TESIS DOCTORAL – *PhD Dissertation*

Programa de Doctorado en Desarrollo Local y Cooperación Internacional

TÍTULO

Vulnerabilidad y capacidad adaptativa de la agricultura a pequeña escala en América Central: brechas actuales y elementos para la gestión de información de sequías y otros fenómenos del cambio y variabilidad climática.

Vulnerability and adaptive capacity of small-scale agriculture in Central America: current gaps and elements for the management of information on droughts and other phenomena of climate change and variability.

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Octubre 2023

Resumen

La agricultura a pequeña escala sigue sosteniendo el empleo y la seguridad alimentaria de las familias rurales de América Central, a pesar de la creciente urbanización y diversificación de las economías de los países de la región. La adaptación al cambio climático de este sector es de alta prioridad, porque América Central es la región tropical a nivel global donde se esperan los mayores impactos de este proceso, y por la degradación de los recursos que sostienen su agricultura.

Los esfuerzos de los gobiernos y de la cooperación técnica para la adaptación de la agricultura a pequeña escala en la región se centran en regulaciones, infraestructura y oferta de tecnologías para el manejo del agua y cultivos. Estos esfuerzos generalmente siguen una aproximación de arriba abajo, sin considerar las condiciones, percepciones, conocimientos y experiencias locales.

El concepto de adaptación transformacional se refiere a cambios en las propiedades y funciones de un sistema para reducir las causas de la vulnerabilidad al cambio climático, cuando las medidas tradicionales y cambios tecnológicos no son suficientes para enfrentar sus efectos. Este trabajo parte de la premisa de que el conocimiento y la información disponible a diferentes niveles en América Central pueden apoyar la adaptación transformacional de la agricultura a pequeña escala en la región.

Este trabajo desarrolla y aplica dos metodologías para caracterizar la vulnerabilidad al cambio climático de los medios de vida agrícolas a pequeña escala en la región, con mayor énfasis en su componente de capacidad adaptativa. La primera analiza información pública sobre el impacto potencial del cambio climático en diferentes cultivos, necesidades humanas básicas y recursos para la innovación y se aplica al conjunto de municipios rurales de los países de América Central con menor Índice de Desarrollo Humano. Con base en este análisis, identifica grupos de municipios con diferentes niveles y tipos de capacidad adaptativa como punto de partida para priorizar medidas de adaptación a nivel nacional y regional. La segunda metodología se basa en procesos participativos en cinco microcuencas de la vertiente del Pacífico de Costa Rica, El Salvador y el Estado de Chiapas en México para caracterizar la vulnerabilidad y la capacidad adaptativa a nivel local, pero también para priorizar opciones de adaptación que apoyen las agendas de las organizaciones de desarrollo que trabajan a ese nivel. Ambas metodologías toman elementos teóricos del enfoque de medios de vida sostenibles, que aborda las dimensiones de las situaciones y procesos relacionados con la mejora del bienestar de las personas y sus comunidades.

Este trabajo también desarrolla y aplica una metodología para evaluar productos de información agroclimática elaborados y distribuidos por organizaciones de diferente naturaleza, una práctica transformacional para gestionar los impactos del cambio climático en la producción agrícola y la seguridad alimentaria. Esta metodología fue aplicada primero en Guatemala, el país de la región con mayores problemas de seguridad alimentaria, y validada y contrastada posteriormente en dos departamentos de Colombia donde existen iniciativas de integración y difusión de información agroclimática. Esta metodología se basa en un proceso iterativo y participativo que pone en valor la experiencia de los usuarios de estos productos; incluye técnicas de análisis de redes para estudiar las relaciones entre productos, sus roles en la provisión de información y su agrupación según temas disciplinarios, escala geográfica o proceso de producción, y técnicas de evaluación de usabilidad para estimar cuán bien estos productos pueden apoyar diferentes decisiones.

La caracterización de la vulnerabilidad a nivel municipal muestra una amplia variación entre Guatemala, El Salvador, Honduras y Nicaragua, y dentro de cada país. Los municipios con menor capacidad adaptativa tendieron a ubicarse en las zonas de frontera agrícola o propensas a la sequía. El índice de capacidad adaptativa ubicó los municipios con mayor capacidad adaptativa relativa cerca a zonas

urbanas y rutas de comercio, mientras los valores más bajos los tuvieron los municipios ubicados en el Corredor Seco, principalmente en el oriente de Guatemala, el occidente de Honduras y el norte y oriente de El Salvador, o en áreas de frontera agrícola. La agrupación de municipios según su afinidad en indicadores de capacidad adaptativa permitió identificar, además, que la satisfacción de necesidades básicas estuvo relacionada con una capacidad adaptativa mayor de los municipios. Encontramos que los grupos de municipios con menos satisfacción de necesidades básicas tendieron a tener menor desempeño de indicadores para innovación y acción, lo que nos sugiere que en estos grupos de municipios los programas de adaptación deberían abordar también la atención a las necesidades básicas. En los grupos de municipios con un mejor desempeño de indicadores de innovación y puesta en práctica de la innovación, los programas de adaptación deberían aprovechar estas ventajas. El análisis señaló también que los grupos de municipios que mayor inversión han recibido en incentivos agrícolas como asistencia técnica y préstamos no tienen necesariamente una capacidad adaptativa mayor. Esto se explica porque estos factores no garantizan oportunidades para la diversificación de ingresos, un aspecto asociado a la reducción de pobreza y vulnerabilidad de las familias agrícolas en estudios previos. Los resultados sugieren que debe considerarse un espectro completo de niveles y estrategias de adaptación progresiva y transformacional en la región, y que la metodología propuesta apoya el establecimiento de prioridades geográficas y la identificación de estrategias de adaptación.

La caracterización participativa en microcuencas de tres países de la región mostró diferencias en la vulnerabilidad, y en especial en la capacidad adaptativa, entre diferentes medios de vida agrícolas. En particular el capital humano y el capital social mostraron amplias diferencias entre medios de vida que tienen acceso a la tierra y el agua de manera estable, y medios de vida que dependen del arriendo de la tierra y de la venta de mano de obra. Aunque en todas las microcuencas donde se realizó esta investigación existió algún nivel de incentivos y asistencia técnica distribuida por entidades gubernamentales y ONG, hubo diferencias en el acceso a estas ayudas entre los medios de vida. Un punto para resaltar es que estas ayudas, como la distribución de insumos y construcción de infraestructura, no necesariamente toman en cuenta las necesidades locales y, por lo tanto, no siempre responden a las necesidades de adaptación de las familias agricultoras. De hecho, las medidas de adaptación implementadas y propuestas en los procesos participativos se distribuyen en un gradiente entre adaptación progresiva y transformacional y en diferentes capitales, y existe conciencia en los representantes de las familias agricultoras de la importancia de fortalecer los capitales no físicos para la viabilidad y sostenibilidad de las medidas de adaptación, y no solo el capital natural y construido. Estos resultados confirman la sugerencia de que los programas de adaptación deben considerar un espectro amplio de niveles y estrategias de adaptación, tomando además en cuenta las necesidades a nivel local para una mejor inversión de recursos para la adaptación.

Finalmente, la evaluación de productos de información agroclimática como medida de adaptación transformacional desde el fortalecimiento de los capitales humano y social muestra que en Guatemala se han hecho algunos progresos en lo que respecta a la gestión de la variabilidad del clima, lo que sugiere una transición de la respuesta reactiva a las crisis a la gestión proactiva de los riesgos. Sin embargo, los resultados muestran también que, si bien las redes de productos incluyen diferentes temas o disciplinas, los productos destinados a apoyar decisiones para gestión de la agricultura y la seguridad alimentaria a nivel local requieren cambios en las prácticas institucionales de compartir y producir información más útil y oportuna para la gestión de sequías y de las crisis alimentarias.

El trabajo intenta poner en valor diferentes fuentes de información y conocimiento para la adaptación al cambio climático, en una región donde es frecuente que se atribuya la falta de decisiones oportunas y objetivas a su ausencia y falta de calidad. Las propuestas metodológicas no están cerradas, sino que tratan de identificar opciones para el mejor uso de los recursos disponibles y esfuerzos para apoyar la adaptación de la agricultura a pequeña escala en América Central.

Resum

L'agricultura a petita escala continua sostenint l'ocupació i la seguretat alimentària de les famílies rurals d'Amèrica Central, malgrat la creixent urbanització i la diversificació de les economies dels països de la regió. L'adaptació al canvi climàtic d'aquest sector és d'alta prioritat, perquè Amèrica Central és la regió tropical a nivell global on s'esperen els majors impactes d'aquest procés, i per la degradació dels recursos que sostenen la seua agricultura.

Els esforços dels governs i de la cooperació tècnica per tal d'adaptar l'agricultura a petita escala a la regió se centren en regulacions, en infraestructura i en oferta de tecnologies per al maneig de l'aigua i dels cultius. Aquests esforços segueixen generalment una aproximació de dalt a baix, sense considerar les condicions, les percepcions, els coneixements i les experiències locals.

El concepte d'adaptació transformacional fa referència a canvis en les propietats i en les funcions d'un sistema per a reduir les causes de la vulnerabilitat front al canvi climàtic, quan les mesures tradicionals i els canvis tecnològics no són suficients per a fer-ne front. Aquest treball neix de la premissa que el coneixement i la informació disponibles a diferents nivells a Amèrica Central poden recolzar l'adaptació transformacional de l'agricultura a petita escala a la regió.

Aquest treball desenvolupa i aplica dues metodologies per a caracteritzar la vulnerabilitat front al canvi climàtic dels mitjans de vida agrícoles a petita escala a la regió, amb major èmfasi en el seu component de capacitat adaptativa. La primera analitza informació pública sobre l'impacte potencial del canvi climàtic en diferents cultius, necessitats humanes bàsiques i recursos per a la innovació, i s'aplica al conjunt de municipis rurals dels països d'Amèrica Central amb menor Índex de Desenvolupament Humà. Basant-nos en aquesta anàlisi, identifica grups de municipis amb diferents nivells i tipus de capacitat adaptativa com a punt de partida per a prioritzar mesures d'adaptació a nivell nacional i regional. La segona metodologia es basa en processos participatius en cinc microconques del vessant del Pacífic de Costa Rica, El Salvador i l'Estat de Chiapas a Mèxic per a caracteritzar la vulnerabilitat i la capacitat adaptativa a nivell local, però també per a prioritzar opcions d'adaptació que recolzen les agendes de les organitzacions de desenvolupament que treballen a aquest nivell. Totes dues metodologies prenen elements teòrics de l'enfocament de mitjans de vida sostenibles, el qual aborda les dimensions de les situacions i els processos relacionats amb la millora del benestar de les persones i de les seues comunitats.

Aquest treball també desenvolupa i aplica una metodologia per a avaluar productes d'informació agroclimàtica elaborats i distribuïts per organitzacions de diferent naturalesa, una pràctica transformacional per a gestionar els impactes del canvi climàtic en la producció agrícola i la seguretat alimentària. Aquesta metodologia va ser aplicada primer a Guatemala, el país de la regió amb majors problemes de seguretat alimentària, i validada i contrastada posteriorment en dos departaments de Colòmbia on existeixen iniciatives d'integració i de difusió d'informació agroclimàtica. Aquesta metodologia es basa en un procés iteratiu i participatiu que posa en valor l'experiència dels usuaris d'aquests productes; inclou tècniques d'anàlisis de xarxes per a estudiar les relacions entre productes, els seus rols en la provisió d'informació i la seua agrupació segons temes disciplinaris, escala geogràfica o procés de producció, i tècniques d'avaluació d'usabilitat per a estimar el grau en que aquests productes poden recolzar diferents decisions.

La caracterització de la vulnerabilitat a nivell municipal mostra una àmplia variació entre Guatemala, El Salvador, Hondures i Nicaragua, i també dins de cada país. Els municipis amb menor capacitat adaptativa van tendir a situar-se en les zones de frontera agrícola o propenses a la sequera. L'índex de capacitat adaptativa va situar els municipis amb major capacitat adaptativa relativa a prop de zones

urbanes i de rutes de comerç, mentre que els valors més baixos van correspondre als municipis situats en el Corredor Sec, principalment a l'orient de Guatemala, l'occident d'Hondures i el nord i orient d'El Salvador, o bé en àrees de frontera agrícola. L'agrupació de municipis segons la seua afinitat en indicadors de capacitat adaptativa va permetre identificar, a més, que la satisfacció de necessitats bàsiques estava relacionada amb una major capacitat adaptativa dels municipis. Trobem que els grups de municipis amb menys satisfacció de necessitats bàsiques tendien a acomplir menys els indicadors per a innovació i acció, la qual cosa ens suggereix que en aquests grups de municipis els programes d'adaptació haurien d'abordar també l'atenció a les necessitats bàsiques. En els grups de municipis amb un major acompliment d'indicadors d'innovació i posada en pràctica de la innovació, els programes d'adaptació haurien d'aprofitar aquests avantatges. L'anàlisi va apuntar també que els grups de municipis amb una inversió més elevada en incentius agrícoles com a assistència tècnica i préstecs no tenen necessàriament una major capacitat adaptativa. Això s'explica perquè aquests factors no garanteixen oportunitats per a la diversificació d'ingressos, un aspecte associat a la reducció de pobresa i vulnerabilitat de les famílies agrícoles en estudis previs. Els resultats suggereixen que ha de considerar-se un espectre complet de nivells i d'estratègies d'adaptació progressiva i transformacional a la regió, i que la metodologia proposada recolza l'establiment de prioritats geogràfiques i la identificació d'estratègies d'adaptació.

La caracterització participativa en microconques de tres països de la regió va mostrar diferències en la vulnerabilitat, i especialment en la capacitat adaptativa, entre diferents mitjans de vida agrícoles. En particular, el capital humà i el capital social van mostrar àmplies diferències entre mitjans de vida que tenen accés a la terra i a l'aigua de manera estable, i mitjans de vida que depenen de l'arrendament de la terra i de la venda de mà d'obra. Tot i que en totes les microconques on es va portar a terme aquesta investigació va existir algun nivell d'incentius i assistència tècnica distribuïda per entitats governamentals i ONG, va haver-hi diferències en l'accés a aquestes ajudes entre els mitjans de vida. Un punt que cal ressaltar és que aquestes ajudes, com la distribució d'inputs i la construcció d'infraestructura, no necessàriament ténen en compte les necessitats locals i, per tant, no sempre responen a les necessitats d'adaptació de les famílies agricultores. De fet, les mesures d'adaptació implementades i proposades en els processos participatius es distribueixen en un gradient entre adaptació progressiva i transformacional i en diferents capitals, i existeix consciència en els representants de les famílies agricultores de la importància d'enfortir els capitals no físics per a la viabilitat i sostenibilitat de les mesures d'adaptació, i no sols el capital natural i construït. Aquests resultats confirmen el suggeriment que els programes d'adaptació han de considerar un espectre ampli de nivells i d'estratègies d'adaptació, tot considerant, a més, les necessitats a nivell local, de cara a una millor inversió de recursos per a l'adaptació.

Finalment, l'avaluació de productes d'informació agroclimàtica com a mesura d'adaptació transformacional des de l'enfortiment dels capitals humà i social mostra que a Guatemala s'han fet alguns progressos pel que fa a la gestió de la variabilitat del clima, fet que suggereix una transició de la resposta reactiva a les crisis a la gestió proactiva dels riscos. No obstant això, els resultats mostren també que, si bé les xarxes de productes inclouen diferents temes o disciplines, els productes destinats a recolzar decisions per a gestió de l'agricultura i la seguretat alimentària a nivell local requereixen canvis en les pràctiques institucionals de compartir i produir informació més útil i oportuna per a la gestió de les sequeres i de les crisis alimentàries.

El treball intenta posar en valor diferents fonts d'informació i de coneixement per a l'adaptació al canvi climàtic, en una regió on és freqüent atribuir la falta de decisions oportunes i objectives a l'absència i a la falta de qualitat d'aquestes. Les propostes metodològiques no són tancades, sinó que tracten d'identificar opcions per al millor ús dels recursos disponibles i esforços per a donar suport a l'adaptació de l'agricultura a petita escala a Amèrica Central.

Abstract

Small-scale agriculture continues to sustain employment and food security for rural families in Central America, despite increasing urbanization and diversification of the region's countries' economies. Adaptation to climate change in this sector is a high priority because Central America is the tropical region globally where the impacts of this process are expected to be the greatest because of the degradation of the resources that sustain its agriculture.

Government and technical cooperation efforts for adaptation in small-scale agriculture in the region focus on regulations, infrastructure, and the supply of water and crop management technologies. These efforts generally follow a top-down approach without considering local conditions, perceptions, knowledge, and experiences.

The concept of transformational adaptation refers to changes in the properties and functions of a system to reduce the causes of vulnerability to climate change when traditional measures and technological changes are not sufficient to cope with climate change. This paper starts from the premise that knowledge and information available at different levels in Central America can support the transformational adaptation of smallholder agriculture in the region.

This paper develops and applies two methodologies to characterize the vulnerability to climate change of small-scale agricultural livelihoods in the region, emphasizing their adaptive capacity component. The first analyses public information on the potential impact of climate change on different crops, basic human needs, and resources for innovation and is applied to the set of rural municipalities in Central American countries with the lowest Human Development Index. This analysis identifies groups of municipalities with different levels and types of adaptive capacity to prioritize adaptation measures at a national and regional level. The second methodology is based on participatory processes in five micro-watersheds on the Pacific slope of Costa Rica, El Salvador, and the State of Chiapas in Mexico to characterize vulnerability and adaptive capacity at the local level, but also to prioritize adaptation options that support the agendas of development organizations working at that level. Both methodologies take theoretical elements from the sustainable livelihoods approach, which addresses the dimensions of situations and processes related to improving people's and their communities' wellbeing.

This work also develops and applies a methodology to assess agro-climatic information products produced and distributed by organizations of different natures, a transformational practice to manage climate change impacts on agricultural production and food security. This methodology was first applied in Guatemala, the country in the region with the highest food security problems, and subsequently validated and contrasted in two departments of Colombia where there are initiatives to integrate and disseminate agro-climatic information. This methodology is based on an iterative and participatory process that values the users' experience of these products. It includes network analysis techniques to study the relationships between products, their roles in the provision of information, their grouping according to disciplinary topics, geographical scale or production process, and usability evaluation techniques to estimate how well these products can support different decisions.

The vulnerability characterization at the municipal level shows a wide variation between Guatemala, El Salvador, Honduras, and Nicaragua, and within each country. The municipalities with the least adaptive capacity tended to be in agricultural frontier areas and/or areas prone to drought. The adaptive capacity index located the municipalities with the highest relative adaptive capacity near urban areas and trade routes; while the lowest values were found in municipalities located in the Dry Corridor, mainly in eastern Guatemala, western Honduras, and northern and eastern El Salvador, or in agricultural frontier areas. The grouping of municipalities according to their affinity in adaptive capacity indicators also allowed us to identify that the

satisfaction of basic needs was related to the municipalities' greater adaptive capacity. We found that groups of municipalities with lower satisfaction of basic needs tended to have a lower performance of innovation and action indicators, suggesting that in these groups of municipalities, adaptation programs should also address basic needs. In the groups of municipalities with better performance on indicators related to innovation and innovation implementation, adaptation programs should take advantage of these advantages. The analysis also pointed out that the groups of municipalities that have received greater investment in agricultural incentives such as technical assistance and loans do not necessarily have a greater adaptive capacity. This is explained by the fact that these factors do not guarantee income diversification opportunities, an aspect associated with reducing poverty and vulnerability of agricultural families in previous studies. The results suggest that a full spectrum of progressive and transformational adaptation levels and strategies should be considered in the region and that the proposed methodology supports the establishment of geographic priorities and the identification of adaptation strategies.

Participatory characterization in micro-watersheds in three countries in the region showed differences in vulnerability, and especially adaptive capacity, between different agricultural livelihoods. In particular, human capital and social capital showed wide differences between livelihoods that have stable access to land and water, and livelihoods that depend on leasing land and selling labor. Although there was some level of incentives and technical assistance distributed by government entities and NGOs in all the micro-watersheds where this research was conducted, there were differences in access to these aids among livelihoods. One point to highlight is that these aids, such as the distribution of inputs and infrastructure construction, do not necessarily consider local needs and, therefore, do not always respond to the adaptation needs of farming families. In fact, the adaptation measures implemented and proposed in the participative processes are distributed on a gradient between progressive and transformational adaptation and in different capitals, and there is awareness among the representatives of farming families of the importance of strengthening non-physical capitals for the viability and sustainability of adaptation measures, and not only natural and built capital. These results confirm the suggestion that adaptation programs should consider a broad spectrum of adaptation levels and strategies, considering the needs at the local level for better investment of resources for adaptation.

Finally, the evaluation of agroclimatic information products as a transformational adaptation measure from the strengthening of human and social capitals shows that some progress has been made in Guatemala in terms of climate variability management, suggesting a transition from reactive response to crises to proactive risk management. However, the results also show that, although the product networks include different topics or disciplines, products aimed at supporting decisions for agriculture and food security management at the local level require changes in institutional practices of sharing and producing more useful and timely information for drought and food crisis management.

The work attempts to highlight different sources of information and knowledge for climate change adaptation in a region where the lack of timely and objective decisions is often attributed to their absence and lack of quality. The methodological proposals are not closed but rather seek to identify options for the best use of available resources and efforts to support small-scale agriculture adaptation in Central America.

Agradecimientos

Agradezco a todas las personas que me acompañaron en esta aventura del doctorado. Pero escribir una lista con sus nombres me llevaría al inevitable error de la omisión. Además, terminando el doctorado a los 57 años, miro hacia atrás y también quisiera que estuvieran en esa lista muchas otras personas. Las de antes y las de ahora me apoyaron a construir un espacio de trabajo y estudio, un espacio que ha tenido muchos momentos felices, y conocerlas ha sido un regalo de la vida.

Entre las personas del ahora están mis coautores, que incluyen académicos e investigadores; personas que trabajan en organizaciones de desarrollo, compañeros y compañeras de trabajo; personas que tuve la suerte de tener como estudiantes; mi mentor que durante tantos años me enseñó, entre muchas cosas importantes, a confiar en mi criterio y a ser más flexible; y el que fuera mi jefe cuando empecé el doctorado. Me dijo: "adelante, te apoyo", y me apoyó hasta el final. Mi directora, que me invitó a este viaje, estuvo siempre presente y me alentó y orientó todos estos años rescatando lo mejor de mi voz y experiencia. Espero contribuir yo también a que más mujeres avancen en su carrera académica y aporte al desarrollo local en América Latina. Y, cómo no, están las personas que revisaron este documento en plena pandemia.

La lista de las personas del antes es muy larga, e incluye muchos de mis profesoras y profesores, compañeros y compañeras de trabajo y estudio, amigos y amigas; hombres y mujeres en los Andes o en la Amazonia, y con quienes tuve la suerte de compartir un camino o una charla y que me enseñaron desde los nombres de diferentes árboles y cultivos, hasta cómo transformar una entrevista en una conversación con sentido. Seguro seguiría aprendiendo mucho de cada una de estas personas. Pero poner ejemplos sería un ejercicio largo para mí y tedioso para los que se animen a leer esta página, así que solo voy a hacer mencionar a mi profesora del curso Evolución de la cultura peruana en la Universidad Nacional Agraria La Molina, que a mediados de los años '80 me abrió los ojos a la anónima historia de la domesticación de plantas y animales y de la gestión del agua. Hay mucho de sus lecciones en este intento de contribuir a la adaptación al cambio climático de la agricultura en otra región de América Latina.

Papá, va por ti, por tu ser profesional y docente que compartiste conmigo.

Índice

1 Introducción

1.1 Presentación y justificación

Hay un consenso en la gravedad del impacto del cambio climático en la agricultura a nivel global, la desigualdad de sus efectos, y la necesidad urgente de apoyar a las familias agricultoras a pequeña escala en su adaptación (FAO (Organización de las Naciones Unidas para la Alimentación y la Agricultura) 2016a).

