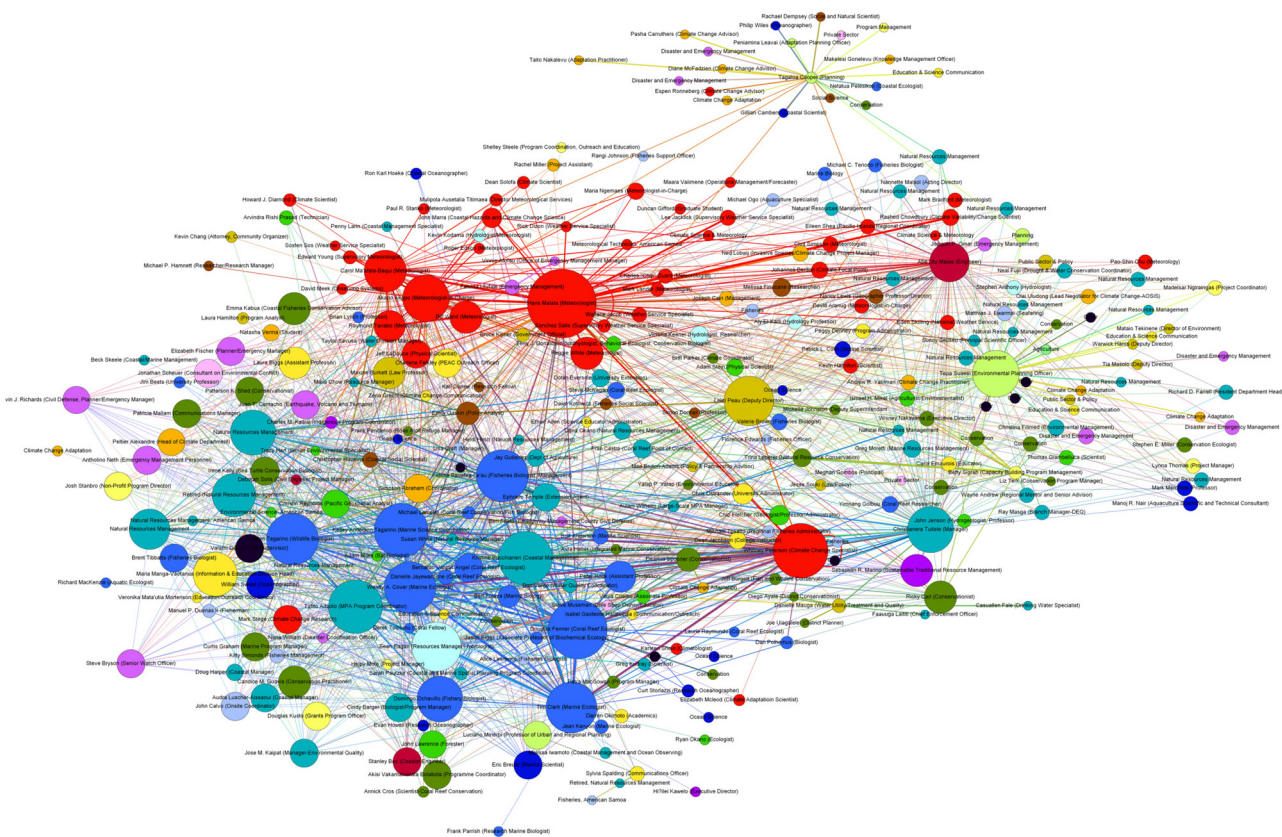


Fig. 8. American Samoa Network map, partitioned by professional sector: Engineering (dark red); climate science and meteorology (bright red); climate change adaptation (orange); education and science communication (yellow-orange); program management (yellow); public sector and policy (tan); social science (brown); conservation (olive green); planning (yellow-green); agriculture (light green); environmental science (kelly green); natural resources management (blue-green); marine biology (blue); ocean science (dark blue); fisheries (blue-gray); hydrology (light blue); disaster and emergency management (light purple); traditional ecological knowledge and cultural activities (purple); private sector (pink); other (black).