En América Central, el área tropical con más efectos esperados del impacto climático a nivel global (Giorgi 2006), se estima que a inicios de la década pasada había al menos 2.35 millones de familias agricultoras a pequeña escala (PRESANCA II (Programa Regional de Seguridad Alimentaria y Nutricional para Centroamérica) y FAO 2011), lo que representa que un tercio de la población total y dos tercios de la población rural dependía de este tipo de agricultura (FAO 2014). Muchas de estas familias cultivan en tierras marginales y en condiciones de secano, carecen de asistencia adecuada para responder a los desafíos del cambio climático (CAC (Consejo Agropecuario Centroamericano) 2017), y enfrentan situaciones de inseguridad alimentaria estacional recurrentemente (Alpízar *et al.* 2020). Las condiciones de estas familias empeoraron en el contexto de la pandemia de COVID-19, por la reducción del acceso a insumos y capital para la producción de alimentos, de mano de obra agrícola y la interrupción brusca en la distribución y comercialización de alimentos (FAO y CELAC (Comunidad de Estados Latinoamericanos y Caribeños) 2020).

Por lo anterior, entender los impactos del cambio climático en las familias agricultoras a pequeña escala en la región y desarrollar estrategias de adaptación apropiadas con ellas son elementos críticos (Harvey *et al*. 2018), sobre todo si se aprovechan recursos disponibles para entender las diferencias y necesidades entre los diferentes medios de vida de estas familias causadas por factores biofísicos, sociales y económicos. Los medios de vida agrícolas a pequeña escala, con profunda raigambre cultural, están basados en el cultivo de granos básicos (maíz y frijol principalmente, y arroz de secano en algunos casos) combinados con la venta de mano de obra y la producción de café, aunque también es común la combinación con la ganadería de doble propósito, la pesca artesanal y las actividades forestales como muestran los mapas de medios de vida elaborados por la Red de Sistemas de Alerta Temprana Contra la Hambruna (FEWS NET 2015, 2016, 2018). En especial los medios agrícolas basados en el cultivo de granos básicos y café son altamente vulnerables al cambio climático, porque los cultivos que los sostienen son sensibles a los cambios graduales en el clima, como las crecientes temperaturas; y a la variabilidad climática, como las lluvias extremas, huracanes, sequías y plagas relacionadas (Schmidt *et al*. 2012, Avelino *et al*. 2015, Hannah *et al*. 2017). Ante la rapidez del cambio climático y la magnitud de su impacto, las medidas de adaptación exclusivamente tecnológicas o las prácticas para enfrentar la variabilidad climática que han sido puestas en práctica durante cientos de años son insuficientes.

Como respuesta, las políticas gubernamentales y de cooperación están incorporando paulatinamente la adaptación al cambio climático de la agricultura entre sus prioridades. Por ejemplo, las Contribuciones Determinadas a Nivel Nacional de los gobiernos de América Central, excepto Panamá, incluyen la adaptación del sector agricultura como prioridad (Comisión Europea 2019). También la Estrategia de Agricultura Sostenible Adaptada al Clima para la región, promovida a través de una plataforma intergubernamental, hace incidencia en este tema con un marco que incluye puntos de entrada en diferentes niveles, consideraciones de contexto y participación de grupos marginados (CAC 2017). En la práctica las medidas adaptación promovidas siguen basándose en la diseminación y ajuste de tecnologías (Hidalgo G. *et al*. 2019), que no siempre serán suficientes para enfrentar cambios drásticos del clima que harán insostenibles, en casos extremos, los medios de vida actuales (Eitzinger *et al*. 2012).

En la literatura existe un énfasis cada vez mayor en el papel central de diferentes conceptos y herramientas para la definición de medidas de adaptación más apropiadas y eficaces, más allá de la investigación en aspectos biofísicos que señalan la evolución esperada de las variables climáticas y su influencia en los cultivos. En este trabajo abordamos algunas de ellas, como la caracterización de la capacidad adaptativa (por ejemplo, Beauchamp *et al*. 2019, Holland *et al*. 2017, Imbach y Prado Beltrán 2014), el uso de un amplio rango de medidas de adaptación, incluyendo la adaptación transformacional (por ejemplo, Colloff *et al*. 2017, Fedele *et al*. 2019, Rickards y Howden 2012, Vermeulen *et al*. 2018), y el fortalecimiento de los servicios climáticos (por ejemplo, Carabajal 2016, Naab *et al*. 2019, Vaughan *et al*. 2019, Vaughan y Dessai 2014).

Este trabajo se centra en estos conceptos y herramientas. Para ello, propone y valida dos propuestas de caracterización de la capacidad adaptativa de los medios de vida de las familias agricultoras a pequeña escala en América Central, uno a gradación gruesa y otro a gradación fina, recurriendo a información pública y al conocimiento local respectivamente. En el trabajo a gradación fina, utiliza además el enfoque de medios de vida para analizar las medidas de adaptación efectivamente implementadas o identificadas como relevantes por grupos locales. Finalmente, el trabajo analiza a mayor profundidad la provisión de servicios climáticos para la gestión de sequías en el Corredor Seco de Guatemala, una medida de adaptación potencialmente transformacional que involucra la cooperación de diferentes actores, ante la constatación de los esfuerzos crecientes de las entidades gubernamentales y de cooperación para fomentar el uso de información que permita respuestas oportunas y apropiadas.

Como fundamentos teóricos el trabajo se articula en torno a los conceptos de vulnerabilidad, sensibilidad y adaptación al cambio propuestos por el Grupo Intergubernamental de Expertos sobre Cambio Climático (IPCC), el enfoque de medios de vida y los servicios climáticos como medida de adaptación.

1.2 Fundamentos teóricos

Esta sección presenta y articula los fundamentos teóricos de este trabajo. Los apartados sobre vulnerabilidad y adaptación al cambio climático, y sobre el enfoque de los medios de vida y su aplicación al análisis de la adaptación al cambio climático retoman y actualizan un trabajo de la Comisión Europea (2013) del cual la autora de esta tesis es también autora principal. La tesis se estructura bajo la modalidad de compilación de artículos, que se presentan en los capítulos 2, 3 y 4, desarrollando este marco teórico con mayor profundidad.

1.2.1 Vulnerabilidad, sensibilidad y adaptación al cambio climático

La conceptualización de la vulnerabilidad en diferentes marcos de trabajo responde a la identificación y promoción de medidas más eficaces para su reducción. El Grupo Intergubernamental de Expertos sobre el Cambio Climático definió la vulnerabilidad en su Tercer y Cuarto Informe de Evaluación (conocidos respectivamente como TAR y AR4) como la capacidad de un sistema para afrontar los efectos negativos del cambio climático, compuesta de su exposición a procesos del cambio climático, su sensibilidad y su capacidad de adaptación a estos procesos (IPCC 2001, 2007). En esta definición, la vulnerabilidad al cambio climático se refiere no solo a cuán propensos son los sistemas socio ecológicos de sufrir impactos que resultan del cambio climático sino también a su habilidad para responder a estos impactos (Adger *et al*. 2007), incluyendo la respuesta de las personas y la sociedad como componente de la vulnerabilidad.

El IPCC redefinió el concepto de vulnerabilidad en su Quinto Informe de Evaluación publicado en 2014 (conocido como AR5), como la "Propensión o predisposición a ser afectado negativamente. La vulnerabilidad comprende una variedad de conceptos y elementos que incluyen la sensibilidad o susceptibilidad al daño y la falta de capacidad de respuesta y adaptación" (IPCC 2014:5). Esta definición es afín al marco de reducción de riesgo de desastres, y desde esta perspectiva la vulnerabilidad se deriva del riesgo de que un sistema quede expuesto a un resultado indeseable por alguna condición o característica preexistente. El Sexto Informe de Evaluación (AR6) continua con este enfoque (Ishtiaque *et al*. 2022).

Las propuestas operativas para evaluar el riesgo usando la definición propuesta en el AR5 (ver, por ejemplo, Das *et al*. 2020, GIZ y EURAC 2017) reducen el peso de la capacidad adaptativa de las personas y la sociedad como factor determinante de la evaluación. Por otro lado, la definición propuesta en los TAR y AR4 sigue siendo ampliamente utilizada en evaluaciones de vulnerabilidad para la planificación de la adaptación al cambio climático desde el nivel local y regional (por ejemplo, Abid *et al*. (2016) para el Punjab; Metternicht *et al*. (2014) para el Gran Chaco y los Andes; y Tapia *et al*. (2017) para ciudades europeas), el nivel nacional (por ejemplo, Dumenu y Obeng (2016) para comunidades rurales en Ghana, y Monterroso-Rivas *et al*. (2018) para el sector agrícola en México) y global (por ejemplo, Chen *et al*. (2018) para orientar la inversión de recursos para la adaptación). Como señalan Gaughan *et al*. (2019), esa definición de vulnerabilidad al cambio climático facilita su cuantificación empírica y su comunicación para hacer que los resultados sean útiles para la toma de decisiones. Por estas razones, este trabajo usa la definición de vulnerabilidad propuesta por el IPCC en el TAR y AR4. Esta definición de vulnerabilidad se basa en tres componentes; exposición, sensibilidad y capacidad adaptativa, como fue señalado anteriormente (IPCC 2001, 2007). En el caso de este trabajo se asume como exposición, los cambios en la temperatura, la frecuencia, intensidad y distribución de la lluvia y la intensidad de los vientos; como sensibilidad, la condición o aspectos del sistema socio ambiental afectados por estar expuestos a los cambios en el clima, y que combinada con la exposición define el impacto del cambio climático; y como capacidad adaptativa, la actitud, la capacidad y los recursos que tienen las personas y sus organizaciones e instituciones para hacer frente al cambio.

A diferencia del concepto de vulnerabilidad, los informes del IPCC han mantenido una definición consistente del concepto de *adaptación* al cambio climático, como los ajustes en los sistemas socio ambientales para responder a estímulos climáticos y a sus efectos actuales o esperados. Visto de una manera práctica, la adaptación al cambio climático es el conjunto de acciones que toma la población y sus organizaciones e instituciones para ajustar sus medios y condiciones de vida al cambio del clima; y para caracterizar sus elementos e identificar recomendaciones para la adaptación, la consideración de la escala apropiada es un elemento fundamental.

Lo que ha evolucionado es la tipología de las medidas de adaptación, acorde a la creciente literatura en el tema. El TAR y el AR4 presentan una tipología de adaptación definida principalmente por la anticipación (adaptación reactiva o anticipada) y a los protagonistas del cambio (pública o privada) (IPCC 2001, 2007), mientras que el AR5 presenta una tipología relacionada al grado de transformación que demanda de un sistema, definiendo dos tipos de adaptación: la *adaptación progresiva* (o incremental) en un extremo, cuyo "objetivo principal es mantener la esencia e integridad de un sistema o proceso a una escala dada"; y la *adaptación transformacional* en el otro, que implica "cambios en los atributos fundamentales de un sistema socio ecológico en anticipación al cambio climático y sus efectos" (IPCC 2014:839). La adaptación de sistemas ocupa un lugar intermedio, y trata de cambios en un sistema de producción, pero sin ser tan profundos que impliquen un cambio a un sistema diferente (Rickards y Howden 2012).

El concepto de adaptación transformacional llama la atención sobre que las estrategias tradicionales o las soluciones exclusivamente tecnológicas no serán siempre efectivas para reducir la vulnerabilidad al cambio climático (Ashley *et al*. 2020). Rickards y Howden (2012) proveen ejemplos de estos tipos de adaptación desde la perspectiva de la agricultura en zonas áridas. Estos autores señalan algunos criterios para definir qué califica como adaptación transformacional, como la profundidad, la escala espacial, y la sostenibilidad del cambio. Un análisis de iniciativas de adaptación transformacional en la agricultura (Vermeulen *et al*. 2018) reconoce la importancia de contar con una visión clara de las tendencias del clima, y los beneficios de contar también con plataformas que faciliten la participación de múltiples actores y fortalezcan el capital social. Finalmente, un análisis de portafolios de proyectos de adaptación a nivel global (Fedele *et al*. 2019) señala otras consideraciones para definir qué puede ser calificado como adaptación transformacional, como la inversión en recursos humanos, la pluralidad de actores y sectores y la interacción entre ellos, los cambios en los valores y los acuerdos de colaboración.

1.2.2 El enfoque de los medios de vida y la adaptación al cambio climático

Temas complejos como la adaptación al cambio climático requieren enfoques y herramientas que ayuden a comprender esa complejidad y a decidir qué hacer y cómo. El enfoque de medios de vida toma como base el análisis de los recursos con que cuenta la comunidad para desarrollar las actividades productivas, recreativas, espirituales y de relación social que les permitan satisfacer sus necesidades. La definición de medios de vida sostenibles provista por Chambers y Conway (1992:6-7) incluye las capacidades, recursos y acciones para satisfacer una forma de vida, además de la aptitud para mantener estos elementos y contribuir positivamente a otros medios de vida en el presente y futuro.

Este enfoque fue adoptado por el Departamento de Desarrollo Internacional del Reino Unido al final de la década de los 90 (Carney 1999, Farrington 2001), cuando las soluciones propuestas por el Consenso de Washington empezaron a ser cuestionadas (ver Scoones 2009). Posteriormente el enfoque fue modificado y enriquecido por otras organizaciones. En particular, el Centro de Desarrollo Rural de la Universidad Estatal de Iowa (EE. UU.) realizó importantes aportes al enfoque respecto la organización social, la cultura, la influencia de la política y el poder (Flora 1998, Emery y Flora 2006, Flora *et al*. 2016, Flora 2004). Bajo el nombre Marco de los Capitales de la Comunidad, el enfoque se ha aplicado ampliamente en América Latina en temas como planificación territorial, adaptación al cambio climático y acceso de las mujeres a fuentes de ingresos y seguridad alimentaria (por ejemplo, Flora 1987, Gutiérrez y Siles 2009, Gutierrez-Montes *et al*. 2009, Thompson y Lopez Barrera 2019).

En esta versión del enfoque, las personas con sus capacidades, habilidades, educación y salud constituyen los recursos humanos de la comunidad. El idioma, creencias, valores y otros aspectos culturales que comparten las personas constituyen los recursos culturales. Los recursos sociales son las relaciones horizontales que la gente mantiene entre sí (p. ej. organizaciones locales), mientras que los recursos políticos son las capacidades de la comunidad o grupo para influir en organizaciones y procesos externos (como entidades gubernamentales y sus políticas). La tierra, el agua y los bosques, entre otros recursos naturales, son los recursos que las personas pueden utilizar para desarrollar sus medios de vida. Los recursos financieros son los recursos en dinero con que cuenta la gente o los recursos que le permiten acceder a él (p. ej. subsidios y créditos). Finalmente, las obras construidas para el soporte social (salud y educación, comunicación, entre otros) y productivo (como centros de acopio) constituyen los recursos de infraestructura física. Los recursos son interdependientes, interactúan, y es importante mantener el balance entre ellos en beneficio de las personas, comunidades, y la sostenibilidad de sus medios de vida. Cuando un recurso recibe atención preponderante o cuando es afectado severamente, los otros recursos se descapitalizan y la sostenibilidad del sistema puede verse comprometida (Emery y Flora 2006, Imbach *et al*. 2009).

El análisis de la capacidad adaptativa local se puede abordar desde la perspectiva de los medios de vida. Este enfoque ayuda a identificar y relacionar los cuellos de botella para la adaptación con los recursos de la comunidad. La percepción que tienen los actores locales de los efectos del cambio climático en los recursos naturales, productivos y/o de infraestructura y sus reacciones ante estos efectos están relacionadas en gran medida con los recursos culturales. La identificación del qué hacer para adaptarse (acciones de adaptación) está relacionada con los recursos humanos, mientras que la decisión y organización para ejecutar acciones de adaptación está relacionada con los recursos sociales, y la gestión de recursos financieros y de apoyo externo está relacionada con los recursos políticos de la comunidad (Imbach y Prado Beltrán 2014).

El enfoque de los medios de vida puede ser utilizado también para clasificar las medidas de adaptación, facilitando una visión de conjunto y no como opciones aisladas. La propuesta presentada por la Comisión Europea (2013), a partir de un inventario de medidas de adaptación desarrolladas en zonas rurales de América Latina, utilizó este enfoque para mostrar que, si bien la mayor parte de los esfuerzos está enfocada en el fortalecimiento de los capitales natural y construido, la viabilidad y sostenibilidad de su implementación depende del fortalecimiento de los recursos humano, social, cultural y político. Esta propuesta es coherente con otras tipologías de medidas de adaptación que se basan en datos empíricos, como la elaborada por Biagini *et al*. (2014) a partir de la revisión de proyectos de adaptación a nivel global. La Figura 1 muestra algunos ejemplos.

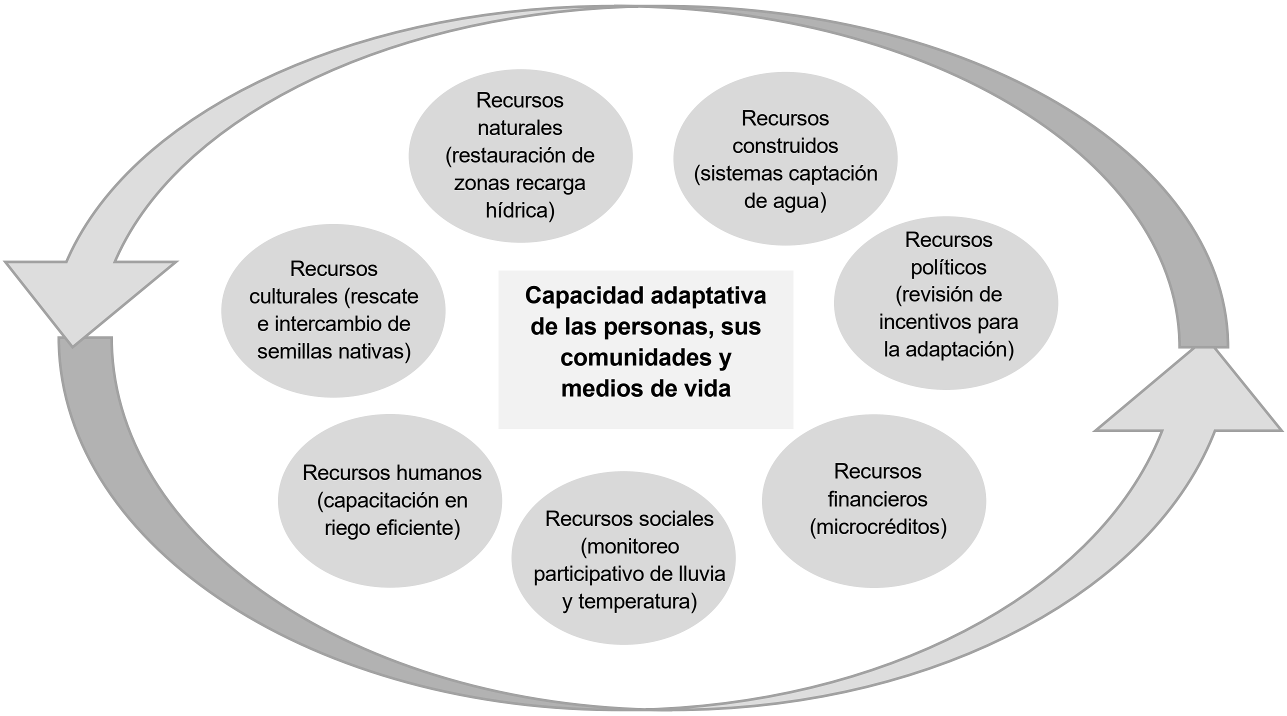

Figura 1. Ejemplos de acciones que favorecen la capacidad adaptativa de las personas, sus comunidades y medios de vida, relacionados al esquema de los recursos o capitales de la comunidad descrito por Flora (2004).

1.2.3 Los servicios climáticos como medida de adaptación

La adaptación – progresiva o transformacional - debe necesariamente apoyarse en información climática para que las medidas propuestas respondan a las condiciones cambiantes del clima a diferentes plazos y evitar la elección de medidas de adaptación incorrectas. De hecho, es el uso de información climática lo que diferencia un proyecto de adaptación de uno de desarrollo o gestión de recursos naturales (Doornbos 2009). Además, el uso de la información climática se considera una medida transformacional que involucra diferentes grupos de actores, como agencias nacionales, proveedores de servicios y familias productoras, como señala un informe que identifica tecnologías y prácticas escalables como parte de una ruta de adaptación para la agricultura (Loboguerrero *et al*. 2018). Ahora bien, la simple información climática no necesariamente puede ser utilizada para tomar decisiones para la adaptación, por lo que existe una creciente inversión en servicios climáticos para que las personas encargadas de la formulación de políticas, técnicos y agricultores puedan utilizar esta información y mejorar sus respuestas de adaptación (Georgeson *et al.* 2017, Hewitt *et al*. 2013, Vaughan y Dessai 2014). Por ejemplo, los servicios climáticos pueden ayudar a estos grupos de personas a pasar de respuestas reactivas a las crisis de la agricultura y la seguridad alimentaria a un enfoque más proactivo de la gestión de los riesgos climáticos (Wilhite 2002, Jones *et al*. 2017).

Los servicios climáticos tienen como objetivo proveer a las personas y sus organizaciones información relacionada al clima de manera oportuna y apropiada para que pueda ser utilizada en la reducción de pérdidas relacionadas al clima y proteger los medios de vida; su generación en el campo de la agricultura implica la producción, traducción, transferencia y uso de información climática y agrícola (Vaughan y Dessai 2014). Para esto, los servicios climáticos combinan pronósticos y alertas meteorológicas y climáticas con estadísticas de producción agrícola, condiciones de mercado de los productos agrícolas y de la mano de obra y datos de otros aspectos según el contexto, para dar recomendaciones relevantes a tomadores de decisiones a diferentes niveles (Ashley *et al*. 2020). A medida que integran diferentes temas, los servicios climáticos tienden a ser producidos por un conjunto de organizaciones, que simplemente pueden agregar información o afrontar un proceso de coproducción. La *coproducción* hace hincapié en la integración de diferentes temas, disciplinas o campos de conocimiento (Vincent *et al*. 2018) a través de la colaboración entre científicos, técnicos, profesionales y usuarios (Porter y Dessai 2017, Tall 2013) para la generación y difusión de productos de información impulsados por la demanda (Lourenço *et al*. 2016). Actualmente los servicios climáticos para la agricultura suelen difundirse a través de productos como boletines, sitios web y aplicaciones de telefonía móvil que conectan la información técnica y científica con diferentes usuarios (Georgeson *et al*. 2017, Vaughan *et al*. 2017).

1.3 El contexto geográfico de la investigación

América Central incluye siete países: Guatemala, Belice, Honduras, El Salvador, Nicaragua, Costa Rica y Panamá, aunque algunos autores incluyen dentro de esta región el sur de México por compartir aspectos históricos (Dym 2012). Para el propósito de este trabajo, que se desarrolló en el Estado de Chiapas en México, Guatemala, El Salvador, Honduras, Nicaragua y la costa del Pacífico de Costa Rica, usamos también el concepto de Mesoamérica que abarca ese espacio geográfico y cultural con características comunes (Rovira Morgado 2007).

El clima de este istmo entre el Océano Pacífico y el Mar Caribe está influenciado por factores oceánicos, y es fuertemente afectado por sequías, huracanes y el fenómeno El Niño-Oscilación Sur (Imbach *et al.* 2017); a nivel global, es la región tropical donde se esperan los mayores cambios en el clima futuro (Giorgi 2006). La cuenca del Pacífico de América Central tiene una estacionalidad de lluvias más pronunciada que la del Caribe por lo que predominan allí ecosistemas semiáridos y subhúmedos; pero a la vez presenta mejores condiciones agroecológicas que la vertiente del Caribe por lo que históricamente ha estado más densamente poblada (Finegan y Bouroncle 2008).

La estación de lluvias en la vertiente del Pacífico del istmo se extiende de junio a septiembre y es interrumpida por un periodo seco o canícula, que coincide con una fase crítica en la producción de cultivos (Imbach *et al*. 2017). El término Corredor Seco Centroamericano llama la atención sobre la tendencia de la canícula a comenzar antes, durar más o ser más intensa (Aguilar *et al*. 2005, Hidalgo *et al*. 2017, Rauscher *et al*. 2008), tendencia que continuará según las proyecciones climáticas (Imbach *et al*. 2018). Sequía, en este contexto, se refiere principalmente a la mayor duración de la canícula (Müller *et al*. 2019). La delimitación del Corredor Seco Centroamericano varía según los criterios utilizados por diferentes instituciones relacionadas con la gestión de la agricultura, el agua y la seguridad alimentaria en la región (ver, por ejemplo, Calvo-Solano *et al*. 2018, y Ramírez citada por CCAD (Comisión Centroamericana de Ambiente y Desarrollo) y SICA (Sistema de la Integración Centroamericana) 2010), pero se limita siempre a los países de América Central (ver Figura 2). Sin embargo, el estudio de referencia de caracterización del Corredor Seco (van der Zee Arias *et al*. 2012), menciona que el Corredor Seco se extiende también a la zona costera del Pacífico y la parte baja de la Sierra Madre de Chiapas.

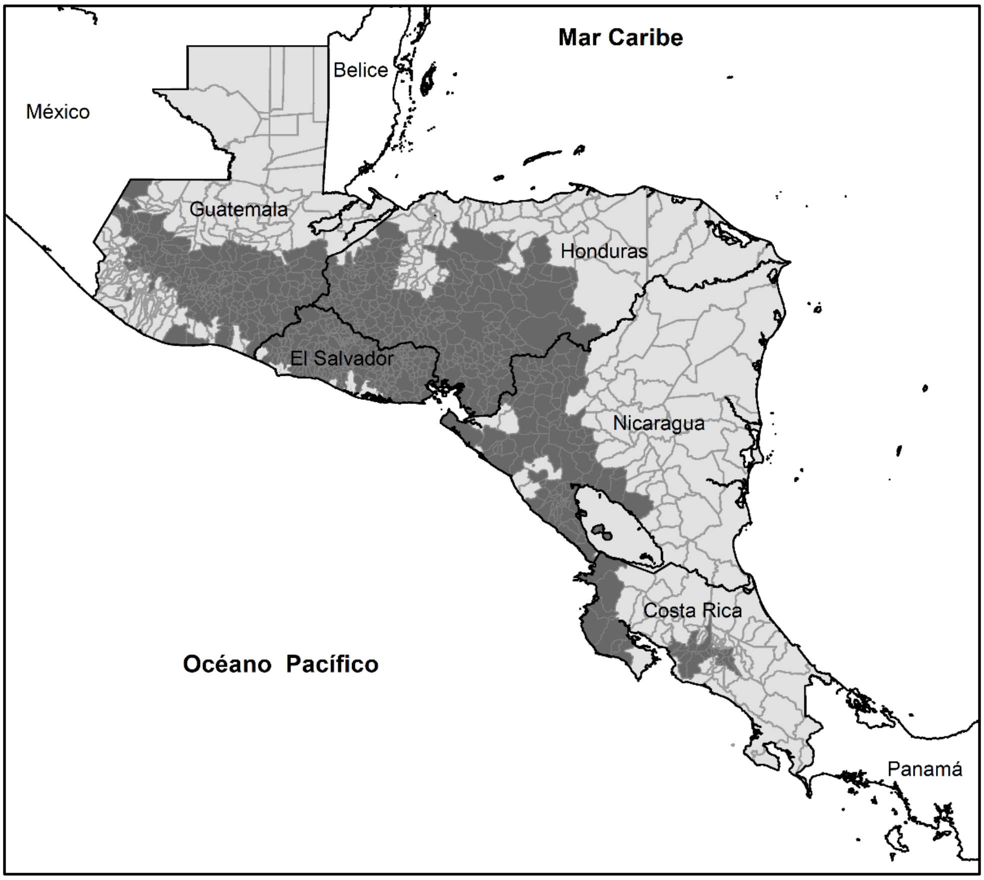

Figura 2. Municipios que tienen al menos la mitad de su territorio dentro del Corredor Seco Centroamericano (CSC), considerando la delimitación proporcionada por FAO (2016b) del CSC que considera áreas con épocas secas mayores a cuatro meses.

La agricultura en América Central es aún el pilar de las economías rurales y de la seguridad alimentaria de los sectores más pobres (Tucker *et al*. 2010) y en Guatemala, Honduras y Nicaragua más de dos terceras partes de la población dependen de este sector, especialmente de la agricultura familiar a pequeña escala (Imbach *et al*. 2017). Como en casi todas las regiones del mundo donde no se dispone de riego, la distribución de lluvias determina el calendario agrícola, principalmente en el Corredor Seco. En esta zona, aproximadamente el 60% de los habitantes vive en condición de pobreza (van der Zee Arias *et al.* 2012). El cambio climático viene a agravar la situación de esta población expuesta a otros factores de riesgo, como conflictos sociales y extrema inequidad social.

El Corredor Seco de Guatemala es una de las zonas más afectadas por la intensificación de la canícula, con impactos severos y generalizados en la producción agrícola de los productores a pequeña escala y de escasos recursos (van der Zee Arias *et al*. 2012, Sain *et al*. 2017). Una proporción significativa de su población vive con inseguridad alimentaria (FEWS NET 2016) y las organizaciones públicas tienen una capacidad de respuesta a las sequías muy limitada (Müller *et al*. 2019). Aunque varios instrumentos de política y planificación de alto nivel reconocen la importancia de la información climática para la adaptación y la gestión integrada del riesgo climático (MARN (Ministerio de Recursos Naturales y Ambiente, Guatemala) 2022), aún falta un marco para su implementación. Diferentes instituciones gubernamentales guatemaltecas diseminan información para apoyar la adaptación a las sequías y enfrentar las crisis de seguridad alimentaria, pero el apoyo institucional al más alto nivel a estos esfuerzos es aún limitado.

1.4 Diseño de la investigación

Lo expuesto previamente nos llevó a plantear como objetivo de esta tesis doctoral, conocer las características de la vulnerabilidad al cambio climático y la capacidad adaptativa de las familias agricultoras a pequeña escala en América Central, así como de la gestión de información del cambio y variabilidad climática para favorecer la adaptación en las zonas más críticas de la región. La intención de este trabajo es apoyar procesos de toma de decisiones para la adaptación en la región poniendo en valor la información pública, el conocimiento local y los esfuerzos existentes en la gestión de información.

Para abordar el objetivo de esta tesis, planteamos dos preguntas principales de investigación:

Pregunta 1 ¿Cómo se caracteriza la vulnerabilidad al cambio climático de las familias agricultoras a pequeña escala en América Central, con especial atención a los factores que diferencian su capacidad de adaptación?

Pregunta 2 ¿Cuáles son las principales características de los servicios climáticos para apoyar la adaptación de las familias agricultoras a pequeña escala a las sequías en Guatemala?

La caracterización de la vulnerabilidad, la capacidad adaptativa y los esfuerzos de adaptación son temas complejos y no estandarizados cuyo abordaje requiere relacionar información de naturaleza diferente. Por lo anterior, basamos el marco metodológico de este trabajo en modelos conceptuales que nos permitieron desglosar las preguntas de investigación, definir las variables para responderlas y los instrumentos para recoger dichas variables usando métodos mixtos (Cuadro 1).

Para responder la primera pregunta nos basamos en el modelo conceptual de vulnerabilidad planteado por el IPCC en el AR4, y lo abordamos a dos niveles. El primer nivel es de gradación gruesa, que para efectos de este trabajo es una escala regional y nacional que toma como unidad de análisis los municipios (división administrativa de tercer nivel en cada país). El segundo nivel es de gradación fina, que para efectos de este trabajo es una escala local (microcuenca) y que toma como unidad de análisis los medios de vida agrícolas desarrollados en su territorio.

A nivel de gradación gruesa, analizamos información pública sobre dos aspectos: el impacto potencial del cambio climático en los cultivos más relevantes para los medios de vida de la agricultura a pequeña escala, e indicadores relacionados con capitales o recursos de la comunidad en los municipios rurales de los países de América Central con menor Índice de Desarrollo Humano. Organizamos los indicadores sobre los recursos de la comunidad en un índice de capacidad adaptativa siguiendo tres criterios: necesidades humanas básicas (p. ej., acceso a vivienda), recursos para la innovación (p. ej., acceso a asistencia técnica) y recursos para poner en práctica la innovación (p. ej., acceso a créditos agrícolas). Posteriormente identificamos grupos de municipios con diferentes niveles y tipos de capacidad adaptativa como punto de partida para priorizar líneas de adaptación.

A nivel de gradación fina, basamos nuestro trabajo en el conocimiento de diferentes actores recogido a través de procesos participativos en cinco microcuencas de la vertiente del Pacífico de Costa Rica, El

Salvador y el Estado de Chiapas en México para caracterizar la vulnerabilidad y la capacidad adaptativa a nivel local. A este nivel de análisis, también usamos el marco de capitales de la comunidad para abordar el análisis de la vulnerabilidad y la capacidad adaptativa.

Cuadro 1. Aspectos del marco metodológico de la investigación

Pregunta de investigación	*Variables*	*Instrumentos de colección de datos*
1 ¿Cómo se caracteriza la vulnerabilidad al cambio climático de las familias agricultoras a pequeña escala en América Central, con especial atención a los factores que diferencian su capacidad de adaptación?		
1.1 A escala regional y local, ¿cómo impacta el cambio climático los medios de vida de las familias agricultoras a pequeña escala?	• *Escala regional*: cambio potencial absoluto de la aptitud climática del territorio para sostener cultivos relevantes para los medios de vida. • *Escala local*: cambios en cantidad y calidad de cosechas y en los ingresos por medio de vida.	• Análisis de información secundaria. • Talleres participativos, grupos focales y entrevistas semiestructuradas.
1.2 A escala regional y local, ¿qué diferencia la capacidad adaptativa de los diferentes medios de vida de las familias agricultoras a pequeña escala?	• *Escala regional y local*: indicadores relacionados a los diferentes recursos de la comunidad.	• Ponderación participativa de indicadores y análisis de información secundaria. • Talleres participativos.
1.3 A escala local, ¿cómo se caracterizan las principales medidas de adaptación?	• *Escala local*: prácticas implementadas e identificadas relacionadas con los diferentes recursos de la comunidad y el nivel de adaptación.	• Talleres participativos.
2 ¿Cuáles son las principales características de los servicios climáticos para apoyar la adaptación de las familias agricultoras a pequeña escala a las sequías en Guatemala?		
2.1 ¿Cómo se caracteriza la oferta de los servicios climáticos para la gestión de sequías para la agricultura y la seguridad alimentaria en Guatemala, en términos de integración disciplinaria y relaciones entre productos?	• Integración temática en los productos de información disponibles • Roles de los productos en la provisión de información climática.	• Análisis de información secundaria.
2.2 ¿En qué grado conocen y usan, para qué usan y cómo perciben la oferta de servicios climáticos las personas encargadas de la agricultura y la seguridad alimentaria ante las sequías en Guatemala?	• Conocimiento de los productos de información por diferentes tipos de usuarios. • Uso de los productos por diferentes tipos de usuarios. • Objetivos y decisiones apoyadas por los productos de información según diferentes tipos de usuarios. • Usabilidad de productos de información climática.	• Entrevistas semiestructuradas.
2.3 ¿Cuáles son las principales recomendaciones para mejorar los servicios climáticos desde las necesidades de los usuarios y su producción?	• Oportunidades para mejorar las relaciones entre productos. • Oportunidades para reducir debilidades identificadas por los usuarios. • Aspectos positivos de los productos a ser reforzados.	• Entrevistas semiestructuradas. • Talleres participativos.

En ambos niveles de gradación utilizamos la tipología de medidas de adaptación basada en el grado de transformación que demandan, para sugerir líneas de adaptación a nivel regional y nacional y para clasificar las opciones de adaptación concretas que apoyen las agendas de las organizaciones de desarrollo que trabajan a nivel local.

Para responder la segunda pregunta, desarrollamos una metodología de evaluación de los servicios climáticos basada en su oferta y la percepción que tienen de ellos sus usuarios para gestionar los impactos del cambio climático en Guatemala, el país de la región con mayores problemas de seguridad alimentaria. Esta metodología fue aplicada primero en Guatemala y validada y contrastada posteriormente en dos departamentos de Colombia donde existen iniciativas de integración y difusión de esta información. Nos centramos en las sequías por ser el fenómeno del cambio climático que más afecta la agricultura a pequeña escala de Guatemala causando daños y pérdidas de cosechas en zonas extensas, y porque, consecuentemente, los esfuerzos de servicios climáticos en el país están centrados en su gestión ya que pueden pronosticarse razonablemente bien para reducir sus efectos (Müller *et al.* 2019). Basamos la metodología en el análisis de los productos de información climática disponibles mediante técnicas de redes para estudiar las relaciones entre productos, sus roles en la provisión de información y su agrupación según temas disciplinarios, escala geográfica o proceso de producción, y en un proceso participativo para conocer la percepción que tienen diferentes usuarios de estos productos y para identificar las principales oportunidades para mejorarlos junto a las entidades que publican los productos.

En todos los instrumentos de investigación consideramos un protocolo para garantizar la participación voluntaria e informada para recoger y organizar conocimientos y percepciones de diferentes actores. Una vez desarrollado el protocolo del instrumento, nos aseguramos de que estuviéramos formulado de una manera apropiada al contexto verificando el lenguaje, secuencia y duración con expertos locales. Incluimos en el protocolo la presentación de las personas que implementaron estas herramientas y el objetivo y alcance de su aplicación, la explicación de que las respuestas serían tratadas de manera anónima, y preguntas para que las personas optaran por participar o no; en el caso de participar, aclaramos que podían optar por no responder las preguntas que no quisieran. Antes de empezar cada entrevista pedimos permiso para tomar notas y grabaciones. Además, en los procesos participativos se hizo énfasis en la inclusión de grupos tradicionalmente marginados.

Terminamos este acápite presentando las principales limitaciones que encontramos durante la investigación. El análisis de vulnerabilidad a nivel regional tuvo como principal limitación la disponibilidad de información secundaria actualizada que permitiera medir indicadores comparables entre los países. Por eso, no pudimos incluir indicadores relacionados a los capitales, social, cultural y político, ni realizar un análisis más profundo que considerara factores de género, más allá del índice de paridad relacionado al acceso a la educación. Otra limitación de este análisis se sitúa en la limitación de recursos para su validación. Aunque recibimos comentarios valiosos de funcionarios de gobierno en Guatemala, Honduras y El Salvador en presentaciones de los resultados preliminares, hubiera sido deseable contar con el financiamiento necesario para desarrollar sesiones de trabajo para identificar y validar medidas de adaptación relacionadas a zonas concretas para cada país y a la región. También reconocemos la limitación de los modelos biofísicos para la estimación del impacto potencial del clima en los cultivos, pues no incluyen los efectos de la variabilidad climática.

La construcción de estrategias locales de adaptación al cambio climático tuvo como limitación principal el corto plazo disponible para su realización. Esto no hizo posible que pudiéramos apoyar la implementación operativa de la estrategia, identificar recomendaciones para mejorar el proceso de planificación, y principalmente, preparar espacios que garantizaran una mayor participación de mujeres y jóvenes en la plataforma de planificación y los mecanismos participativos de consulta y planificación.

La evaluación de los productos climáticos en Guatemala tuvo como principal limitación la parálisis temporal del sistema de extensión agrícola gubernamental causada por la transición de gobierno en 2016, el año que realizamos las entrevistas en el país. Esto causó limitaciones en la inclusión de funcionarios y extensionistas de este sistema, que consideramos uno de los principales usuarios de los productos climáticos.

1.5 Estructura de la tesis

Esta tesis opta por la modalidad de compendio de publicaciones. Según la normativa vigente del programa de doctorado en el que se presenta este trabajo (Programa de Doctorado en Desarrollo Local y Cooperación Internacional) se presenta la tesis con una compilación de tres artículos indexados en revistas de alto índice de impacto o capítulos de libros publicados por editoriales de prestigio. Este compendio incluye tres publicaciones, de las cuales la doctoranda es primera autora: dos artículos en revistas indexadas en SCImago y ubicadas en el primer cuartil de cambio global y ciencias atmosféricas, y un capítulo de libro publicado por la editorial Routledge. La estructura de la tesis es la siguiente:

- Capítulo 1: articula los capítulos de la compilación, entendiendo que la combinación de ellos es fruto de un único proceso de investigación. Este capítulo presenta el marco conceptual y metodológico, así como los objetivos y preguntas generales de la tesis, y aborda un resumen de cada capítulo publicado, su razón de ser y los elementos concretos en los que profundiza.
- Capítulos 2 a 4: recogen el contenido de las tres publicaciones que forman parte de la tesis.
- Capítulo 5: recoge la discusión general de los resultados de los tres artículos, en relación con los objetivos y las preguntas generales de la tesis.
- Capítulo 6: presenta las conclusiones generales del conjunto del trabajo.

1.6 Guía de lectura de los capítulos

Esta sección presenta una introducción a los capítulos que contienen las publicaciones incluidas en la tesis, señalando su contribución para responder a las preguntas generales de investigación. Los capítulos 2 y 3 abordan la primera pregunta desde diferentes escalas de trabajo, mientras que el capítulo 4 aborda la segunda pregunta de investigación. El Cuadro 2 relaciona las preguntas de la tesis con los capítulos en donde se tratan.

Cuadro 2. Relación entre preguntas de investigación y capítulos de la tesis

Preguntas de investigación	*Capítulos*
1 ¿Cómo se caracteriza la vulnerabilidad al cambio climático de las familias agricultoras a pequeña escala en América Central, con especial atención a los factores que diferencian su capacidad de adaptación?	
1.1 A escala regional y local, ¿cómo impacta el cambio climático los medios de vida de las familias agricultoras a pequeña escala?	2 y 3
1.2 A escala regional y local, ¿qué diferencia la capacidad adaptativa de los diferentes medios de vida de las familias agricultoras a pequeña escala?	2 y 3
1.3 A escala local, ¿cómo se caracterizan las principales medidas de adaptación?	3
2 ¿Cuáles son las principales características de los servicios climáticos para apoyar la adaptación de las familias agricultoras a pequeña escala a las sequías en Guatemala?	
2.1 ¿Cómo se caracteriza la oferta de los servicios climáticos para la gestión de sequías para la agricultura y la seguridad alimentaria en Guatemala, en términos de integración disciplinaria y relaciones entre productos?	4
2.2 ¿En qué grado conocen y usan, para qué usan y cómo perciben la oferta de servicios climáticos las personas encargadas de la agricultura y la seguridad alimentaria ante las sequías en Guatemala?	4
2.3 ¿Cuáles son las principales recomendaciones para mejorar los servicios climáticos desde las necesidades de los usuarios y su producción?	4

Capítulo 2: Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies
Autores: Claudia Bouroncle, Pablo Imbach, Beatriz Rodríguez-Sánchez, Claudia Medellín, Armando Martinez-Valle y Peter Läderach
Publicado en Climatic Change 141(1):123-137 (2017). DOI: 10.1007/s10584-016-1792-0
SCImago Journal Rank (SJR), 2017: 2.035; H Index 2019: 209, Q1 in Atmospheric Science and in Global and Planetary Change in 2017 (SCImago n.d.).

El segundo capítulo desarrolla una metodología y presenta los resultados de un análisis de vulnerabilidad al cambio climático de los medios de vida de familias agricultoras a pequeña escala, para 1019 municipios rurales de los cuatro países con menos Índice de Desarrollo Humano de América Central. El análisis de vulnerabilidad se basa en la definición provista por el AR4. El análisis presenta un Índice de Vulnerabilidad municipal que sintetiza los resultados de la caracterización del impacto potencial (información biofísica) y la capacidad adaptativa (información socioeconómica).

El impacto potencial es representado como el cambio esperado que tendrá el territorio de cada municipio en los 2030 (periodo 2020 – 2049) en su aptitud climática con relación al clima de base (periodo 1960 – 2000). Es decir, es representado como pérdidas o ganancias de aptitud del territorio para sostener la combinación de ocho cultivos (café, maíz, frijol, arroz de secano, sorgo, plátano y yuca) que son la base de la seguridad alimentaria y las fuentes de trabajo de las familias agricultoras a pequeña escala, y representan el 72% de la extensión cultivada en Guatemala, El Salvador, Honduras y Nicaragua según los últimos censos agropecuarios disponibles. El cambio en la aptitud climática se basó en el cálculo en la exposición a cambios en temperatura y precipitación y la sensibilidad estimada con parámetros fisiológicos de cada cultivo y el área relativa ocupada por cada cultivo en cada municipio (sub-pregunta 1.1, nivel regional).

Para la caracterización de la capacidad adaptativa de los medios de vida agrícolas, el trabajo propone primero un Índice de Capacidad Adaptativa de la población rural de los municipios considerando tres condiciones relacionadas con las dimensiones humana, natural, de infraestructura y financiera: la satisfacción de necesidades básicas, el acceso a recursos para la innovación y el acceso a recursos para llevar la innovación a la práctica. Posteriormente, el trabajo desarrolla un análisis estadístico multivariado para identificar y caracterizar grupos de municipios con diferentes patrones de capacidad adaptativa de sus poblaciones rurales (sub-pregunta 1.2, nivel regional). Finalmente, el capítulo discute las implicaciones de los resultados del análisis para la planificación de la adaptación a nivel regional y nacional.

Capítulo 3: Building local strategies for the adaptation to climate change of farming livelihoods. Review of a participatory approach applied in Mesoamerica
Autores: Claudia Bouroncle, Alejandro Carlos Imbach, Andrea Zamora, Omaira Urueña y Alejandra Boni
Publicado como capítulo 3 del libro *Community Capacity and Resilience in Latin America*, editado por Paul R. Lachapelle, Isabel Gutierrez-Montes y Cornelia Butler Flora (2021). p. 32 – 51.
Editorial: Routledge. DOI: 10.4324/9781315111605-3

El tercer capítulo desarrolla una metodología participativa y presenta los resultados del análisis de vulnerabilidad al cambio climático de medios de vida de familias agricultoras a pequeña escala, desarrollados en cinco microcuencas de la vertiente del Pacífico de América Central y el sur de México (Estado de Chiapas), donde hubo interés manifiesto de alguna organización para realizar un análisis de vulnerabilidad al cambio climático y desarrollar una estrategia local de adaptación. El análisis de vulnerabilidad formó parte de la construcción de estrategias locales de adaptación al cambio climático, que se desarrollaron en tres pasos. La definición del alcance del trabajo en cada microcuenca (paso 1) incluye la definición de las instituciones participantes, el alcance territorial y los medios de vida a ser incluidos. El análisis de vulnerabilidad en sí (paso 2), se basa en métodos participativos para caracterizar la exposición al clima, la sensibilidad de los medios de vida y el impacto actual en los diferentes medios de vida (sub-pregunta 1.1, escala local). El análisis de vulnerabilidad incluye también la caracterización de la capacidad adaptativa de los diferentes medios de vida en cada microcuenca (sub-pregunta 1.2, escala local). Como parte de la preparación de las estrategias de adaptación (paso 3), se caracterizan las medidas actuales y propuestas de adaptación, utilizando el marco de capitales de la comunidad y la profundidad del cambio (medidas progresivas a transformacionales (sub-pregunta 1.3). Finalmente, el capítulo identifica conclusiones y recomendaciones para la implementación de la metodología. La metodología recurrió a técnicas participativas de recolección y organización de información primaria, como grupos focales, entrevistas semiestructuradas y talleres.

Capítulo 4: A systematic approach to assess climate information products applied to agriculture and food security in Guatemala and Colombia

Autores: Claudia Bouroncle, Anna Müller, Diana Giraldo, David Rios, Pablo Imbach, Estuardo Girón, Fernando Portillo, Alejandra Boni, Jacob van Etten y Julian Ramirez-Villegas

Publicado en Climate Services 16:100137 (2019). DOI: 10.1016/j.cliser.2019.100137

SCImago Journal Rank (SJR), 2019: 1.942; H Index 2019: 33, Q1 in Atmospheric Science and in Global and Planetary Change in 2019 (SCImago n.d.).

El cuarto capítulo muestra los resultados de una evaluación de productos de información para la agricultura de subsistencia y seguridad alimentaria en el Corredor Seco de Guatemala, así como los resultados de su validación en dos departamentos de Colombia. En estos países de América tropical los medios de vida agrícolas y la seguridad alimentaria son muy vulnerables al cambio climático, pero difieren en términos de institucionalidad y necesidades de los usuarios finales de información.

El enfoque de evaluación aborda conjuntos de productos de información que cubren el nexo del clima, la agricultura y la seguridad alimentaria. El enfoque usó dos metodologías. El análisis de redes proporcionó una perspectiva del conjunto de productos de información para examinar su integración disciplinaria y las relaciones de intercambio de información, mientras la evaluación centrada en los usuarios examinó los productos individualmente y recogió recomendaciones para su mejora.