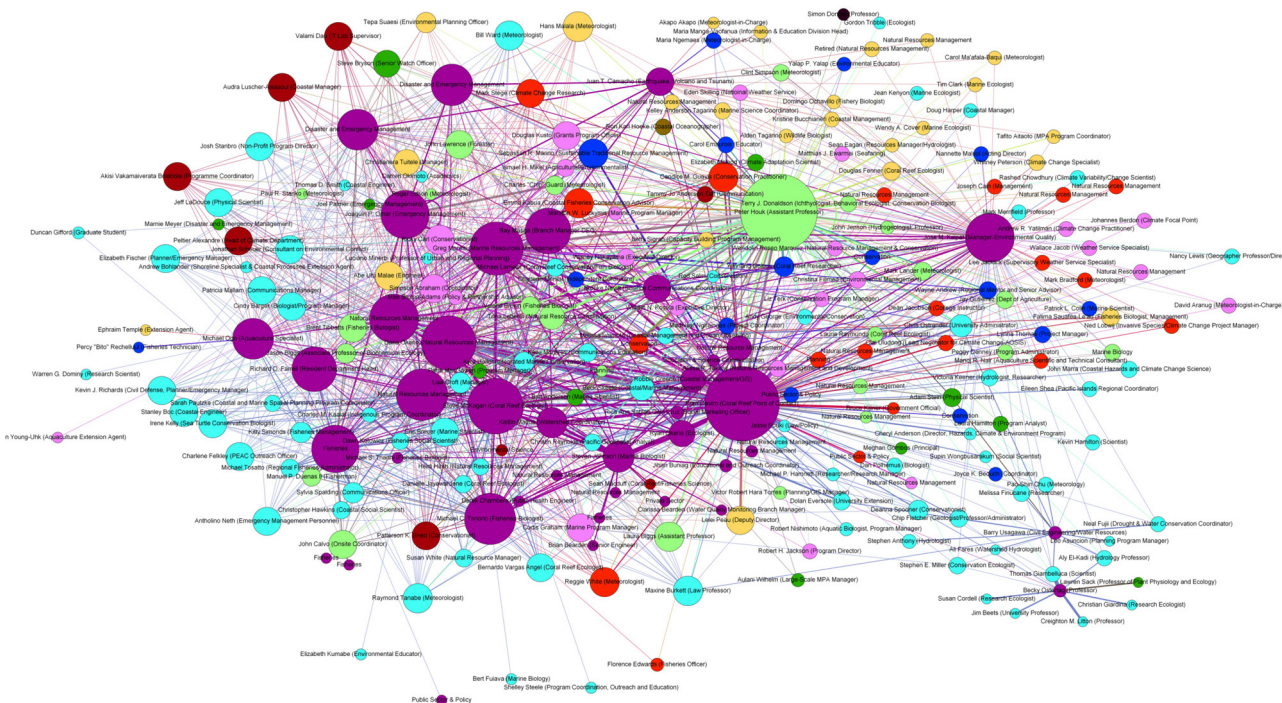


Fig. 9. Commonwealth of the Northern Mariana Islands Network map, partitioned by region: Hawai'i (light blue); Federated States of Micronesia (light purple); American Samoa (orange); Guam (light green); Palau (dark blue); Republic of the Marshall Islands (red); Commonwealth of the Northern Mariana Islands (purple); mainland United States (dark green); other Pacific Islands (dark red); Australia/New Zealand (brown); other international (black).

Houk maintaining his hub status (at least for a time) after his move.

Conclusions

This study sought to quantify the strength of regional collaborations, and to develop tools to increase future communications and collaborations across the region. Specifically, this study set out to (1) assess the structural nature and expanse of climate-based communication; (2) identify hubs and isolated groups sectorally and spatially; and, (3) create place-based tools to facilitate connectedness of climate change resources.

The experimental survey methodology used a blended approach to collect data on network communications in a very large and nebulous network. The result was the creation of a preferential attachment network that nevertheless included 600 more network members than participants and 800 more than were listed on the original survey. Though such a network cannot be considered exhaustive, it does provide a solid foundation on which future research can be constructed to further explore sub-regional networks and track the actual flow of information from one region to another or one profession to another.