La evaluación inició con la elaboración de un inventario (paso 1) de productos con información relevante para la adaptación de la agricultura ante las sequías y la gestión de crisis de seguridad alimentaria relacionadas, definiendo así una oferta de información climática basada en quince productos. En Guatemala, siete de estos productos reportaron la evolución de variables de clima, cultivos y seguridad alimentaria, mientras ocho ofrecieron pronósticos de estas variables. Dos productos fueron elaborados por plataformas intergubernamentales centroamericanas (nivel regional), diez por elaborados por entidades gubernamentales y de cooperación, y tres por municipios, ONG, u otras entidades en localidades del Corredor Seco, la zona del país más expuesta a estos eventos (nivel local). Una vez elaborado el inventario, se determinó cuáles productos citaban a otros como base para análisis estadísticos. El análisis multivariado (paso 2) exploró si existe integración disciplinaria en la oferta de productos, y el análisis de redes exploró los roles de difusión e intermediación de información de los productos (sub-pregunta 2.1). La evaluación de los productos centrada en los usuarios (paso 3) se basó en el análisis de 40 encuestas semiestructuradas, 17 realizadas a personas en Ciudad de Guatemala y 23 en localidades del Corredor Seco, e identificó para qué son usados los productos de información, es decir, a qué tipo de decisiones apoyan y a qué plazo, y cómo son percibidos en términos de contenido, credibilidad, legitimidad, resolución (escala), transmisión de conocimiento, procedimientos de elaboración y difusión, y utilidad de las recomendaciones para influir decisiones (sub-pregunta 2.2). En el último paso (paso 4) se definieron, con participación de las organizaciones responsables de los productos de información, las oportunidades para su mejora, con recursos disponibles o con nuevos recursos (sub-pregunta 2.3).

1.7 El contexto institucional de la investigación

Esta sección describe el contexto institucional de desarrollo de esta tesis, desde mis roles de investigadora en adaptación al cambio climático en el Laboratorio de Modelado Ambiental (LMA), una unidad del Programa de Cambio Climático y Cuencas del Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), y docente de la Maestría Profesional en Práctica del Desarrollo (MPD) de la Escuela de Posgrado de dicha organización.

El CATIE es un centro regional, con trece países latinoamericanos miembros regulares y sede en Costa Rica, dedicado a la investigación y la enseñanza de posgrado en agricultura, manejo, conservación y uso sostenible de recursos naturales. Entre 2012 y 2016 el LMA apoyó la planificación, toma de decisiones y gestión de la acción climática, vinculando la investigación en agricultura y servicios ecosistémicos con procesos regionales, nacionales y locales en América Central. Este propósito se basó en la generación, análisis y puesta en valor de datos; el modelado biofísico y socioeconómico; y la interacción con organizaciones gubernamentales, no gubernamentales, comunitarias y privadas. El LMA fue posteriormente incorporado a la Unidad de Acción Climática del CATIE. Entre 2011 y 2021, la MPD contribuyó a la formación de profesionales universitarios en procesos de desarrollo rural a escala local. Los participantes realizaban un trabajo profesional de graduación respondiendo a la demanda de una organización activa en este tipo de procesos.

Formulé el plan de investigación de esta tesis basándome en tres proyectos de investigación y enseñanza que lideré como investigadora del LMA y docente de la MPD. Estos proyectos respondieron a demandas de diferentes organizaciones, requirieron de trabajo interdisciplinario e interinstitucional, abarcaron un espacio geográfico amplio y combinaron diferentes fuentes de financiamiento; por lo que el plan de investigación puede haber tenido un desarrollo diferente al de los proyectos de investigación financiados por becas doctorales.

El *Análisis de vulnerabilidad y capacidad adaptativa de municipios de América Central*, origen del Capítulo 2 de esta tesis, fue cofinanciado por el Programa de Investigación en Cambio Climático, Agricultura y Seguridad Alimentaria (CCAFS por sus siglas en inglés) del CGIAR[1] y el Portal Regional para la Transferencia de Tecnología y la Acción Frente al Cambio Climático en América Latina y El Caribe (REGATTA) del Programa de las Naciones Unidas para el Medio Ambiente (PNUMA). Este proyecto abarcó 1019 municipios rurales de Guatemala, El Salvador, Honduras y Nicaragua y se benefició de la colaboración del personal del LMA y del Centro Internacional de Agricultura Tropical (CIAT, organización encargada de la implementación del CCAFS en América Latina) para la recuperación y organización de datos de censos agropecuarios y de población y vivienda (incluyendo a veces su digitalización) y el modelado del impacto potencial del cambio climático en cultivos agrícolas. La sección de reconocimientos en Bouroncle *et al*. (2017) menciona el apoyo institucional relacionado a este trabajo de investigación.

[1] El CGIAR (antiguamente Grupo Consultivo para la Investigación Agrícola Internacional) es un consorcio de centros de investigación que incluye la Alianza Bioversity International - Centro Internacional de Agricultura Tropical (CIAT).

Mi labor en este proceso consistió en liderar el diseño del marco conceptual y metodológico, analizar los resultados del modelado del impacto potencial del cambio climático en los cultivos, seleccionar y supervisar la recopilación de información de estadísticas, realizar el análisis estadístico e interpretar los resultados. Presenté la primera versión de los resultados ante representantes de entidades gubernamentales en El Salvador, Guatemala y Honduras y en el congreso *Adaptation Futures* en Brasil en 2014, los comentarios en los eventos nacionales fueron especialmente importantes para mejorar la estructura de indicadores de capacidad adaptativa. Presenté la segunda versión del análisis en un evento de investigadores en agricultura, recursos naturales y cambio climático en Costa Rica en 2015, cuyos comentarios fueron de mucha utilidad para la redacción del artículo presentado en el Capítulo 2.

El desarrollo de las *Estrategias Locales de Adaptación al Cambio Climático en Mesoamérica*, origen de la información analizada en el Capítulo 3 de esta tesis, abarca cinco estudios de caso desarrollados en microcuencas de la vertiente del Pacífico de Mesoamérica. Dos estudios de caso fueron desarrollados con el apoyo de REGATTA-PNUMA en América Central y tres en el Estado de Chiapas, con el apoyo de *The Nature Conservancy* entre 2014 y 2015. Una condición para la selección de las microcuencas es que hubiera organizaciones locales que expresaran su interés en diseñar estas estrategias locales. La sección de agradecimientos en Bouroncle *et al*. (2021) menciona el apoyo institucional relacionado a este trabajo de investigación.

En la construcción de los estudios de caso mi labor también fue liderar el diseño del marco conceptual del análisis de vulnerabilidad, otro docente de la MPD lideró el diseño del proceso participativo de planificación; ambos marcos fueron complementarios y ampliamente discutidos en talleres con la participación de estudiantes y ambos docentes. Asimismo, ambos docentes supervisamos cercanamente la formulación y aplicación de los instrumentos para la recolección de información de campo en América Central, tareas que estuvieron a cargo de dos estudiantes de la MPD. Una vez graduadas, las antiguas estudiantes de la MPD aplicaron el marco conceptual y metodológico mejorado en Chiapas, México. Terminados los estudios de caso, preparé una sistematización de la experiencia para identificar lecciones y mejoras en la aplicación de la metodología, la cual recibió aportes de diferentes profesionales del LMA y MPD.

El Capítulo 3 presenta una revisión del conjunto de las estrategias locales de adaptación. Como líder de esta revisión, profundicé el marco conceptual, ahondando el uso del enfoque de medios de vida y sumando el concepto de adaptación transformacional, y validé la propuesta conceptual y metodológica al mostrar la consistencia de su aplicación en diferentes medios de vida y contextos geográficos. El docente que lideró la formulación del marco conceptual del proceso participativo de planificación hizo críticas y aportes a este proceso, y además realizó entrevistas no formales de seguimiento a miembros de las organizaciones locales participantes, las graduadas aportaron información complementaria y en conjunto validamos las conclusiones de esta revisión.

La *Evaluación de productos de información agroclimática aplicados en la gestión del impacto de las sequías en la agricultura y seguridad alimentaria en Guatemala* se basa en un proyecto desarrollado por el LMA entre 2014 y 2016, fue financiado también por el Programa CCAFS y apoyado técnicamente por el equipo de Bioversity International en Costa Rica. La sección de reconocimientos en Bouroncle *et al*. (2019) menciona el apoyo institucional relacionado a este trabajo de investigación.

Mi labor en este proceso nuevamente consistió en liderar la definición del marco conceptual y metodológico, validar los instrumentos de recolección de información, aplicarlos en conjunto con socios locales, analizar los resultados de su aplicación, interpretar los resultados, formular las conclusiones y redactar el artículo final. Participé en la selección de personas a entrevistar y la realización de las entrevistas, con fuerte colaboración en esta tarea de personal de la Oficina Nacional del CATIE y de la oficina nacional de Acción contra el Hambre, ambas en Guatemala.

Redacté la primera versión de los resultados de esta evaluación para su publicación como documento de trabajo del CCAFS y la presenté en el II Congreso Nacional de Cambio Climático en Guatemala en 2016. La metodología de evaluación fue validada entre 2017 y 2018 en dos departamentos de Colombia por personal de CIAT, también bajo el Programa CCAFS. El Capítulo 4 recoge ambas experiencias, cuyo contraste ofrece una mejor oportunidad para la discusión del enfoque utilizado y para proponer mejoras para su futura aplicación. También en esta oportunidad lideré la redacción del artículo, prestando especial atención a la consistencia del análisis de los resultados de ambas experiencias. Preparé la presentación de este estudio para su difusión en la Conferencia Internacional de Servicios Climáticos realizada en Pune, India en 2020, presentación que fue realizada por una de las coautoras que tuvo acceso a financiamiento para asistir a este evento.

Además de las tareas descritas, lideré la publicación de los resultados parciales de los estos tres capítulos de la tesis, difundidos a través de canales de libre acceso, en castellano y en un lenguaje más accesible para técnicos y profesionales de la región, incluyendo entradas a blogs, reportajes en un periódico local y resúmenes para decisores. Las estadísticas de ResearchGate y Google Scholar muestran que varios de estos productos y los artículos publicados son utilizados. Por ejemplo, el capítulo sobre seguridad alimentaria (Mbow *et al*. 2019) del informe especial *El cambio climático y la tierra* publicado por el IPCC recoge resultados del análisis de vulnerabilidad y capacidad adaptativa de municipios de América Central. Por otro lado, la metodología de evaluación de productos de información agroclimática aportó al establecimiento de espacios de análisis y discusión para identificar recomendaciones para la adaptación a la variabilidad y cambio climático a nivel local.

En definitiva, el proceso de investigación ha transcurrido entre el plano académico y profesional, en colaboración con diferentes equipos de trabajo, en un espacio geográfico amplio, y existen indicios de su utilidad para la gestión de la adaptación al cambio climático de la agricultura de América Central, el motivo central del trabajo.

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2 Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies

This chapter of the dissertation is an adaptation of:

"Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies" by Claudia Bouroncle, Pablo Imbach, Beatriz Rodríguez-Sánchez, Claudia Medellín, Armando Martinez-Valle and Peter Läderach, published in Climatic Change 141(1):123-137 (2017), DOI: 10.1007/s10584-016-1792-0.

Minor changes were made to adapt the article to this Ph. D. dissertation, such as layout, fonts, and acknowledgments section. Supplementary material and production modifications (such as copy-editing) were not included. Amendments in citations and references are included at the end of the dissertation.

Title: Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies

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Abstract

Climate change is one of the main threats to rural livelihoods in Central America, especially for small and medium-sized farmers. Climate change vulnerability assessment (CCVA) integrates biophysical and socioeconomic information to support policy decisions. We present a CCVA of agricultural livelihoods of four countries in Central America, at the municipality level. We use the IPCC definition of vulnerability, and address the potential impact of climate change on suitability for major crops and adaptive capacity using indicators of basic human needs, as well as resources for innovation and action framed in a livelihoods approach. Adaptive capacity was estimated using ranking techniques for municipalities and descriptive multivariate analysis. Projected changes in climate suitability for crops show a wide variation between Guatemala, El Salvador, Honduras and Nicaragua, and within each country. Cluster analysis of adaptive capacity values shows a gradient between higher values close to urban areas and lower values in agricultural frontier areas and in those prone to drought. Municipalities with a high proportional area under subsistence crops tend to have less resources to promote innovation and action for adaptation. Our results suggest that a full spectrum of adaptation levels and strategies must be considered in the region to achieve different adaptation goals. They also show that the adaptive capacity ranking and characterization are complementary and support geographical prioritization and identification of adaptation strategies, respectively.

Keywords: climatic suitability, adaptation, agriculture, Guatemala, El Salvador, Honduras, Nicaragua

1 Introduction

Central America is the tropical region where the biggest changes in future climate are expected (Giorgi 2006). It is expected to become drier resulting from reduced precipitation and increased temperatures (Imbach et al. 2012) as well as to have stronger dry seasons (Rauscher et al. 2008), the factor that driver the agriculture calendar. The region is recursively affected by droughts, cyclones and the El Niño-Southern-Oscillation (Bárcena et al. 2011). Between 1960 and 2000, it experienced increases in temperature and although significant changes have not been observed in total annual precipitation, an increased proportion of precipitation has been observed during extreme events (Aguilar et al. 2005). The global climate risk index (Harmeling and Eckstein 2012) shows that between 1992 and 2011 Honduras was the world's most vulnerable country to extreme weather events, Nicaragua the 3rd most vulnerable, Guatemala the 11th, and El Salvador the 15th; Costa Rica and Panama, the southernmost countries of the region, are much less exposed to extreme weather events and less vulnerable according to this index (72nd and 108th respectively). Imbach et al. (2016, this issue) provide a more detailed description of the region´s climatic trends and projected future changes.

Agriculture, still a pillar for rural economies and for the food security of the poorest sectors of Central American society (Tucker et al. 2010), is one of the region´s most vulnerable sectors to climate variability (CCAD 2010). Despite favourable socio-economic changes in recent decades, inequality and rural poverty still persist across countries (Corbacho and Davoodi 2002; Siegel 2005). UNDP (2014) classifies El Salvador, Guatemala, Honduras and Nicaragua as Medium Human Development countries, while Panama and Costa Rica are classified as High Human Development countries with less agriculture-dependent economies.

Lower crop productivity in the region is related to low population density, rainfall seasonality and low soil fertility (Kok and Veldkamp 2001). The Pacific watershed has more pronounced rain seasonality and has been more densely populated due to better agro-ecological conditions (Finegan and Bouroncle 2008). The Central American Dry Corridor comprises the driest, most seasonal part of this area and runs from Guatemala to Costa Rica. National statistics show that subsistence crops, like maize and other basic grains, are located predominantly in areas with lower population density. Agro-industrial crops like sugarcane predominate in areas with higher population density and in coastal areas and coffee predominates on volcanic soils at intermediate altitudes.

To promote proactive adaptation in agriculture, policy makers need to know who are most vulnerable, what stresses they face, and what resources are available for adaptation (Ford et al. 2010). Climate change vulnerability assessments (CCVA) are commonly used to define and prioritize climate change adaptation interventions (Metternicht et al. 2014; Tonmoy et al. 2014). Studies across Central America have shown the potential impacts (PI) of climate change on coffee (Bunn et al. 2015, Ovalle-Rivera et al. 2015), maize (Gourdji et al. 2015, Schmidt et al. 2012), and beans (Schmidt et al. 2012) at the country level, and assessed the vulnerability of coffee smallholders (Rahn et al. 2013; Baca et al. 2014) and groups of communities that depend on maize and beans cultivation (Schmidt et al. 2012). However, the PI studies focus on selected crops (especially coffee) and the climate change vulnerability assessments focus on farmer groups (e.g. coffee cooperative members or farmers with organic certification), and most of them present results only for certain areas within countries. A truly regional assessment integrating the range of crops important to smallholders is therefore still lacking. To our knowledge, existing regional (SICA 2008, CCAD 2010) and national strategies (MAGA 2012, MAG 2012, SAG 2010, MAGFOR 2013) for adaptation of the agricultural sector and dependent rural livelihoods in Central America lack a definition of geographical priorities (where to adapt) and type of adaptation measures (how to adapt). Regional-scale CCVA captures key gradients of biophysical and socio-economic factors (Tonmoy et al. 2014). Approaches based on indicators and visualization techniques, and that use available information, are cost-effective and transparent frameworks for comparative analysis, and help to understand context-specific aspects of vulnerability and to identify actions (Malone and Engle 2011).

To contribute to the identification of adaptation priorities of smallholder agricultural livelihoods in Central America, we quantify climate change vulnerability at the municipality level across four countries with the lowest human development in the region, according to UNDP, using sector wide census data and crop suitability modelling. We also present a ranking approach and a multivariate statistical analysis to determine the geographic distribution of adaptive capacity (AC) of rural populations, identify and describe groups of municipalities with similar AC (e.g. Sietz et al. 2011, 2012) and discuss the implications of our results for adaptation planning.

2 Data and methods

2.1 Vulnerability assessment assumptions

We developed a quantitative indicator-based CCVA of rural agricultural livelihoods and applied it at the municipality level in Guatemala, El Salvador, Honduras and Nicaragua. Municipality, as defined by national constitutions in these countries, is the second level of administrative division and is also the basis of their territorial, political and administrative organisation. The first level of administrative division (departments) was too large for the purposes of this study.

We defined rural agricultural livelihoods as the combination of cash and subsistence crops for small- and medium-scale farmers in each municipality. Crops included were coffee, maize, beans, upland rice, sorghum, plantain, and cassava. Each of these crops accounts for more than 0.5%, on average, of the cultivated area in the four countries (excluding pastures) (Supplementary Material 1) according to the latest agricultural census or statistics for each country (Supplementary Material 2). We considered 1019 municipalities in our analysis and excluded those lacking rural population (18), census data (1) or out of the current and projected environmental ranges of all their current crops (6).

We define vulnerability as expected change in agricultural livelihoods over a given timeframe, as a function of exposure, sensitivity and AC (Parry et al. 2007). Exposure is defined as the degree and direction of change of climate variables, sensitivity as the characteristics that determine how a system is affected by these changes, and AC as the ability of a system to adjust to these changes. The combination of exposure and sensitivity define the potential impact (PI) that may occur given a projected change in climate, without considering adaptation (Locatelli et al. 2008).

2.2 Potential impact (crop modelling)

PI was represented for each municipality as the expected absolute change in climatic suitability for crops in it, weighted by the proportional area of each crop (the area occupied by a given crop divided by the total area occupied by all crops). We quantified current exposure for the 1960-2000 period using 19 bioclimatic variables available in WorldClim (Hijmans et al. 2005). Future exposure was derived from 24 General Circulation Models from the IPCC Fourth Assessment Report for the 2020-2049 (2030s) period and A1B mid-emission scenario, using the downscaling procedure of Ramírez-Villegas and Jarvis (2010). We used the EcoCrop mechanistic model (Hijmans et al. 2001) to quantify current and future suitability ranges for each crop. Variables used to calculate current and future suitability and to parameterize EcoCrop were defined by previous research and expert judgment, including that of crop specialists (Supplementary Material 3). We obtained the proportional suitability change for each crop as the difference between the projected and current potential suitability values in each pixel. For each municipality we determined the mean suitability change for each crop and a Weighted Average Suitability Change (WASC), as the mean suitability change for each crop weighted by the fraction of total agricultural area occupied by that crop.

2.3 Adaptive capacity and vulnerability ranking

We mapped the Adaptive Capacity Index (ACI) of the rural population in the municipalities as a function of three conditions selected by us in relation to human, natural, built, and financial capitals (Scoones 1998; Flora et al. 2015): basic needs satisfaction, resources for innovation and resources for transforming innovation into actions. We developed criteria to characterize each condition based on the livelihoods approach recommended for CCVA of rural smallholder farmers (Knutsson and Ostwald 2006; Eakin and Bojórquez-Tapia 2008; Imbach and Prado 2013). We based the selected indicators for each criteria (see Table 1) on literature specific to Central America (Corral and Reardon 2001, Lanjouw 2001, Ruben and Van Den Berg 2001). The same indicators and calculations (Supplementary Material 4) were applied in all municipalities, so indicator selection was constrained by available spatial information covering all countries from the latest population and housing censuses and public health statistics (Supplementary Material 2). We normalized indicator values linearly to a 0-1 interval based on their minimum and maximum values in each country, to avoid biases regarding differences in socioeconomic development between countries. We used the inverse values of some indicators, so that increases in values always represent increases in AC.

We assumed equal weights for the three ACI conditions as they represent successive steps in an innovation process (Imbach and Prado 2013), based on basic needs satisfaction (the Maslow perspective applied to human development, see Hagerty 1999) and motivation and information as the basis for a transition from reactive to planned responses (Flora 2004). Criteria weights (Table 1) were based on a survey completed by 33 regional experts (from 44 approached) from Central American public agencies, universities, research and development organizations, global agriculture and climate change research organisations, and multilateral agencies (Supplementary Material 5). The experts were selected by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) and their respective organisations to participate in a workshop in 2013 to define regional priorities for this program. We asked the experts to rank criteria and assessed the mode of the resulting values for each criterion using the ranking sum method (Stillwell et al. 1981) to generate numerical weights, as recommended by Malczewski (1999) for small sets of parameters. We evaluated most criteria through one indicator, when two were available used the average as the criterion value.

INSERT TABLE 1 NEAR HERE

Finally, we calculated a Vulnerability Index (VI) for each municipality as the sum of PI and ACI, and the values obtained were normalized linearly to a 0-1 interval, again based on their minimum and maximum values in each country; we used these values to classify municipalities into three quantiles representing lower, intermediate and higher vulnerability. We also calculated an index by weighting indicators using the principal component analysis (PCA) eigenvector values (section 2.4). We performed calculations separately for each country.

2.4 Adaptive capacity clusters

Cluster analysis has been used in previous CCVA (Sietz et al. 2011, 2012) to reveal vulnerability patterns that show typical combinations of the units of analysis based on their attributes. In this study, we grouped municipalities with similar AC patterns in each country separately using cluster analysis with Euclidean distance and Ward´s algorithm. We selected the minimum number of clusters that showed (i) the greatest decline of the k-means algorithm and (ii) tolerance to misclassification <20%, using the apparent error rate obtained from discriminant analysis. We used multivariate analysis of variance (MANOVA) to determine whether indicator values differed significantly between clusters and inferred the main determinants of AC using PCA. We compared AC clusters using the mean values of individual indicators for each weighted by the eigenvectors from the first PCA component. Finally, we compared mean cluster values of AC indicators, other social indicators not directly related to AC and the proportion of area occupied by different crops, using analysis of variance (ANOVA) and Tukey´s test. All statistical analysis was done using InfoStat 2015 (Di Rienzo et al. 2015).

3 Results

3.1 Potential impact of climate change on crops

Almost half the municipalities (514) will lose some climatic suitability to sustain their current cash and subsistence crop combinations (WASC between -0.1% and -31%). The rest (505) will gain suitability (WASC between 0.1% and 59%). Around half (512) of the municipalities had a WASC of 10% or less (Supplementary Material 6). On average, El Salvador and Nicaragua are projected to experience a decline of WASC (-5% and -6% respectively), but increases are projected for mountainous Honduras and Guatemala (0.5% and 8% respectively). Coffee, beans and plantain are likely to suffer decreases in suitability across all countries, resulting from increased temperatures in low altitude areas. Maize (a C4 photosynthetic pathway crop), cassava, upland rice and sorghum (also C4) will gain climatic suitability in all countries (details in Supplementary Material 6 and 7).

INSERT FIGURE 1 NEAR HERE

3.2 Adaptive Capacity Index and Vulnerability Ranking Index

ACI showed a gradient from higher values close to major urban areas and trade routes to lower values in municipalities prone to drought (Dry Corridor, mainly eastern Guatemala, western Honduras and northern and eastern El Salvador) or closer to areas where agriculture is expanding progressively at the expense of natural forests (in northern Guatemala, north-eastern Honduras, and eastern Nicaragua) which is hereafter called "the agricultural frontier" (Figure 2a).

INSERT FIGURE 2 NEAR HERE

Municipalities with lower PI and higher ACI are in the category of lowest VI. Examples are municipalities including or close to urban areas in the Pacific coast of Guatemala, El Salvador and Nicaragua, where combinations of maize, sorghum, and agro-industrial crops predominate (Figure 2b, Case 1). Higher VI values include municipalities with higher PI due to high suitability changes (e.g. suitability gain for coffee and beans, Guatemala; or suitability loss for the same crops in Honduras, Figure 2b, Case 2) and lower ACI. Municipalities with intermediate VI have higher ACI and lower PI or the inverse. Examples of the former are municipalities that contain or are close to major urban areas and face higher suitability change (e.g. suitability gain for beans, Guatemala; suitability loss for the same crop, Honduras, Figure 2b, Case 3). Among the latter are municipalities in agricultural frontiers that will experience smaller changes in suitability (e.g. suitability gain for maize, Guatemala; suitability gain for upland rice and cassava, Nicaragua, Figure 2b, Case 4).

3.3 Adaptive Capacity clusters

The minimum number of clusters of municipalities is highest in Guatemala and El Salvador (7 clusters in each), intermediate in Honduras (6), and lowest in Nicaragua (5). MANOVA indicated significant differences ($p<0.001$) between all clusters in each country. Apparent error rates in the allocation of municipalities to clusters, i.e. the probability that a municipality has been erroneously assigned to a cluster, ranged between 10 and 17% (Guatemala 15%, El Salvador 17%, Honduras 16%, Nicaragua 10%). The spatial distribution of clusters by AC level follows the same trend found for ACI (Figure 3).

INSERT FIGURE 3 NEAR HERE

In most countries, the indicators with higher eigenvectors on the first component of the PCA (PC1, see PCA biplots in Supplementary Material 8 and eigenvector values in Supplementary Material 9) included those related to basic needs satisfaction and access to resources for innovation and action. That is, better performance inferred from these indicators (higher mean indicator values) was related to higher AC of the clusters. These basic needs satisfaction indicators include safe drinking water (in Honduras and Nicaragua), rural school-aged population attending school (in all countries), rural dwellings built with long-lasting materials (in all countries) and the rural gender parity index (in all countries), those for access to resources for innovation and action include road density (in Guatemala, El Salvador, Nicaragua), rural economically active population with non-agricultural employment (in all countries), and rural demographic dependency ratio (in all countries). Some indicators nevertheless do not follow this pattern. Indicators with lower or negative eigenvector values on PC1 include those related to agricultural and health services. Better performance inferred from these indicators is related to clusters with intermediate or lower AC. These indicators include primary healthcare units per 1000 people (in El Salvador, Honduras, and Nicaragua) and the proportion of agricultural production units that receive technical assistance and/or an agricultural loan (in all countries). The proportion of entitled agricultural production units is highly negatively related with PC1 in Guatemala and Nicaragua and less so in El Salvador and Honduras.

In all countries, clusters with higher AC have higher population density and higher proportions of agricultural land under cash crops, while those with lower AC have a higher proportion of land under basic grains (all comparisons using ANOVA; see *p* values in Supplementary Material 10). Clusters with higher proportions of agricultural production units receiving technical assistance and loans also have higher proportions of land under coffee, and intermediate AC. Clusters with higher proportions of agricultural production units with secure land tenure also have higher proportions of land under basic grains. Most of these clusters have intermediate or lower AC. In El Salvador, the cluster (VI) with the highest proportion of agricultural production units with secure land tenure is also that with the highest proportion of land under coffee.

4 Discussion

Our study provides insights to guide adaptation implementation in four vulnerable Central American countries. We show, for example, that municipality clusters with lower basic needs satisfaction tend to underperform on indicators for innovation and action, suggesting adaptation actions focused on basic needs should receive high priority. We show that selecting indicators that underpin AC, like non-agricultural employment, instead of outcomes (e.g. child mortality) can also support prioritization for planned adaptation. Rural economically active population with non-agricultural employment was one of the most important factors defining AC clusters. Regional (Reardon et al. 2007) and country studies (Corral and Reardon 2001 in Nicaragua; Lanjouw 2001 in El Salvador; Ruben and Van Den Berg 2001 in Honduras) have shown that a good performance of this indicator contributes to poverty reduction among smallholders. Access to credit and technical assistance (associated with coffee farms) is related to intermediate AC, because these factors do not guarantee opportunities for income diversification, highlighting that rural development policies emphasising agricultural incentives are not effective to promote territorial development (Reardon et al. 2007). Finally, distance to urban or more densely populated areas and higher non-farm employment have important effects on poverty (Plant 1998, Jamieson 1999), and our study highlights their relationship to AC. We found the rural demographic dependency ratio to be an important indicator of AC and potentially relevant to development interventions, as it is related to rural-urban migration or migration to other countries.

Evaluations of criteria and indicators to assess CCVA, as in our study, have previously been performed using both ranking and multivariate analysis for spatial comparative approaches (e.g. Nelson et al. 2009, Monterroso et al. 2014) with a high degree of consistency of results. We also found a high correlation (Spearman´s r correlation > 0.8) between ACI and mean indicator values weighted by factor scores on PC1 (as suggested by Monterroso et al. 2014). Comparison between those two approaches to weighting indicators in terms of their effects on the ranking results is recommended. We used inputs from experts to estimate weights under the assumption that they reflect an overall view of the relative importance of different AC characteristics across the region. Further research should also focus on alternative standardization and weighting procedures to that used here to estimate AC and vulnerability indexes. The clustering analysis used here avoids some of these caveats by assuming that changes in indicator values are relevant to the characterization of AC and therefore depend on expert weighting of indicators. Our approach has regional scope and shows cluster-specific attributes that could define entry points for adaptation planning. However, we suggest that our results should be validated using local scale case studies (e.g. Sietz et al. 2011).

Although our results show high correlation between AC calculated using the ranking and cluster methods, we foresee different potential applications. Ranking can support prioritization of regions for interventions seeking improved AC and reduced vulnerability. Clustering can support the identification of regions requiring similar development strategies, for example, the improvement of basic needs satisfaction. Potential obstacles and opportunities can also be explored for regional strategies. For example, because of migration, labour availability may be insufficient for the implementation of novel farm practices in areas where current crops suitability will be lost.

Research priorities to improve CCVA at regional scales include, for PI assessment, integration of climate variability and non-climatic stresses and their interaction with climate change variables; and for AC assessment, the understanding and integration of indicators of social, cultural and political capitals, as well as the validation of AC distribution with existing local case studies and/or outcomes indicators. Governmental organizations or NGOs promoting local development could provide consistent information for this purpose.

Overall, our results regarding PI of climate change on current crop combinations are congruent with Schmidt et al.'s (2012) proposal of three future scenarios for Central American agriculture. The first scenario, pressure areas, is represented in our study by municipalities that are becoming more suitable for certain crops; the second scenario, adaptation areas, is represented in our study by those municipalities where current crop combinations are expected to remain viable with technological adjustments. Finally, the third scenario, hotspots, is represented in our study by municipalities where the expected suitability reduction is such that current crop combinations might not be economically feasible.

5 Conclusions

Projected changes in climate suitability for crops show a wide variation between Guatemala, El Salvador, Honduras and Nicaragua, and within each country. Results suggest that crops such as Gramineae (both C3 and C4 photosynthetic pathways) and roots will experience increases in average climatic suitability in all countries, but that others, like tree crops and beans, will experience decreases. Many of the gains occur in municipalities where suitability will increase for crops that are currently not a component of food-security (e.g. sorghum in the Caribbean basin), or in the highlands, where other land uses are currently a priority (e.g. protected areas). Both gains and losses of climatic suitability are therefore a challenge for adaptation.

A full spectrum of adaptation levels, as defined by Rickards and Howden 2012, must be considered in these four countries. In pressure areas and hotspots (respectively: areas that are becoming more suitable for certain crops, and areas where expected suitability reduction for current crop combinations may mean that current crop combinations become economically unfeasible), proposed adaptation pathways might require major and purposeful responses to climate change impacts and other drivers at the farm and supra-farm level (transformational adaptation). These adaptation strategies could include restoration of degraded lands, rearrangement of land uses across territories, livelihood diversification, and even migration. Where relatively low PI is expected - adaptation areas - changes in practices and technologies within current systems (incremental adaptation), that include adaptation strategies as changes of sowing dates or water harvest are recommended. Indeed, relatively small changes within the current systems (that include adaptation strategies as changes to drought resistant crops) might suffice. Current adaptive responses of small- and medium- scale agriculture in the region, like crop and income diversification, are well documented strategies of incremental and systems adaptation. This responses relies on land availability, cultural and social capital, and access to information, credits and subsidies (Magrin et al. 2014). Our results will help guide priorities for international cooperation as well as local agendas for the development of adaptation strategies based on expected impacts and gradients of AC. For example, where to focus on basic needs satisfaction to complement the development of adaptation strategies, or spatial prioritization for incremental or transformational adaptation.

Our approach can be applied in other countries or regions to identify spatial priorities for adaptation using widely-available data, though we suggest refinement of some aspects. Among these aspects (see, for example, Nelson et al. 2009 and Monterroso et al. 2014) are firstly, the estimation of PI in terms of changes in crop productivity related to climate variability (e.g. Schmidt et al. 2012), not just climatic suitability; secondly, the inclusion of social, cultural and natural assets in the characterization of the AC, and finally, a focus on agricultural landscapes rather than administrative divisions like municipalities.

We highlight the ranking method as a soundly-based, practical procedure for spatial prioritization of adaptation actions. However, given the different spatial patterns regarding of values of different indicators, cluster analysis is a valuable tool to define adaptation strategies for groups of municipalities. ACI and cluster analysis coincide in showing that current AC conditions form a gradient between municipalities where cash crops are grown, close to major urban areas; and municipalities where basic grains predominate at the agricultural frontier. The analysis of conditions for adaptation showed that municipalities with a higher basic needs satisfaction, generally also have high values of indicators regarding resources for innovation and action. This result confirms the coherence of our structure of criteria and indicators of AC conditions for showing development as a sequence of steps in adaptation processes.

6 Acknowledgements

(Please see this section in the final published version of this article: https://link.springer.com/article/10.1007/s10584-016-1792-0#Ack1).

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Figure 1. (a) Average change in suitable areas for the current crop combination (coffee, beans, maize, upland rice, sorghum, plantain, and cassava, based on the most recent agricultural censuses) for 2030 in municipalities of Guatemala, El Salvador, Honduras and Nicaragua. (b) Proportion of agricultural area occupied by at least one of the crops considered in the study.

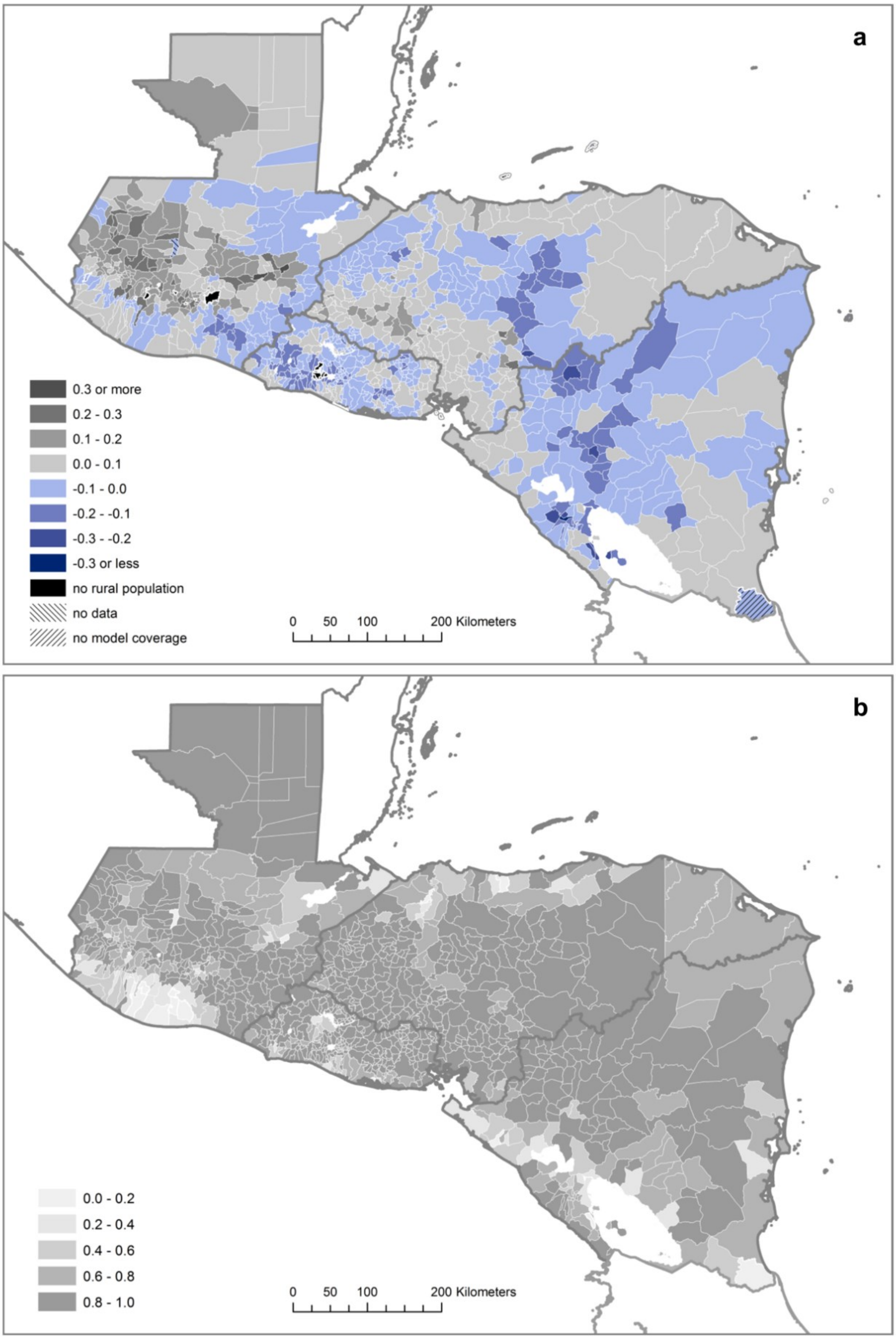

Figure 2. Adaptive Capacity Index - ACI (a) and Vulnerability Index – VI (b) of municipalities determined by the ranking analysis. Numbers on (b) show cases referred to in the text.

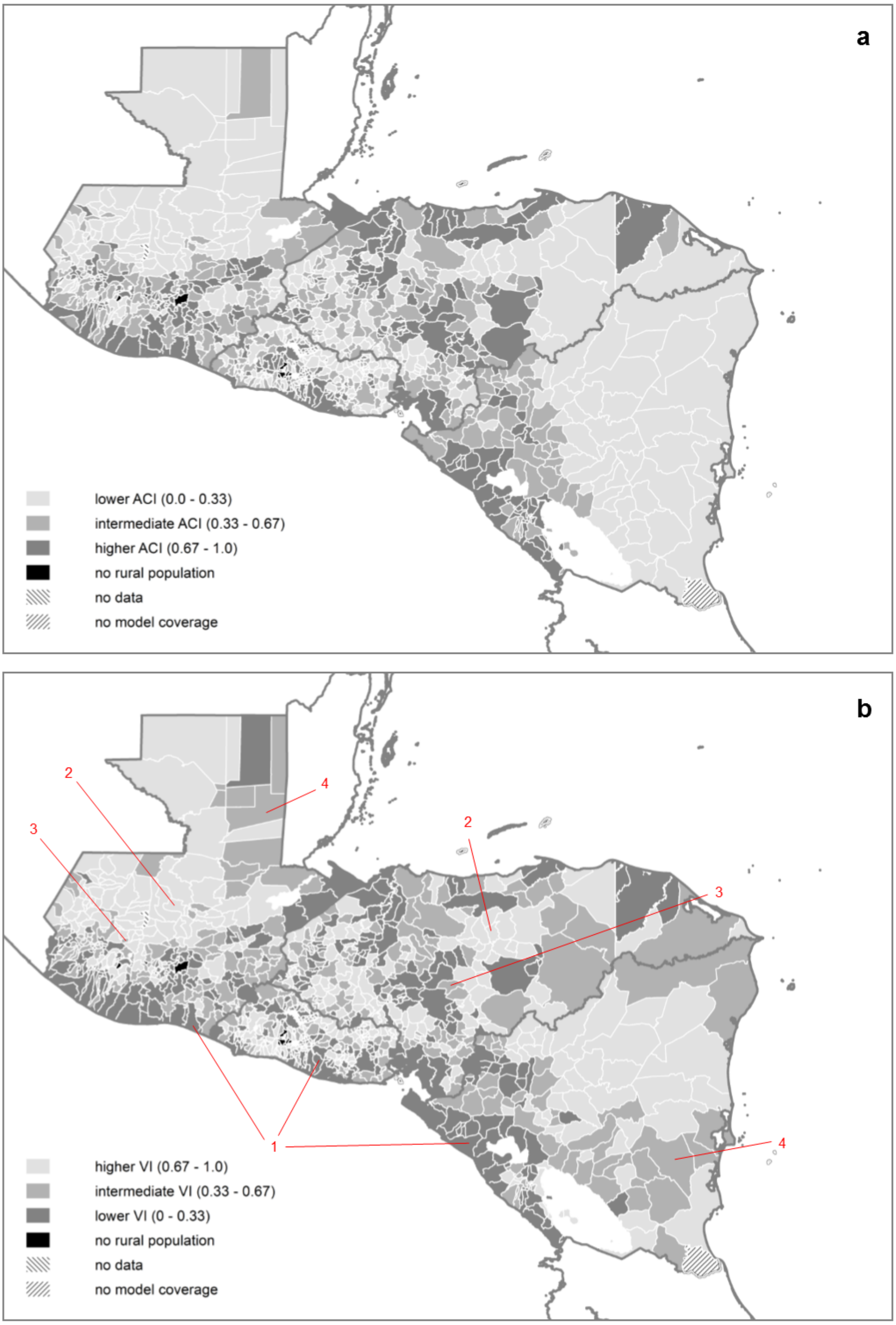

Figure 3. Adaptive capacity distribution based on the results of cluster analysis depicting the combination of indicators at the cluster centres. (a) Guatemala, (b) El Salvador, (c) Honduras, and (d) Nicaragua. Indicator values at the cluster centres are weighted by factor scores from the first component of a Principal Component Analysis. Adaptive capacity of municipality clusters decreases from left to right on the bar diagrams.

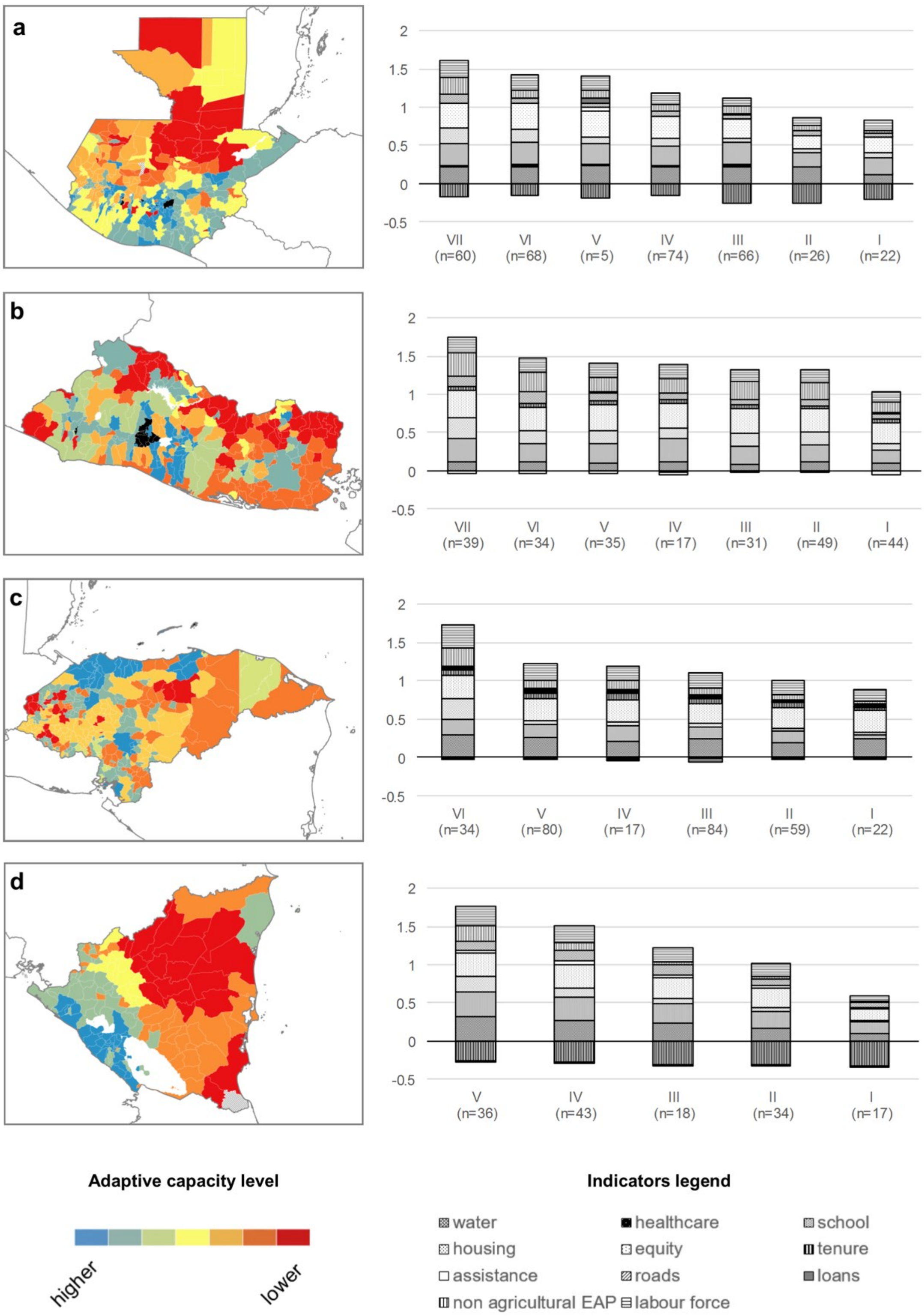

Table 1. Adaptive capacity conditions, criteria and indicators used in this study. Figures in brackets show the weighting values assigned to the criteria within each condition using expert opinion, and letters show the capital to which each criterion is related: H (human), B (built), N (natural), and F (financial). When the name of the indicator includes the word 'rural', the measurement of the indicator considered only individuals and dwellings in the rural areas of each municipality (see Online Resource 4 for calculation method of each indicator).

Adaptive capacity condition	Criteria (weight)	Indicator	Indicator average (Standard Deviation)							
			Guatemala (n = 321)		El Salvador (n = 251)		Honduras (n = 296)		Nicaragua (n = 151)	
Satisfaction of basic needs	Safe drinking water (0.33, P)	Rural households with access to safe drinking water	0.89	(.11)	0.83	(.14)	0.70	(.15)	0.62	(.18)
	Public health (0.27, H)	Primary healthcare units per 1000 people	0.12	(.11)	0.23	(.21)	0.29	(.23)	0.35	(.22)
	Education (0.20, H)	Rural school-aged population (aged 7-17) that attends school	0.72	(.08)	0.75	(.06)	0.62	(.09)	0.68	(.11)
	Housing (0.13, P)	Rural dwellings built with long-lasting materials	0.26	(.19)	0.31	(.13)	0.12	(.15)	0.17	(.12)
	Equity (0.07, H)	Rural gender parity index	0.22	(.15)	0.12	(.10)	0.09	(.08)	0.09	(.07)
Resources for innovation	Land (0.50, P)	Entitled agricultural production units	0.68	(.21)	0.71	(.12)	0.40	(.22)	0.88	(.10)
	Technical assistance (0.33, H)	Agricultural production units that received technical assistance	0.04	(.08)	0.05	(.04)	0.07	(.05)	0.19	(.09)
	Infrastructure (0.17, P)	Roads density	0.15	(.09)	0.18	(.12)	0.14	(.07)	0.13	(.06)
Resources for action	Financial resources (0.66, F)	Rural economically active population employed in non-agricultural activities	0.32	(.22)	0.51	(.16)	0.25	(.14)	0.29	(.20)
		Agricultural production units that received a loan	0.04	(.08)	0.09	(.06)	0.06	(.06)	0.13	(.10)
	Labour force (0.34, H)	Rural demographic dependency ratio	1.02	(.13)	0.82	(.09)	1.02	(.10)	0.83	(.14)

3 Building local strategies for the adaptation to climate change of farming livelihoods: review of a participatory approach applied in Mesoamerica

This chapter of the dissertation is an adaptation of:

"Building Local Strategies for the Adaptation to Climate Change of Farming Livelihoods. Review of a Participatory Approach Applied in Mesoamerica" by Claudia Bouroncle, Alejandro Carlos Imbach, Andrea Zamora, Omaira Urueña and Alejandra Boni, in "Community Capacity and Resilience in Latin America" edited by Paul R. Lachapelle, Isabel Gutierrez-Montes and Cornelia Butler Flora, published by Routledge (2021), pages 32-51. DOI: 10.4324/9781315111605-3. Used under a Creative Commons Attribution 4.0 International License, CC BY 4.0 (https://creativecommons.org/licenses/by/4.0). Original available at http://doi.org/10.4324/9781315111605-3.