The methods used in this study were innovative, using a blended approach to maximize the scope and comprehensiveness of this large and dynamic network. By using a combination of nominalist and realist approaches in data collection, participants were able to reflect the strength of their “local” (spatial and professional) network as well as the cross-regional and professional connections that are inherent in this multi-country network of climate change professionals. Furthermore the lack of confidentiality of the network study created a unique opportunity to develop tools to facilitate future collaborations. This lack of confidentiality actually appears to have increased participant support for the study, as participants joined the study with the understanding that results would be used to actively support professionals across the region.

The findings of this network support the existence strong spatial and professional connections in Hawai’i and the USAPI. No sub-region was in danger of isolation even with a theoretical loss of up to half of the network’s members. Professional sectors are perhaps in even less danger of isolation due to the nature of professionals in the region holding multiple positions and/or wearing many hats within a single position. Because of their limitations, the professional network mapping tools cannot be used to construct hard and fast conclusions about the nature of information sharing or collaborations in the region. However, despite these limitations, very interesting patterns emerge, such as sub-region specific clusters of marine biologists and natural resource managers in American Samoa. There are also strong ties across spatial and professional boundaries, for example, of the meteorological and climate services across the entire region and to different professions within each sub-network. Future studies may further explore the extent to which regional meteorological services in other states or global regions are integrated into the interdisciplinary climate change networks, to compare the activities of this network to other contexts.

Additionally, the two most central network members in the Full Network, Core Network, and Hawai’i Sub-Regional Network work in professions (conservation and policy, respectively) that support and require a strong emphasis on local and international professional networking among climate change professionals in diverse fields. Both are based in Hawai’i and therefore have access to human, economic, political, and infrastructure resources that support their networking positions. Though no region or profession is in danger of isolation, the strength of the connectedness of these two professionals should be considered. When feasible,

organizations may find benefit from promoting such positions to increase their interdisciplinary and international reach, thereby strengthening potential project outcomes. When spatial or resource barriers make this infeasible, organizations can instead seek to promote collaborations with professionals who already have this reach. Future research can assess the benefits and potentials associated with hiring and/or collaborating with climate change professionals whose positions include networking components.

Despite the high level of connection across regions and professions, the study did inadvertently reveal a gap in communications. The high turnover rate and the standard for wearing multiple professional hats make it difficult to keep track of who exactly holds which position at any given time. Furthermore, there is no systematic mechanism for sharing news of promotions, retirement, death, moves, and other changes to the network outside of one’s immediate professional and spatial sphere. In such a large network, news of this type can sometimes lag for a period of months or even years.

Anecdotally, reception of the study was positive, and interest in the tools has been far-reaching. Climate change professionals from across Hawai’i and the USAPI, across the greater Pacific region, and from Caribbean nations, have contacted the Pacific RISA to solicit guidance and professional support for furthering the research in their respective countries and regions. Already, research has begun in the Solomon Islands to duplicate the study. Conversations are in process with several international agencies to follow up and extend the research to predict and actively facilitate future collaborations on climate change research and activities across Hawai’i and the USAPI.

Future research should evaluate the use and function of the tools and explore ways to increase usability, particularly among extremely remote locations who have the greatest need for collaborations with outside resources as well as the greatest barriers to achieving these connections. Additionally, each sub-region should further explore local and international network connections. Focused within a sub-region, more detailed exploration of inter-island communication within a country can be mapped than was feasible in this large study. Finally, future research should map the process of information sharing and dissemination across spatial and professional boundaries. Previous network analysis research supports the exploration of information and opinion dissemination through network connections as both apparent and traceable through rigorous studies (e.g., Doreian, 2001; Frank & Fahrback, 1999; Tardy & Hale, 1998); applications within a network of multidisciplinary climate change professionals could include explorations of scientific, cultural, and adaptation knowledge across urban, rural, and very remote island communities. Though initial findings in this study reflect strong connections, future research should parse out the types of information that are and are not shared through these communication lines.

Conflict of interest

The authors have no conflict of interest to declare.

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