Minor changes were made to adapt the book chapter to this Ph. D. dissertation, such as layout and fonts. Production modifications (such as copy-editing) were not included. Amendments in citations and references are included at the end of the dissertation.

Building local strategies for the adaptation to climate change of farming livelihoods: Review of a participatory approach applied in Mesoamerica

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Current impacts of climate change on Mesoamerican ecosystems and rural communities are undeniable, as evidenced by scientific studies (Castellanos et al., 2013; Harvey et al., 2015; Robalino, Jiménez, & Chacón, 2015) and the perception of smallholder farmers (Forero, Hernández, & Zafra, 2014; Vélez-Torres, Santos-Ocampo, Tejera-Hernández, & Monterroso-Rivas, 2016). Livelihood diversification and local organization are strategies with which rural families in the region have faced high natural climatic variability for hundreds of years (Altieri, 2013), but increase in the rate of change and intensity of drought conditions and climate variability, plus unprecedented pressures on natural ecosystems and agricultural systems, make adaptation increasingly difficult (Baethgen, Meinke, & Giménez, 2003). Further, information that allows a better understanding of the vulnerability of smallholder farmers in order to develop adaptation measures is extremely limited in the region (Holland et al., 2017). On the other hand, there is a growing effort to define policy frameworks and strategies for adaptation in the agriculture sector in Mesoamerican countries (UNEP & Euroclima, 2015), which support food security, rural employment, and make a substantial contribution to export earnings. These efforts have resulted in adjustments in policy, institutional, and financing mechanisms (Donatti, Harvey, Martinez-Rodriguez, Vignola, & Rodriguez, 2017). However, adaptation is mostly a local process. Therefore, processes that allow linkage of these efforts with local requirements are needed.

Here we present a summary of a methodological proposal for the participatory building of local strategies for adaptation to climate change (ELACCs, by its Spanish acronym) based on the Community Capitals Framework (CCF) (Flora, 2004). We review the results of its application between 2014 and 2016 in five micro-watersheds of the Pacific slope of Mexico, El Salvador, and Costa Rica using three criteria: first, the consistency of the perceptions of exposure to climate processes and impacts on livelihoods (Pearce et al., 2010; Simelton et al., 2013); second, the constraints in the adaptation process (Imbach & Prado, 2014); and third, the transformational level of the adaptation measures proposed (Rickards & Howden, 2012). Finally, we identify some conclusions and recommendations for the implementation of the ELACCs proposal. As far as we know, this is the only methodological proposal based on the CCF, within the emerging body of methodologies for local planning for adaptation to climate change (e.g., Adapt-Chile & Euroclima, 2015; Diesner, 2013; Frankel-Reed, Fröde, Porsché, Eberhardt, & Svendsen, 2013).

We focused on subsistence farming livelihoods, the predominant form of smallholder agriculture in the study region, where it is expected that climate suitability for coffee, maize, beans and even extensive cattle ranching will decrease in many areas in the coming years (Baca, Läderach, Haggar, Schroth, & Ovalle-Rivera, 2014; Bouroncle et al., 2017; Eitzinger et al., 2012; Thornton, Steeg, Notenbaert, & Herrero, 2009). Subsistence farming livelihoods are in general highly vulnerable to climate change, due to their reliance on rainfall and ecosystem services, and limited access to financial and technical assistance (Holland et al., 2017).

Developing and Reviewing the Local Strategies

Sites selection and description

We carried out the ELACCs to answer specific requests from governmental organizations, sponsored by a regional cooperation agency and an international NGO. The sites were selected according to the predominance of subsistence farming livelihoods (Table 1). Livelihoods based on coffee (site or S1, S2, S3 and S4); staple grains (beans and maize; S1, S3, and S4), and livestock farming for dairy and beef production (S1, S3, S4, and S5) predominate.

<TABLE 1 HERE>

Since rain-fed agriculture on the Pacific slope of Mesoamerica depends on the onset, length and temporal distribution of rainfall (Magaña, Amador, & Medina, 1999), knowledge of current and projected changes of climate is critical for the estimation of the vulnerability of subsistence farming livelihoods. Key characteristics of the regional climate, and relevant to all our study sites, described by these authors are: the bimodal distribution of the rainy season, with peaks of precipitation during May and June and, less pronounced, during September and October; the midsummer drought (*canícula*) during July and August, and a dry season from November through April. Intra-annual temperature variation is minor and is associated with stronger trade winds in December-January and July (Taylor & Alfaro, 2005). Rising temperatures and changes in rainfall seasonality have been observed in the region over the last several decades (Aguilar et al., 2005; Hidalgo, Alfaro, & Quesada-Montano, 2017; Rauscher, Giorgi, Diffenbaugh, & Seth, 2008) and climate projections suggest these trends will continue (Magrin et al., 2014; Marengo et al., 2014). This overall climatic context is accentuated in the Dry Corridor, a region with an extended dry season (IICA, 2014) which includes all our study sites except S2.

The sites were located in narrow micro-watersheds with of 200-500 km2, typical of the Mesoamerican Pacific slope. This type of watershed rapidly concentrates run-off and generate high peaks of flow rates after rain events, and eventually, floods. Remnants of natural forests (shade-grown coffee in the case of El Salvador) in the upper watersheds are thus key for groundwater recharge and water flow regulation (Calder, Hofer, Vermont, & Warren, 2007). In the Mexican and Costa Rican sites, sectors of these natural forests are in state protected areas.

Stages of the process of developing strategies

We began the process (Stage 1 – Scope of the strategy) with the definition of the participation platform, that is, the group of key actors committed to the formulation of the strategy. This platform defines the territorial scope of the process, considering its rural livelihoods, and relatively homogeneous environmental, human and social characteristics. We facilitated the development of climate change vulnerability assessments (VAs, Stage 2) using the IPCC (2007) criteria of exposure to climate change, impacts of climate change on livelihoods, and adaptive capacity. For these assessments, we used social science research tools to identify relevant aspects of the climate, characterizing the type of climate change impact, and documenting the response capacity, according to recommendations of Ford et al. (2010). We registered smallholder farmer perceptions of what is changing in the climate and how (exposure), and trends in quantity and quality of production and investment inputs for each livelihood (current impacts). We then built a description of adaptive capacity based on a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. For the design of the local adaptation strategy (Stage 3) we developed the basic steps of strategic planning for local organizations (see, for example, Terstegen & Willemsen, 2005) through workshops in which representatives of the participatory platforms validated the results of Stage 1 and identified and prioritized the measures to be considered in local strategies. This process followed the principles of the Participatory Rural Appraisal approach (Chambers, 1994). Stage 3 ideally continues with the insertion of the strategy in local development agendas (e.g., local government plans or NGO projects). We show a summary of the process of construction of the local strategies in Table 2.

<TABLE 2 HERE>

We used three methods to collect and validate information and carry out participative planning; focus groups with smallholder farmers, semi-structured interviews with technical staff who provide assistance to the farmers, and planning workshops with representatives of the participation platform. PAPDC and LMA (2015) presents in detail the development of each of the stages, steps and protocols for each technique applied, and PCCC and PAPD (2014a, 2014b), and Zamora and Urueña (2014, 2015a, 2015b) present the results for each site in detail.

We dedicate an average of three weeks of work in the territory and an additional five weeks for its formulation, review and final writing for each strategy; that was the expected time for these activities. Maintaining the number of weeks, we were able to reduce the facilitation team from three to two people in the last three sites, as we gained experience in applying the methodology. Once finalized, we followed-up the ELACCs implementation, through occasional meetings with members of the platforms.

Stakeholder participation

All platforms included representatives of smallholder farmers, technical staff from agricultural and environmental governmental agencies, NGOs, and leaders of farmer organizations. In Mexico, where there is a common property regime over land, representatives from ejidos also participated in the platforms. In El Salvador, the leadership was shared between a project of the Ministry of the Environment and an association of municipalities; in Mexico, the platforms were led by watershed management councils. All leader entities had technical staff and planning instruments. At the Costa Rica site, an ad hoc committee was established to support the process.

The number of people who participated in the different stages of the process (Table 3) varied between 36 (S5), and 100 (S3), depending mainly on the number of focus groups (at least one per livelihood). In all the sites a balance was reached between the number of technical staff and farmers (approximately 1:3.5), but the participation of women in all sites was unfortunately meager, varying between 9 and 28% of the participants.

<TABLE 3 HERE>

Review of the strategies

For the analysis of the VAs we assumed that preexisting conditions that determine how the impacts of climate change are experienced and shape coping or adaptation responses must be made explicit (Jurgilevich, Räsänen, Groundstroem, & Juhola, 2017). Consequently, we review the results generated from smallholder farmers focus groups, technician interviews, field observations and secondary sources to identify and describe such non-climate issues. To verify the consistency of climate and impact perceptions, we organized and synthesized qualitative information about climate processes and impacts using procedures proposed by Simelton et al. (2013) and Pearce et al. (2010). Finally, we organized the description of adaptive capacity for each livelihood using the approach of Imbach and Prado (2014), which shows the influence of different capitals from the CCF on successive steps of an adaptation process; cultural capital has a decisive influence on the beginning of the adaptation process, that is, on the perception that climate change is a different process from historical climatic variability; human capital has a greater influence on the identification of adaptation measures; social capital, on the mechanisms and scale of implementation of these measures; and financial and political capital on the management of external support.

For the analysis of planning aspects, we classified the adaptation measures prioritized in the planning workshops according to the adaptation levels proposed by Rickards and Howden (2012) for rural production systems. These levels are i) incremental adaptation, which involves relatively minor changes in a system (e.g., changing traditional crop varieties for drought-resistant varieties), ii) system adaptation, which involves more profound changes within the system (e.g., introducing an arboreal component in coffee plantations under open sun, or hiring labor for more intensive production), and iii) transformational adaptation, which entails profound changes in the system (e.g., leaving agricultural production to conserve water sources). The assignment to one level of adaptation or another then depends on whether there are changes in the objective of the production system, the depth, spatial scale and permanence of the change, and changes in the relationships between the elements of the system. In addition, we classified the prioritized adaptation measures according to their emphasis on different capitals. Likewise, we classified the actors identified for implementation of adaptation measures, as belonging to government agencies, municipal agencies, local producer and community organizations, watershed councils, research and academic organizations, NGOs or the private sector.

Results of the Review

Characterization of local livelihoods and their vulnerability

Access to land, natural resources and infrastructure, availability of labor force, traditional agricultural practices implementation, non-climate sources of stress and common practices to face them are common preexisting conditions that influence how the impacts of climate change are experienced by different smallholder's groups as described below.

Producers of staple grains cultivate very small plots (under 1 hectare), as tenants (S1), *avecindados* (people who work the land through an agreement with an *ejidatario* or community member, S3), or *ejidatarios* (S4). Most plots are on highly degraded hillsides because of intensive cultivation with short fallows and lack of soil conservation practices. Apart from small barns, they generally do not have other infrastructure. Most staple grain production is for home consumption, and their primary sources of income are off-farm labor and remittances, except in S3 where most of the production is for sale. Increase in the off-farm labor, migration and selling food reserves are responses to crop failures attributable to climatic hazards, price competition with imported subsidized grains and increasing prices of farm inputs. Coffee farmers cultivate small plots (under 5 hectares) but are owners or have rights of access, allowing them to maintain perennial crops. Coffee is produced under shade in all sites, a traditional practice largely adopted in Mesoamerica to retain soil moisture and reduce air temperature. The partial adoption of genetically improved varieties, fertilizer use and other practices is a result of governmental extension programs. Most coffee farmers own the necessary infrastructure to process the coffee bean or have access to it through cooperatives. The productivity of these systems is nevertheless rather low. Main stress elements are prices fluctuations, and since 2012 the coffee rust epidemic linked to management practices and climate change (Avelino et al., 2015). Cattle ranchers, are also owners (S1; S3, S4, S5 in lower watershed - Lo) or have rights of access (S3, S4, S5 in middle watershed - M) raise cattle for beef and milk production based on natural paddocks and cultivate forage in small (less than 1 hectare; S1, S3, S4, S5 in M) and medium plots (between 2 and 5 hectares, S4, and S5 in Lo) to feed the animals during the dry season; live fences and scattered trees for shade, are a frequent component of the production system. In three sites cattle rangers manage genetically improved livestock breeds, have basic infrastructure as feeders and sheds, and access to animal health attention (S3 in M, S4, S5 in M). Selling cattle heads is a common response to prices fluctuation and climate hazards.

In all places and all livelihoods, production is based on family labor, and wage labor is hired when necessary. A vital source of income for staple grain farmers is the coffee harvest, so the coffee rust also affects them. In some cases, women are in charge of tasks such as the management of the post-harvest process of staple grains (S1) and the sale of milk in the local market (S1). In all sites, we recorded perceptions of adverse effects of high emigration, mostly among young people and affecting mostly staple grains farmers families. Emigration is linked to the lack of profitability and high risk of agricultural activities, and better working conditions urban areas. We also found a range of conditions affecting access to finance, mainly for coping with stress factors. Staple grains producers in S1 rent the land, so they do not have any guarantee to access credits and incentive to invest in strengthening their natural or built capitals. They migrate, increase off-farm labor and sell food reserves in drought years to obtain cash. Coffee farmers in S2, who are owners of their farms, and coffee farmers and cattle ranchers in sites 3, 4 and 5 that have an established communal property regime, are in a much more favorable situation and some of them are able to access micro-credits. Off-farm labor, remittances (S1, S3, S4) and government subsidies are important income-generating options of coffee farmers for coping with stress factors. Cattle farmers mainly cope by selling animals. Other strategies to access financial resources are adding value (coffee certified as carbon neutral, S2), selling additional products (such as tree fruits that shade the coffee plantations; S1, S2, S3) or selling directly to consumers (livestock farmers; S1, S5) or through cooperatives (S2) (Table 4).

<TABLE 4 HERE>

Exposure

Smallholder farmers in all sites perceive the same trends of change in the climate (Table 5). Except in S2 (outside the Dry Corridor), they perceive an increase in temperature across the year. In S2, a more humid site, they observe an increase in temperature during the dry season and a decrease in the number of cold nights and frost events. Also, in all sites except S2, they observe a delay of up to two months in the onset of the rainy season, and at least in three sites (S3, S4, S5) farmers mention that the rainy season ends earlier. In all cases, the perception is that the rainy season is shorter than before. Across sites, there is agreement that there are more heavy rain events, distributed in fewer days, and that the *canícula*, either because it is longer and/or because it is drier and warmer. Finally, they have a common perception that wind intensities have increased, sometimes in association with the onset of the rainy season.

<TABLE 5 HERE>

Current impacts

Farmers identify negative impacts of climate change on all livelihoods, regardless of where they are located. Impacts include reduction of the quantity and quality of the harvest, and increased costs due to additional supplies or labor. They also describe negative impacts on water, soils, and forests. However, some positive impacts are identified by coffee smallholder farmers. In S1, occasional rains at the beginning of the dry season can increase yield from fruit-producing shade trees, at a time when these fruits have high market demand. In S2, the extension of the dry season increases the yield and decreases the quality of the coffee grain at intermediate altitudes but increases the quality at higher altitudes (Table 6).

<TABLE 6 HERE>

Smallholder farmers group the impacts of processes that cause water stress, and when a livelihood develops in different areas of a watershed, they observe more negative impacts of these processes in the lower areas. Increased wind can generate water stress but these impacts were described separately because winds also cause physical damage. No impacts related exclusively to the gradual increase in temperature were described. Farmers also describe impacts from heavier rain events for all livelihoods and natural resources, while effects of erratic rains only relate to coffee and staple grains. No farmers felt their livelihoods were becoming unsustainable. However, some cattle ranchers from S4 and S5 said that the lengthening and intensification of the dry season and *canícula* made practically impossible to grow maize for family consumption.

Perception of current processes and impacts

Smallholder farmers of all livelihoods at all sites are aware of changes in the climate. Moreover, their perceptions are consistent with the published observations of rising temperatures and changes in seasonality and precipitation patterns over the last few decades in Mesoamerica, showing that their perceptions are accurate despite the high historical variability of the climate. Likewise, smallholder farmers who share livelihoods identify the same impacts of climate change on these.

Identification of adaptation measures

The first difference in the adaptation process is the identification and implementation of measures that are consistent with climate impacts. The following examples illustrate this result. Coffee farmers in S4 mentioned the importance of local organization for the marketing of coffee and plantation renewal with varieties resistant to coffee rust, measures that had already been implemented in S2, decades ago in the case of local organization; while coffee farmers in S2 mentioned the importance of greater access to certification mechanisms and consequently, higher incomes for coping with climate impacts. Cattle ranchers in S1 mention the importance of pasture diversification, irrigation, and silage, measures that have been adopted by some groups in S3, S4 and S5. Neither staple grains farmers in S1, S3 and S4, nor coffee-growers in S3, identified any adaptation measures for their cropping systems (Table 7).

<TABLE 7 HERE>

Preparedness for the implementation of adaptation measures

We also found apparent differences between sites and livelihoods in degrees of local organization (Table 7). All the groups, except staple grains farmers in S1 and coffee farmers in S3, have some level of organization for the implementation of adaptation measures. However, in five of these groups the organization has the sole purpose of complying with the logistics to receive technical assistance and training from governmental and non-governmental organizations (coffee farmers and cattle ranchers, S1) or shares this purpose with applications for financial incentives to government organizations (coffee farmers, S3; staple grains farmers, S4; cattle ranchers, S5). In seven groups there is sufficient organization for the purchase and sharing of supplies (coffee farmers, S2 and S4; cattle ranchers, S3, S4, S5 in M and Lo) and to establish joint practices such as irrigation (cattle ranchers, S3, S4, S5 in M and Lo). Additionally, it is essential to consider the organization level that has made it possible to carry out adaptation measures at the landscape scale. In Mexico, the *ejido* organization has supported reforestation campaigns and fire control. In all sites, there is little participation of young people and women in associations, workgroups, and cooperatives.

Finally, we also found wide differences in access to specific incentives and technical assistance to face climate impacts provided by government and NGOs (Table 7). Credit, financial and technical assistance programs have all been designed by external entities, and do not necessarily respond to the adaptation needs and demands of smallholders. For example, staple grains farmers in all sites receive seeds and fertilizers from government programs, and mention that these programs are inadequate, because the seeds are of hybrid varieties and have low yields (S1), the programs do not include technical assistance (S3) or reach only a small proportion of farmers (S4). Another example is the access to payment for ecosystem services to recover and conserve forests and reduce fires near protected areas, and temporary jobs in the construction of soil and water conservation measures (S3, S4, S5). Although several groups of producers perceive that these programs are effective, they do not necessarily make immediate contributions to their livelihoods. It is important to emphasize the influence of technical assistance programs on the adaptation measures implemented, since virtually all non-traditional adaptation practices have their origin in these programs and in the incentives that accompany them. Finally, smallholder producers in all sites mention that if they could influence what kind of help they would like to receive, this would be focused on obtaining credits to add value to their products.

Vulnerability levels and main constraints on adaptation

We used the information systematized in the previous sections to identify at each site, different groups of producers according to their level of vulnerability. We assume that there are no differences in exposure to climate change, so that the elements of vulnerability are mainly focused on preexisting conditions, the impact of climate on production systems and the availability of capital for adaptation (Table 8). In addition, we do not include aspects related to the perception of changing climatic conditions and their implications, since, as mentioned above, smallholder farmers of all livelihoods at all sites are aware of them.

<TABLE 8 HERE>

Types of adaptation measures and stakeholder proposals for their implementation

Most of the adaptation measures proposed in the planning stage of the ELACCs correspond to the incremental and system levels according to Rickards and Howden (2012). Only two transformational measures were identified, both related to the conservation and restoration of ecosystem services at the watershed level; the measures themselves related to natural capital, and the corresponding financial mechanisms (Table 9). On the other hand, the classification adaptation measures according to their affinity with different capitals shows that they are complementary, and that awareness exists in the planning platforms of the importance of strengthening not only the natural and built capital but the strengthening of soft capitals for viability and sustainability.

<TABLE 9 HERE>

The responsibility for obtaining the resources and executing the adaptation measures remained mainly with government agencies in all sites; however, the participation of local organizations, such as development associations, cooperatives, and producer associations was important in S1 and S2, where there are less governmental resources. In all sites, the little participation was expected from the private sector, though that of academia and NGOs stood out in S4, where several conservation and development projects have been sustained in recent years (Table 10).

<TABLE 10 HERE>

Follow-up meetings with members of the ELACCs platforms give no evidence that the ELACCs or any individual adaptation measures have been put into practice.

CONCLUDING REMARKS

The methodology supports the rapid characterization of vulnerability based on local knowledge and participative processes, generating the programmed results in all its stages. The use of the CCF through the proposed methodology is advantageous to characterize local livelihoods and their vulnerability and to identify the main constraints for its adaptation. Its application highlights interactions between the changing climate and non-climatic factors, as well as the capacity of small producers to adapt, as an input for planning local adaptation. The CCF also shows non-tangible but critical aspects for the viability and sustainability of the adaptation process. However, the planning stage of the methodology is still insufficient for the valuation of this information in such a way that adaptation considers transformational alternatives that address temporal and geographic scales be-yond of production systems and their cycles. This step is necessary to face up to the reduction of water availability for different uses. On the other hand, the planning stage is also insufficient to influence the agendas of decision makers. To address this aspect, we recommend the inclusion of fora for capacity building, for example, through exchange of experiences, and to link the ELACCs with direct access to resources for implementing local plans (Sharma, Orindi, Hesse, Pattison, & Anderson, 2014). As an example, the ELACCs could be used as a starting point for the design of programs and projects, recognizing local perspectives and knowledge. Finally, local perception of the benefits of adaptation measures is a key factor in sparking a new cycle of adaptation based on successful experiences and lessons learned.

Our review of the ELACCs shows that the construction process does not capture differentiated perceptions and opinions of women and men. This is an important knowledge gap because the effects of climate change differ between men and women and are likely to be more serious for the latter, whose access to resources for adaptation is more limited, and who are likely to have different response strategies from men (Segnestam, 2017); therefore, the adaptation measures proposed by the strategies may not be appropriate for women. In addition to the mainstreaming of gender in local adaptation planning (see, for example, Edvardsson & Hansson, 2013), we recommend that livelihoods components that are generally managed by women, such as the cultivation of home gardens, are included in the ELACCS., Also, the vulnerability of livelihoods and crisis response strategies should be differentiated by gender, given that the growing migration is reconfiguring the division of labor (Segnestam, 2017). Ultimately, building the capacity of community members to better anticipate, mitigate, and adapt to the myriad impacts of a changing climate will only serve to more effectively prepare smallholder farmers of all livelihoods to build resistant and resilient stockpiles of capital to draw on and expend.

ACKNOWLEDGMENTS

The authors are grateful for the support of the Regional Gateway for Technology Transfer and Climate Change Action in Latin America and the Caribbean (REGATTA) and the United Nations Environment Program (UN Environment) for the development of the strategies of Honduras, El Salvador and Costa Rica between 2013 and 2014; and for the support of The Nature Conservancy for the development of the strategies of Mexico in 2015. The points of view expressed in this chapter are solely those of the authors and do not necessarily reflect the positions of the aforementioned institutions.

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Table 1. Study sites and predominant rural livelihoods. U: upper watershed, M: middle watershed, Lo: lower watershed.

Site, country (site code)	Altitudinal range (masl)	Predominant livelihoods
Jalponga, El Salvador (1)	100 – 2000	Coffee (U), livestock, basic grains (M)
Pirrís, Costa Rica (2)	1000 – 2000	Coffee (U, M)
Coapa-Pijijiapan, Mexico (3)	60 – 2400	Coffee (U), basic grains (M), livestock (M-Lo)
El Tablón, Mexico (4)	800 – 2550	Coffee (U); livestock, basic grains (M-Lo)
Lagartero, Mexico (5)	0 – 2400	Livestock (U, M, Lo)

Table 2. Summary of the construction process of a Local Strategy of Adaptation to Climate Change (based on PAPDC & LMA, 2015)

Stage	Step	Key questions	Main actors and participative tools
1 Scope of the strategy	1.1 Participation platform	Who is interested in an ELACC? Why?	Meetings with representatives of local organizations
	1.2 Territorial scope	For which territory will the strategy be built? Why?	
	1.3 Livelihoods	What do people do to live? Where?	
2 Vulnerability assessment	2.1 Exposure to climate change	What are the most obvious climate change trends in the last decade?	Smallholder farmers focus groups and semi-structured interviews with technicians.
	2.2 Livelihoods sensitivity	How do these climate factors affect the different livelihoods of the territory?	
	2.3 Livelihoods adaptive capacity	Which adaptation measures are already implemented in the territory? Are there other measures identified? How is the preparation to implement these measures?	
3 Design of the local strategy	3.1 Business as Usual scenario	What would happen in this territory if everything continues as normal?	Workshop with representatives of the participation platform and different livelihoods
	3.2 Long-term vision of the territory	What is the desired state of the territory and the different livelihoods?	
	3.3 Long-term objectives and indicators	What are the main changes needed for adaptation? How can they be demonstrated?	
	3.4 Identification of activities	What are the main actions for adaptation? Who are in charge of implementing them?	

Table 3. Number of participants involved in different events. The total number of people involved in the process is less than the sum of people participating in interviews, focus groups and workshops because some participated in more than one space.

Site code	Interviews (people)	Focal groups (number / people)	Workshops (number / people)	Total * (people)
1	11	4 / 42	3 / 25	65
2	16	4 / 21	2 / 21	63
3	15	6 / 75	2 / 30	100
4	7	4 / 39	2 / 39	58
5	8	3 / 19	2 / 27	36

Table 4. Characteristics of products marketing, according to smallholders focus groups and interviews with technical personnel. Numbers correspond to site codes, SG: staple grains, L: livestock, C: coffee, U: upper watershed, M: middle watershed, Lo: lower watershed

Added value. Most sell products without value-added, except coffee with special labels (2)
Products diversification for sale.
fruits (1 C, 2 C, 3 C) and rural tourism (2 C)
pigs & other farm animals, forage (5 L in Lo)
Sale of products. Most sell their products through private intermediaries ('coyotes'), except
organized and direct selling of cattle in the local market with the support of the local government (1 L)
direct selling of forage (5 L in Lo)
through cooperatives (2 C)

Table 5. Changing climatic conditions for most important livelihoods and natural resources, according to smallholder farmers perceptions. Numbers correspond to site codes.

	Amount	Frequency	Intensity
Rain season onset	2 weeks later (5) 1-2 month later (1, 3, 4)	Fewer rainy days (all sites) Fewer foggy days (4)	Heavier rains, especially after dry spell (1) Heavier rains (2, 3, 4, 5) Random rains before onset (2, 3, 4)
Rain season cessation	1-2 months earlier (3, 4, 5)		
Temperature		Fewer cooler nights (2, 3) Fewer frost events (2)	Warmer dry season (1, 2, 4, 5) Higher temperatures along the year (1, 3, 4, 5)
Dry spell			Longer (1, 2); drier and warmer (3, 4, 5)
Winds		Fewer windy days (2)	Stronger winds (1, 2, 3, 5); associated with rain season cessation (4, 5) Stronger cold fronts (4)

Table 6. Smallholder farmer perceptions of the implications of the changing climate for the most important livelihoods and natural resources. The sign (↓) or (↑) represents negative or positive effects respectively on yield (Y), quality (Q), and incomes (I), or in characteristics of natural resources. Numbers correspond to site codes.

	Extended and intensified dry season and *canícula*	Stronger winds	Heavier rain events	Erratic rains
Coffee growing	↓Y coffee trees wilting (4) ↓Y loss of leaves, flowers, and fruits (1, 2, 3, 4) ↓Y ↓Q ripening of berries affected (1, 2, 3, 4) ↑Y ↓Q in mid watershed (2), ↑Q in the upper watershed (2) ↓Y pests and diseases, higher susceptibility to coffee rust (1, 2, 3, 4) ↓I pests & diseases control, reseeding and other management practices (2, 3, 4)	↓Y shade trees fall and break coffee trees (2, 3, 4) ↓Y coffee trees wilting (4) ↓Y loss of leaves & flowers (2) ↓Y ↓Q ripening of berries affected (2, 3, 4) ↓I reseeding (3, 4) ↓I grains selection (3) ↓I infrastructure repair (2)	↓Y loss of flowers and berries; ripening of berries affected, empty grains (2, 3, 4) ↓Q spotted grains (3) ↓Y pests and diseases (2) ↓Q taste characteristics (2, 4) ↓I pests & diseases control (2) ↓I road repairs (2)	↓Y flowers loss (1, 3) ↓Y ripening of berries (1, 2) ↓Y pests and diseases (2) ↓Y during harvest time, affects the next blooming (2) ↓Y uneven production (3) ↑Y additional harvest from fruit trees in shade layer (1)
Maize and beans (impacts are for both if not specified)	↓Y it is now difficult to produce maize (4), it is not possible (5) ↓Y↓Q smaller spikes, smaller or empty grains (1, 3, 4) ↓Y↓Q pests and diseases (1, 3, 4) ↓Y harvest (1, 4) ↓I pest & disease control (3, 4)	↓Y loss of flowering (beans) (4) ↓Y maize plants broken (1, 3, 4) ↓Y ↓Q smaller or empty grains (1, 3, 4) ↓I reseeding (3)	↓Y loss of flowering (beans) (3) ↓Y ↓Q diseases, rotting (maize) and fungus (4)	↓Y bean plants germinate and then die (1)
Livestock	↓Y grassland fires (5) ↓Y fodder crops (1, 3, 4, 5) ↓Y cattle lose weight, get sick, some die (3, 4, 5) ↓Y↓Q meat & milk (3, 4, 5) ↓I food & water supplies (1, 3, 4, 5) ↓I pest & disease control (3, 4, 5)	↓Y fodder crops and pastures (3, 5) ↓Y animals lose weight, some die (3, 5) ↓Y↓Q meat & milk (3, 5) ↓I food supplies (3, 5)	↓Y fodder crops and pastures (3, 4) ↓Y pests & diseases (3, 5) ↓Y milk production (3, 4, 5) ↓I pest & disease control (3, 5) ↓I management costs (5)	
Water and soils	↓ wells diminish (3, 4, 5) ↓ reduction of river flow (4)	↓ dry streams (3, 5) ↓ erosion (2, 3, 5) ↓ landslides when winds come with rain (4)	↓ stream siltation, overflows and floods, landslides & gullies (4, 5)	
Trees and forests	↓ wildfires, mainly of pine-oak forests (5)	↓ falling of trees (3, 4, 5) ↓ wildfires (5)	↓ falling of riparian trees (4, 5)	

Table 7. Human, social, financial and political capitals for adaptation, identified by smallholder focus groups. Numbers correspond to site codes, SG: staple grains, L: livestock, C: coffee, U: upper watershed, M: middle watershed, Lo: lower watershed

Human capital: The smallholders know what to do and put it into practice?	
Already put in practice conservation and exchange of native seeds (1SG, 3SG, 4 SG) crops and pastures diversification (1C, 2C, 4C; 5L in M & Lo) coffee plantation renewal (2C) crop irrigation (3SG) pastures irrigation (3L in M, 4L, 5L in M) silvopastoral practices (3L, 4L, 5L) silage (4L, 5L in M) composting (4C) soil and water conservation practices (2C, 4C, 5L in U & M) reforestation, forest conservation (2C, 3L, 4L, 4SG, 5L in U & M) added value (2C)	*New measures identified* pasture diversification (1L) coffee plantation renewal (3C, 4C) pasture irrigation (1L) silage (1L, 3L in M & Lo, 5L in U) joint marketing (4C, 4L) organic certification as special label (2C)

Social capital: Are smallholders organized to ask for support or to implement adaptation measures?	Financial and political capitals: Do smallholders obtain external support for adaptation? What for?
To receive technical assistance all sites, except 1SG, 3C, 4SG, and 5L in U *To establish best practices* irrigation systems and sowing forage (3L in M, 4L, 5L in M) *To buy and share supplies* agricultural supplies (2C, 3L) pulper, storage tanks and others (4C) forage choppers and other equipment (4L, 5L in M & Lo) *To ask for government incentives* local or community (ejidos) associations (all livelihoods in 3, 4 and 5) *For purposes other than productive* water management, risk and/or fire management (all sites, except 5L in U)	*Supplies, credits, and incentives* seeds and fertilizers from agriculture governmental agencies (1SG, 3SG, 4SG) micro-credits from development banks, associations or cooperatives (2C, 4L, 5L in M & Lo) governmental subsidies (3C, 4C) payment for environmental services (some farmers of each livelihood in 2, 3, 4, and 5) *Technical assistance* sustainable production programs promoted by ministry of environment (1C), cooperatives (2C), and protected areas administration (3C, 4C; 3 SG, 4 SG; 3 L3, 4 L, 5L except in U) specific training activities to improve crops and livestock management from governmental agencies and NGOs (all sites)

Table 8. Vulnerability levels and the main constraints on adaptation as validated by smallholder focus groups. SG: staple grains, L: livestock, C: coffee, N: natural capital, H: human capital, S: social capital, F: financial capital, P: political capital, U: upper watershed, M: middle watershed, Lo: lower watershed.

Site	Lower vulnerability	Medium vulnerability	Higher vulnerability
1	*Coffee* ↓↓ Loss of harvest (N), but ↑↑ additional harvest of fruits ↑ Some adaptation measures in place (H) ↓ No collective actions (S) ↑↑ Incentives and training framed in sustainable production program (F, P)	*Livestock* ↓ Fewer food supplies for animals (N) ↓ Fewer food supplies for animals (N) ↑ Some adaptation measures in place (H) ↓ No collective actions (S) ↑ Some training, but not in an integral manner (P)	*Staple grains* ↓↓ Loss of harvest, (N) ↓ Difficulty in identifying adaptation measures (H) ↓↓ No local organization to support collective actions (S) ↓ No access to incentives and training (F, P).
2	*Coffee* ↓ Quantity and quality of grains diminished (N) ↑ Some adaptation measures in place (H) ↑ Some collective actions (S) ↑↑ Incentives and training framed in sustainable pro-duction program (F, P)		
3	*Livestock* ↓ Fewer food supplies for animals (N) ↑↑ Several adaptation measures in place (H) ↑ Some collective actions (S) ↑↑ Incentives and training framed in sustainable production program (F, P)	*Staple grains* ↓↓ Soil degradation, increase of pests and diseases (N) ↑ Some adaptation measures in place (irrigation) (H) ↓ No collective actions (S) ↓ No access to incentives and training (F, P).	*Coffee* ↓↓ Soil degradation, in-crease of pests and diseases (N) ↓ Difficulty in identifying adaptation measures (H) ↓ No collective actions (S) ↓ No access to incentives and training (F, P).
4	*Livestock* ↓ Fewer food supplies for animals (N) ↑↑ Several adaptation measures in place (H) ↓ Few collective actions (S) ↑↑ Incentives and training framed in sustainable production program (F, P)	*Staple grains* ↓↓ Loss of harvest (N) ↓ Difficulty in identifying adaptation measures (H) ↓ Few collective actions (S) ↑↑ Incentives and training framed in continuous sustainable production program (F, P)	*Coffee* ↓↓ Loss of harvest (N) ↓ Difficulty in identifying adaptation measures (H) ↓ Few collective actions (S) ↓ No access to incentives and training (F, P)
5	*Livestock (M)* ↓ More pests and diseases (N) ↑↑ Several adaptation measures in place (H) ↑ Some collective actions (S) ↑↑ Incentives and training framed in sustainable production program (F, P).	*Livestock (Lo)* ↓ Fewer food supplies for animals (N) ↑ Some adaptation measures in place (H) ↓ Few collective actions (S) ↑ Incentives and training, but not in an integral manner (F, P)	*Livestock (U)* ↓↓ Fewer food supplies for animals, more landslides (N), roads damage (B) ↓ Difficulty in identifying adaptation measures (H) ↓ No collective actions (S) ↓ No access to incentives and training (F, P).

Table 9. Adaptation measures proposed in the local strategies according to the levels proposed by Rickards and Howden (2012) and community capitals (Flora, 2004). Numbers correspond to site codes, SG: staple grains, L: livestock, C: coffee. Measures are for all livelihoods in the site, if not specified.

Capitals	Incremental adaptation measures	System adaptation measures	Transformational adaptation measures
Natural	- Native seeds (1 SG) - Varieties resistant to water-stress, pests, and diseases (1, 4) - Genetic improvement of cattle for higher resistance and performance (1L, 5L) - Pasture management (5L)	- Crops diversification (1) - Organic or agroecological practices (1C, 2C) - Integrated pest management (1SG, 1C) - Agroforestry systems (1, 3) - Animal health practices (1L)	- Restoration and protection of water recharge areas (1, 2)
Built	- Soil and water conservation works (1, 2, 4, 5) - Diagnosis of the state of systems for water collection, storage, and distribution (1) - Pasture silage (1L) - Grain warehouses (1SG)	- Collection and distribution center of dairy and meat products (5 L)	
Human	- Dissemination of climate change trends and effects (1, 2, 3, 4) - Training on adaptation measures (2, 3)	- Early warning systems (1)	
Cultural	- Native seeds selection & exchange (1SG, 4SG) - Natural capital relevance for adaptation (4, 5) - Dissemination of local adaptation experiences (1, 2, 3, 4)		
Social	- Farmer to farmer extension (5L) - Farmer organization for technical assistance (1, 3) - Participative forest surveillance (3) - Organization of young people and women to intervene in decision-making (1, 2)	- Farmer organization for technical and financial support (1, 3, 4, 5) and political lobbying (5) - Collective management of tools and machinery (1)	
Financial	- Incentives to establish organizations of producers (1 SG) - Grants and loans (5)	- Agricultural insurance (1) - Micro-financing programs (2) - Value chain management (1, 4)	- Ecosystem services incentives and payments for forest conservation in the upper watersheds (1, 2, 5)
Political	- Watershed management council establishment / strengthening (3, 4, 5) - Dissemination of adaptation needs between local organizations and institutions (1) - Seeking academic and governmental technical assistance (3, 5)	- Review of plans and projects to support adaptation efforts (1) - Review of policies and regulations to support adaptation efforts (1) - Joint projects between government, private sector, and cooperatives (5)	

Table 10. Proportion of different stakeholder groups identified to implement prioritized adaptation measures.

	Site 1	Site 2	Site 3	Site 4	Site 5
central government	0.24	0.35	0.58	0.40	0.44
municipalities	0.32	0.10	0.08	0.04	0.06
local organizations	0.36	0.35	0.05	0.01	0.16
watershed councils			0.08	0.01	0.09
Academia			0.08	0.28	0.03
NGOs		0.05	0.12	0.21	0.03
private and finance sector	0.08	0.15		0.04	0.19

4 A systematic approach to assess climate information products applied to agriculture and food security in Guatemala and Colombia

This chapter of the dissertation is an adaptation of:

"A systematic approach to assess climate information products applied to agriculture and food security in Guatemala and Colombia" by Claudia Bouroncle, Anna Müller, Diana Giraldo, David Rios, Pablo Imbach, Estuardo Girón, Fernando Portillo, Alejandra Boni, Jacob van Etten and Julian Ramirez-Villegas, published in Climate Services 16, 100137 (2019). DOI: 10.1016/j.cliser.2019.100137. Original available at https://doi.org/10.1016/j.cliser.2019.100137.

Minor changes were made to adapt the article to this Ph.D. dissertation, such as layout, fonts, and acknowledgments section. Supplementary material, Figure 4, and production modifications (such as copy-editing) were not included. Amendments in citations and references are included at the end of the dissertation.

Title: A systematic approach to assess climate information products applied to agriculture and food security in Guatemala and Colombia

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Abstract

Increased interannual climate variability affects agricultural livelihoods throughout the world. In many regions, climate services support decision-makers in their adaptation efforts. The range of these services and the number of associated information products have increased dramatically in recent years. However, the relationships between these products and their use and usability for targeted decision-making have rarely been systematically evaluated. Here, we report on the development of a systematic and user-centered approach to assess climate information products and networks of products; and apply it to products covering the nexus of climate, agriculture, and food security in Guatemala and Colombia. Across both countries, we assessed 28 products used for agricultural decision making, outreach, planning research, and design of emergency responses. While climate-only information products play a central role in each network, information products intended to support agriculture and food security need to integrate information from different themes or disciplines and sources at different scales. We find that major improvements in the credibility, legitimacy, scale, cognition, procedures, recommendations, and content of most existing products are required. Brevity and clarity of language are highlighted as desirable in both countries, as well as use of trusted and publicly-available data, and non-paper-based delivery formats. The approach and methodology are valuable for facilitating the prioritization of actions for improvement and/or the development of new products, thereby helping climate services for agriculture and food security to realize their true potential.

Keywords: user-centered assessment; network analysis; climate services assessment; climate services usability

Practical implications

Climate variability associated with climate change affects agricultural production and rural livelihoods throughout the world. Climate services (CS) address this challenge by making new information products available to policymakers, agricultural technicians, and farmers in order to enhance their adaptive capacity. Most of the literature on assessment of CS focuses on (a) their climate forecasting or crop modeling capability or (b) their socio-economic value. This study focuses on the use and usability of information products and the relationships among them. To explore these aspects, we developed an approach for systematic assessment of information products and applied it in two different contexts (droughts and food security in the Dry Corridor of Guatemala, and climate and agriculture in Colombia), thereby demonstrating the broad applicability of the method. The approach is suitable for operationalization by governmental, international cooperation, and private organizations. Regular application to monitor and assess sets of information products developed for specific thematic and geographic areas could contribute to their enhancement, in terms of information content and usability.

The approach comprises four steps. Step 1 determines the geographic and thematic scope of the analysis and identifies the information products to be included in the study. Step 2 explores the relationships between these products, in terms of information flows among networks of products, using standard statistical analysis. Step 3 assesses the use and usability of individual products from the perspective of users and gathers qualitative information on users' perceptions of the characteristics of an 'ideal' information product. Step 4 provides feedback to the technicians and scientists involved in creating the products, summarizing the conclusions of the study in the form of recommendations for potential improvements to products and the network of products.

In practice, application of the approach would help guide future investments in CS and provide valuable information to producers of CS to orient their future development, for example, by filling information gaps and enhancing their usability. The practical implications derived from the application of the approach in the two case study context can be summarized as follows:

1 Knowing the position of the products in a CS network is crucial to identify measures that could be taken to enhance their effectiveness.

- In Guatemala and Colombia, Regional Climate Outlook Forums occupy a central position in CS networks and play a key role as primary sources of seasonal climate outlooks for use by the agriculture and food security sectors.
- In Guatemala, the Regional Outlook on Food and Nutritional Security occupies a less central position in the network that might be expected. This may make it more difficult for agricultural and food security stakeholders to access the climate forecasts that they need to inform decision making. This limitation could be addressed by building the capacity of stakeholders to use climate forecasts for food security management, and by strengthening linkages among stakeholders in the climate, agriculture, and food security sectors.

2 Knowledge of which products are currently used by the different groups of decision-makers can pinpoint gaps in the information available.

- In Guatemala, national-level decision-makers tend to use products that integrate national-scale climate, agriculture and food security forecasts. However, these products lack spatial and temporal detail required for application at local scales. Local decision-makers use shorter-term national-scale climate products. These results indicate a requirement for co-produced integrative local-scale products, and these are currently being developed.

3 Decision-makers' perceptions of products currently available provide information on their evolving needs and inputs for the design of technical and procedural improvements. These could include:

- Optimizing timing, frequency, and delivery mechanism/channels.
- Enabling two-way (user-provider) communication and providing downloadable source information (identified as a priority in both countries).
- Using plain language, logical structure, and visual aids (priority in Guatemala).
- Integrating of climatic, agronomic, and food security information (priority in Guatemala).
- Using and comparing of trusted sources, and providing information on methods, results, and uncertainty levels to improve credibility (priority in Colombia).
- Incorporating local feedback to improve legitimacy (both countries).
- Providing information at an appropriate scale (both countries).
- Providing recommendations linked explicitly to the timeframes of decision-making processes, for example relating to sowing or harvesting (both countries).

4 Providing feedback on the assessment process to stakeholders is essential to validate its results.

- In both Guatemala and Colombia, CS providers stated that the synthesis of user perspectives helped them to understand how their products are being used. Information on user perspectives helped justify existing plans for improvements to their products as well as identifying further improvements that could be made.

CS is a dynamic field and new actors and products are continually emerging, reflecting the increasing importance of climate information for agriculture and food security under climate change. Thus, ideally, the systematic assessment of the usability of climate information products should be integrated into an M&E scheme that is implemented regularly to capture changes and developments.

1 Introduction

Climate variability associated with climate change affects agricultural production and rural livelihoods throughout the world (Porter and Semenov, 2005; Sultan et al., 2005). On average, about a third of the variation in global crop productivity can be attributed to climate variability (Ray et al., 2015). Climate variability is expected to increase, leading to more frequent climate extremes, with adverse outcomes for agricultural production and food security (Osborne and Wheeler, 2013; Springmann et al., 2016; Wheeler and Von Braun, 2013). In response, investments in new climate services (CS) address this challenge by increasing the information available to policymakers, agricultural technicians, and farmers in order to enhance their adaptive capacity (Georgeson et al., 2017; Hewitt et al., 2012; Vaughan and Dessai, 2014). CS may help decision-makers to move away from reactive responses to agricultural and food security crises, towards a more proactive approach of climate risk management (Jones et al., 2017; Wilhite, 2002).

CS involve the (co-)production, translation, transfer, and use of tailored climate information to improve decision-making at multiple scales (Vaughan and Dessai, 2014). For example, at the farm scale, a CS may deliver a seasonal forecast to help farmers to select planting dates and crop varieties (Hammer et al., 1996; Soler et al., 2007); at the regional scale, seasonal to interannual climate forecasts could improve decision-making by agronomists (Adams et al. 2003; Jury 2002) and planners responsible for water resource management (Clements et al. 2013) and flood prevention (Rayner et al. 2005). Around the world, CS are often provided through information products such as bulletins, websites, and mobile phone applications that connect technical and/or scientific information to a practical problem (Fraisse et al., 2006; Georgeson et al., 2017; Vaughan et al., 2017). These information products support decision-making if they are tailored to decision-makers' needs and are relevant to the decision-making context (Lemos et al., 2012; Rayner et al., 2005; Rosas et al., 2016).

Previous assessments of CS focus on their technical effectiveness. One stream of research examines how well models predict climate and crop yields at the seasonal or inter-annual timescale (Capa-Morocho et al., 2016; Hammer et al., 1996; Ramírez-Rodrigues et al., 2016; Roudier et al., 2016). Another considers the socio-economic value of CS, including organizational aspects and policy contexts that facilitate their use (Solís and Letson, 2013; Tall et al., 2018; Vaughan et al., 2017). These studies look for evidence of behavioral change and downstream development impacts such as yield gains, improved food security, or increased incomes through CS use (Tall et al., 2018; Vogel et al., 2017). Although the need for evaluation of the usability of information products is recognized (e.g., McNie, 2012; Moss, 2016), less emphasis has been placed on understanding the roles of different information products as part of an 'information ecosystem' and on evaluating their usability systematically (Vaughan and Dessai, 2014).

Climate services may be produced by a single organization or through a process of co-production. In co-production, the emphasis in on demand-driven products, the integration of different topics, disciplines or fields of knowledge (Vincent et al., 2018), and the deliberate, collaborative product-development work among scientists, technicians, practitioners, and users (Porter and Dessai, 2017). This is an approach to the production of knowledge for decision making that differs from traditional scientific paradigms. To capture the potential contribution of co-production to the effectiveness of CS, evaluation methodologies should view the set of information products under consideration as a whole and not merely as a collection of isolated elements.

In Latin America, climate information products for agricultural and food security range from seasonal bulletins produced in the Regional Climate Outlook Forums (RCOFs) to locally-relevant bulletins, websites and mobile phone applications (Baethgen et al., 2016; FENALCE, 2018; Fraisse et al., 2006). Most of these products are designed and distributed following a 'loading-dock' model: the information is produced by the supplier with little coordination, collaboration, or consultation with the users or other information providers (Cash et al., 2006; Vogel et al., 2017). Where users lack the technical capacities to understand and contextualize the information they receive, its use and societal benefits are limited (Kirchhoff et al., 2013; Vogel et al., 2017). However, the use, usability, salience, legitimacy, and credibility of existing products have rarely been systematically assessed (see Esquivel et al., 2018). Consequently, little is known about whether and how information products are used as sources of information for decision making, or how they could be improved (Tall et al., 2018; Vaughan et al., 2017). The assessment of climate information products is strategic for Latin American countries. By identifying gaps and improving existing products, such an assessment provides the basis for the emergence of a climate services knowledge network, incorporating a range of products and linking knowledge and know-how held by people and institutions at different locations and scales. In a knowledge network, the flow of knowledge and its adjustment to specific decision contexts depends more on interactions among stakeholders than on formal organizational mechanisms (Kalafatis et al., 2015).

Here we present the development and testing of a systematic, four-step user-centered approach to assess a set of climate information products covering the nexus of climate, agriculture, and food security, made available by a broad range of organizations in Guatemala and Colombia. The assessment approach builds on two methodological foundations: network analysis, to provide a holistic perspective on the set of information products as a whole; and user-centered evaluation to examine the products individually.

We first applied the method in Guatemala and subsequently adjusted and validated it in Colombia. In these countries of tropical America, agricultural livelihoods and food security are highly vulnerable to climate change and variability (Bouroncle et al., 2017; Magaña et al., 1999; Poveda et al., 2011; Ramirez-Villegas et al., 2012), but differ in terms of organizational context, end-users needs, and the level of user engagement in co-production of CS. Our paper has a dual purpose. We first present the results of the application and validation of the method in the two countries. Then we discuss its strengths and limitations and propose a way forward for the broad-based operationalization of our approach for the assessment of climate information products in Latin America.

2 Materials and methods

2.1 Framework for the systematic assessment of climate information products in agriculture

We developed and validated an approach for assessing climate information products and their network relationships using quantitative and qualitative methods. We define *information product* as a publication that is periodically made available to a potential target group of users to support their decision-making. Products can contain a combination of data, information, and expert advice, and may use different communication channels, such as websites, mobile phone applications, bulletins, text messages, and radio and television programs. We define *information product network* as a set of information products that exchange information among themselves in a given geographic and/or thematic context.

The workflow of the approach is presented in Fig. 1. In Step 1 we identify the objectives and scope of the assessment, identify relevant information products and examine the relationships between them. Step 2 we explore the integration of themes or disciplines of the information network and information flows between products. In Step 3, we assess the use and usability of individual products and gather product-specific feedback and recommendations for their improvement, applying a user-centered approach. Step 4 draws on the results of Step 3 to derive recommendations for the organizations publishing the products to enhance their usability and their role in the network (e.g. as information providers or integrators). These four steps are described below in more detail.

[Figure 1 near here]

Step 1. Create an inventory of products

As with any assessment, the first step is to determine the objectives of the process and, specifically, the geographic and thematic scope of the assessment, in collaboration with all the organizations involved. The *geographic scope* is defined in accordance with the geographic area(s) of interest, while the *thematic scope* corresponds to products these organizations generate, use, or seem relevant to their work. This is followed by a compilation of an inventory of pertinent information products, using systematic searches and following up on recommendations from experts. If the assessment encompasses products ranging from the national to the local scale, it may also be useful to include supranational products in the inventory (e.g., bulletins of Regional Climate Outlook Forums), if these are related to national or local information products. *Thematically*, the criteria for inclusion in the inventory can be as broad (e.g. food security) or as narrow (e.g. mid-summer drought) as needed. If the initial list is very large or includes products not targeting specific users, it could be useful to reduce the size of the inventory by selecting the most relevant products, with the participation of the organization(s) involved in the assessment and support of other agencies related to the thematic scope of the assessment. This selection should be carried out applying consistent and explicit criteria to avoid biases and maintain consistency in the selection process. For example, it might be decided to eliminate products that only contain forecasts (such as a map of rainfall over the next 48 hours) if this information is included in other more elaborate products (for example, including both a map of rainfall and recommendations for farmers).

In this case, the scope of the assessment was defined as climate information products containing information related to different themes or disciplines (Balaghi et al., 2010) to support decision making in Colombia and Guatemala. We carried out systematic searches using the Google engine and appropriate keywords. We complemented this search by reviewing the Web pages of governing organizations on the subject, private sector, research centers, and international cooperation agencies. We included in the inventory only products published or updated regularly that had at least one year of continuous publication, and that were available at the time of doing the search (2014–2015 for Guatemala and 2016–2017 for Colombia). We added some products, mainly locally produced, after interviews with key decision-makers of the organizations involved in the assessment. In Colombia, since the initial list was extensive, we selected the most relevant products with the help of IDEAM, the government agency responsible for hydrology, meteorology, and environmental studies. The workforce at IDEAM includes members of staff with specific responsibility for coordination with the Ministry of Agriculture for the provision of agroclimatic services. Finally, the products are described in relation to a defined set of attributes, including theme, scale, and production process.

Step 2. Analyze the relations among products

In Step 2, the relationships between the climatic information products of the inventory are established through statistical analysis of citation data.

First, the products of the inventory are grouped according to the citation patterns among them. This analysis explores the extent to which products assigned to a particular topic or discipline cite products related to other themes or disciplines, to provide a preliminary indication of the structure of knowledge flows among the products, i.e. how information relevant for decision making is acquired and transferred (Cash et al. 2002). We did this by implementing a hierarchical cluster analysis of citation data. This analysis classifies items into groups based on sets of values of several variables, and is commonly used to explore the structure of multivariate observations. The results of the analysis are displayed as dendrograms, which show groups of items with different degrees of similarity in terms of values of the considered variables (Casanoves et al., 2012). In this case, the dendrograms show groupings of products based on patterns of citations among them.

To apply this analysis requires the construction of matrices of citations between pairs of products. For each information product, we reviewed all published editions over a year and counted as a citation the mention of information from another information product using a traditional bibliographic citation system or the reproduction of fragments of information (including maps, graphs, and charts). We then organized the citation data in n-by-n matrices (with n = number of products) with the rows representing the citing products and the columns the cited products (Liu and Wang, 2005). We constructed the matrices following the conventions proposed by Borgatti et al. (2002). First, the names of the products are listed in the same order in the row and column headings; second, the value "1" represents the occurrence of a relation (citation data) and "0" the absence of one. Thus, for example, a "1" in the cell at the intersection between the column headed by product A and the row headed by product B means that product "A" is cited by product "B". Note that the matrix ignores possible self-citations; so the intersections of columns and rows headed by the same product are all shown as "0". We used the R package *Cluster* (Maechler et al., 2018) to perform the cluster analysis using Ward's method and Euclidean distance. We excluded from this analysis isolated products, that were not cited by and did not cite other products.

Next, *relationships between products* in terms of information flows are examined. This stage of the analysis focuses on the structure of networks of information flows. We carried out social network analysis using the citation matrices we prepared for the hierarchical cluster analysis (Hermans et al., 2017; Wang et al., 2017) to identify (a) the products that are important *providers of information* to other products in the network (measured as *centrality*, or the number of links that a product has with others) and (b) those that are important *communicators of information* (measured as *betweenness*, or the location of a products on the shortest paths between pairs of other products) (Borgatti et al., 2009, 2002). In the network analysis, nodes in the network are considered interdependent units and the links between the nodes are resource flow channels; the network structure is defined by the relations between nodes, that indicate opportunities for flows of resources (Wasserman and Faust, 2013).

We created visualizations of the network analysis and migration analysis displaying origin, destination, direction, and volume of information flow among all products (Qi et al., 2017) using the Igraph (Csárdi and Nepusz, 2006) and Circlize (Gu et al., 2014) packages in R (R Core Team, 2018) respectively.

The network diagram shows the results of the network analysis. It shows the nodes (products) and the flows of resources (information) between them. The analysis also distinguishes between different types of products (i.e. their attributes), their role in the network, and the directions of flows of information between them. In our case, the product codes represent the type of publishing organization (color) and the principal theme (shape). The size of the node symbol indicates its importance in terms of the degree of connectedness with other nodes (popularity). The diagram identifies nodes with occupy a central position in the network (i.e. those with large numbers of direct connections to other nodes), those that are important as intermediaries (by linking otherwise unconnected nodes) and those that are located on the periphery of the network (with few connections) The arrows on the lines linking the nodes indicate the direction of the information flow (Borgatti et al., 2002). The description of the network includes a measure of its density, calculated as the number of current connections in relation to the total number of potential connections between products).

The network analysis is complemented by a migration analysis, whose results are shown a circular migration plot (Sander et al., 2014), showing the direction of flows of information between each pair of nodes.

Step 3. User-centered assessment of individual products

In Step 3, the level of knowledge and the usability of the products of the inventory are assessed from the perspective of a broad range of users.

Information was gathered from users for whom climate information is relevant for their activities in the fields of agriculture and/or food security. Respondents were asked about (i) their level of knowledge of each of the products of the inventory; (ii) the usability of a subset of products, and (iii) key characteristics of an 'ideal' information product. We used a semi-structured interview for this step (see Supplementary Text S1), carried out with decision-makers from governmental, non-governmental, international technical cooperation, and academic organizations (see section 2.2). To define the sample, we combined a targeted selection with 'snowball' sampling, asking targeted respondents to recommend other people for an interview. The approximately 90-minute interview included questions related to the mapping of agro-climatic information flows (Blundo Canto, 2015) and knowledge-related questions derived from the literature on agro-climatic information product evaluation (Fountas et al., 2006; Stone and Meinke, 2005). The interviews were carried out in 2015–2016 in Guatemala and in 2018 in Colombia.

The interviews comprised five sections, with questions designed to elicit the following information:

1 The identity of the user, his or her organization, and position in the organization.

2 The user's area of work and the key decisions he or she makes based on agro-climatic information.

3 The user's knowledge of the products using a Likert scale ranging from 1 (= never heard of this product) to 5 (= I use this product frequently). A maximum of five products was selected from the products rated 4 and 5 by the user for the next steps. If there were more than five products used frequently by the user, the selection considered the relevance of the products for the decision-making process.

4 The user's opinions regarding the usability of the products, following the System Usability Scale (SUS; Brooke, 1996; Lewis, 2018). The SUS is a broadly used, standardized set of questions used to evaluate the usability of a product according to users' perceptions (Lewis, 2018). The test contains ten statements that alternate between positive and negative opinions about different aspects of usability (odd items positive, even items negative) (Brooke 1996, Sauro and Lewis 2011). The interviewees express their level of agreement with each statement using a Likert scale from 1 to 5 where 1 equals strongly disagree, and 5 equals strongly agree. The negatively worded statement is included to reduce the acquiescence response bias (Sauro and Lewis 2011). At the end of each statement, we gave respondents the opportunity to comment on the score they had awarded (see Supplementary Text S1, Section 4). For each completed SUS test, we calculated the SUS score following the methodology described by Brooke (1996). Then, we located the median score of each product in the categorical scale proposed by Bangor et al. (2009). Products in the categories 'worst imaginable', 'poor,' and 'ok' were considered unacceptable. Those in the 'good' category were considered marginally acceptable, whereas only those in the categories 'excellent' and 'best imaginable' were considered acceptable. We also counted and transcribed the comments on each statement, and classified them according to the common constraints of climate information products proposed by Patt and Gwata (2002).

5 Qualitative information on the user's perception of an 'ideal' information product with regard to content, format, language, frequency of publication, and the factors that can limit use. We classified

the answers into six categories of constraints (Patt and Gwata 2002), namely sources of information and analysis procedures (credibility); review processes (legitimacy); appropriate scale for decision making (scale); clarity of the structure, language and graphic elements (cognition); timely distribution for planning and decision making (procedures); and definition of more specific conclusions and recommendations for different topics and actors (options or choices). We added a category related to the content (main knowledge areas, namely climate, agriculture, and food security) of the set of information products.

Step 4. Generation and communication of recommendations

In Step 4, conclusions of the study are formulated in the form of recommendations for potential improvements both to individual products and the network of products. These are intended to provide feedback, based on the results of the assessment, to the technicians and scientists involved in creating the products, and can be communicated and socialized by various means, including summary reports, detailed reports, and personal meetings.

We formulated the recommendations based on the results of the previous steps of the assessment, focusing on (i) the relationship of the product(s) with other products, highlighting its role, for example, as an information provider or integrator (Step 2); (ii) the identity of the current users of the product(s) (Step 3); (iii) users' knowledge and perception of the product(s); and (iv) the main positive aspects and limitations of the products and improvements suggested by users (Step 3).

2.2 Context: Climate services in Guatemala and Colombia

We applied the methodology in Guatemala and Colombia. In both countries, there is a growing availability of climate information products, designed to orient the design, target, and implementation of interventions of a broad range of organizations related to agriculture and food security. In this section, we first describe the main factors that influence the vulnerability of agriculture and food security in both countries, such as exposure to different climate processes, the characteristics of agricultural systems, and the institutional environment. Then we explain the thematic and geographical focus of our work in each of these countries.

Guatemala is one of the most vulnerable countries to climate change and variability in Latin America, with significant exposure to climatic extremes, including droughts. Cyclical drought is a significant climate hazard in Guatemala that has widespread and severe impacts on agricultural production and food security (van der Zee Arias et al., 2012). The cyclical midsummer drought is an extended dry spell during the rainy season that coincides with a critical phase in crop production (van der Zee Arias et al., 2012). In recent years there has been a tendency for this dry spell to start earlier and/or last longer (Aguilar et al., 2005; Hidalgo et al., 2017; Rauscher et al., 2008), and climate projections suggest these trends will continue (Magrin et al., 2014; Marengo et al., 2014). The agricultural sector is dominated by small-scale, resource-poor producers, with a significant share of the population living in food insecurity (FEWS NET, 2016). Farming systems in substantial parts of the territory show limited adaptive capacity (Bouroncle et al., 2017; Sain et al., 2017). Specifically, public organizations in the agricultural and food security sectors have limited capacity to respond to droughts (Müller et al., 2019). A national adaptation strategy and a framework for the implementation of adaptation policies and instruments are still missing (Vera et al., 2012). Guatemala´s Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) and Central America's Regional Climate-Smart Agriculture strategy both recognize the importance of climate information for adaptation and integrated climate risk management (CAC, 2017; República de Guatemala, 2015). The National Meteorological Service (INSIVUMEH), the Ministry of Agriculture and Livestock (MAGA), and the Food and Nutrition Security Secretariat (SESAN) lead the production of agro-climatic and food security information, but at the highest level, there is still limited institutional support for these efforts. However, Local Technical Agro-Climatic Committees have been recently (in 2019) been established in five municipalities under the coordination of the INSIVUMEH.

Colombia's agricultural sector is also highly vulnerable to climate variability and change (Delerce et al., 2016; Ramirez-Villegas et al., 2012; World Bank et al., 2015). In most regions of the country, rainfall is strongly influenced by ENSO, with reductions in precipitation and sometimes widespread drought during El Niño (warm) years, leading to significant agricultural productivity losses, lower farmer incomes and/or higher market prices (CIAT-MADR, 2015; Cortés Bello et al., 2013; Iizumi et al., 2014). Both the public and the private sectors in Colombia are making substantial efforts to adapt to climate variability (IDEAM, 2017; Ramirez-Villegas and Khoury, 2013). Notably, in 2015 the Nationally Determined Contribution of Colombia towards the Climate Agreement (UNFCCC) established a framework for climate risk management whereby both private and public organizations must co-generate climate services for agriculture through Local Technical Agro-Climatic Committees; these committees have been working for some years in several departments of the country, under the coordination of the Ministry of Agriculture and Rural Development (IDEAM, 2017). In 2017 Colombia launched the National Framework for Climate Services that establishes the National Meteorological Service (IDEAM) as a link between agriculture, health and energy teams for the development of these services. Thus, the workforce at this organization includes members of staff with specific responsibility for coordination with those sectors. These efforts create a complex interplay of stakeholders that co-generate, transfer and use agro-climate information. As a result, many information products have been created that inform decision making in the context of climate variability, from the national through to the local scale.

In Guatemala, we focused on information products that support decision-making related to drought impacts on agriculture and food security in the country's Dry Corridor. We selected the area because of the high risk of droughts; it encompasses nearly 10% of Guatemala's territory (MAGA, 2010) and contains 12% of the total population (INE, 2013). Livelihoods in the Dry Corridor are generally based on subsistence maize and bean production and off-farm income-generating activities such as coffee harvesting. Maize and bean production are sensitive to rising temperatures and changing rainfall patterns (Eitzinger et al., 2012), and as farmers depend on rain-fed agriculture, extended droughts reduce yields and exacerbate food insecurity and poverty (Pereyr and Ibargüen, 2015).

The focus in Colombia was on information products that support responses to climate variability by the agricultural sector. Geographically, we focused on the departments of Córdoba and Santander since both are involved in ongoing efforts to produce CS, which, however, differ in terms of organizational setting, history, and users. Both have functioning agro-climatic committees, whose role is to generate weather and climate forecasts tailored to local conditions through the participation of farmers, the private sector, research organizations, and national and local government organizations (Loboguerrero et al., 2018). In Córdoba an agro-climatic committee was created in 2015, providing seasonal agro-climatic outlooks for small and medium-scale maize producers across the department (FENALCE, 2018; Loboguerrero et al., 2018). In Santander, the co-production and use of agro-climatic information are more recent, with the establishment of the agro-climatic committee in 2017.

3 Results

3.1 Inventory of information products

In Guatemala we found 15 information products with relevant information on drought management for agriculture and food security (Bouroncle et al., 2015), seven are related to the monitoring of climate, crops, and food security variables, while eight are related with forecasts of variables of these themes (see Table 1). An iterative approach was adopted to compile the inventory in conjunction with INSIVUMEH, MAGA, and SESAN. As explained above, these are the three leading governing organizations involved in the production of agro-climatic and food security information, and they were involved in the assessment from the outset. An online search identified products published by national and regional (supranational) organizations. The first round of interviews with key decision-makers from these three organizations provided information on further, locally published products. The majority of products identified contain national-scale information and are produced by central government organizations and international cooperation programs. Regional-scale products are produced by intergovernmental platforms and international cooperation programs. A smaller and more recent group of products addresses the need for local-scale information and includes bulletins from a municipality and a municipal inter-organizational working group. The last was the only case of product generated in Guatemala through co-production between multiple organizations.

In Colombia, from an existing list of 41 climate information products related to climate and agriculture (an initial list, includes 20 additional products related with disaster risk management, fisheries and other themes, Perez Marulanda et al., 2016), we prioritized 13 for the assessment in conjunction with the National Meteorological Service (IDEAM). Three are related to the monitoring of climate, crops and agro-climate variables, white ten are related with forecasts of variables of these themes (see Table 1). As the leading government provider of climate services in Colombia, IDEAM was involved in the assessment from the outset. The selection of products in Colombia was based on two criteria: first, the exclusion of products that include only primary data (most of them produced by the IDEAM), if those data are included in another product of the same publishing organization; second, the inclusion of the products most used by agricultural stakeholders based on the knowledge of IDEAM staff. The 13 products included websites, bulletins, and mobile phone applications at local, national and regional scales that directly support agricultural decision making (Table 1). Three of the products are generated through co-production between multiple organizations (private and public), including in the local agro-climatic committees (Loboguerrero et al., 2018).

[Table 1 near here]

3.2 Analysis of the relationships between products

From the 15 products in Guatemala, two (GTM_N_FMH, GTM_N_PB) had no connections with any other product (that is, they did not cite other products, and other products did not cite them) and were hence not included in the cluster, network and migration analyses. In Colombia, all the selected products were included in these analyses.

Groups of products determined by citation patterns

In Guatemala, the 13 remaining products were grouped into three main clusters according to their scale of application (Fig. 2a). The first group includes a single regional product, namely, the Central American Seasonal Climate Outlook (GTM_R_CACP) of the Climate Forum of Central America. This is the result of the collaboration between the country's national meteorological service (INSIVUMEH) and the other national meteorological services of the Central American region. The second group includes the Crop Monitoring System (GTM_N_CMS) and the Food and Nutrition Security Forecast (GTM_N_FFNS). These are both national-scale products that aggregate sector-specific information from a variety of sources. The third group combines products focused on different themes targeting regional, national, and local scales.

In Colombia, the cluster analysis (Fig. 2b) defines two groups of information products according to their production process. The first group includes the co-produced information products; they are grouped because they have a similar citation pattern that reflects a range of different themes considered in the co-production processes. As in Guatemala, the last group combines thematic products prepared in a conventional way targeting users different scales.

Dendrograms from cluster analysis of information products with relevant information on (a) drought management for agriculture and food security in Guatemala available in 2015, and (b) agro-climatic information available in Colombia in 2018. The dendrograms show the grouping of information products according to their citation patterns, colors indicate the group of products for a statistical solution of three and two clusters respectively. In Guatemala the citation pattern grouped the products according to their geographical scale, while in Colombia they grouped them according to whether they were co-produced or prepared in a conventional manner.

[Figure 2 near here]

Roles of products in the information exchange network

In Guatemala, network analysis shows that the Central American Seasonal Climate Outlook is at the center of the network (Fig. 3a), being both the main source of climate information for the network and the main entry point of regional information. It is cited by eight products as shown by the migration plot (Fig. 4a). The Crop Monitoring System and the Food and Nutritional Security Forecast display good connectedness in the network, although with less centrality (Fig. 3a), and a similar citation pattern in terms of number and diversity (Fig. 4a). These two products have the most potential for the integration of information from different themes in the network. Other products, focused on different knowledge areas, are located in peripheral areas of the network (Fig. 3a) and have a lower number of connections (Fig. 4a).

In Colombia, the National Agro-climatic Bulletin (COL_N_NAB) is the product with the largest number of connections (Fig. 3b). The Monthly Bulletin on Climate Prediction (COL_N_MBCP) also has a large number of connections in the network (Fig. 3b). Due to the nature of the connections (i.e. mostly as an information provider, Fig. 4b), the COL_N_MBCP is in the second group of products. Members of this group of products generally make fewer citations than they receive; their products cover a range of themes including weather forecasting (COL_N_AMF), short-term (COL_N_AF) and seasonal (COL_L_AFP) agro-climatic forecasting, early warning (COL_L_EWS), and input prices (COL_N_MBI).

[Figures 3 and 4 near here]

In both countries, the density of the networks, measured as the number of connections between products in relation to the total number of potential connections, is relatively low (13.5 % in Guatemala, and 25 % in Colombia).

3.3 User-centered assessment of individual information products

A total of 40 and 35 people were interviewed in Guatemala and Columbia, respectively. In Guatemala, 17 interviewees were based in the capital city, Guatemala City, and the remaining 23 were based in the Dry Corridor. In Colombia, 19 interviewees were based in the capital city, Bogota D.C., and the remaining 16 were based in Santander and Córdoba. In Colombia, most interviewees were from the central government (12), whereas in Guatemala, most interviewees were from international cooperation agencies (14). A full list of interviewees, broken down by sector and location, is provided in Supplementary Table S1.

Decision-makers' knowledge of the products

In Guatemala, 10 out of the 15 information products were significantly better known by the interviewees working in the capital city than by those working in the Dry Corridor (Table 2). These products, none of which are intended to support local-scale decision-making, were typically rated 4 or 5 by interviewees based in Guatemala City, indicating that they use the product or have done so in the past. By contrast, most of those national- and regional- scale products were rated with a 2 ("I have heard about it before") by interviewees based in the Dry Corridor. While none of the products was rated 5 ("I use it and consult it frequently") by interviewees in the Dry Corridor they tended to give higher ratings to simple and short-term national-scale climatic products and local produced products.

[Table 2 near here]

In Colombia, statistically similar levels of knowledge across the three groups of interviewees (Bogotá D.C., Córdoba, and Santander) were found for 9 of the 13 products assessed. These included all national-scale products, and one local-scale information product. This suggests that, unlike in Guatemala, the dissemination of national-scale information products in Colombia is relatively uniform across scales, although not all are widely known. For example, the Monthly Bulletin of Agricultural Inputs (COL_N_MBI) and the Seasonal Climate Outlook Bulletin (COL_R_CABC) are barely known in the capital city, or in Santander and Córdoba. Both of these are ranked as "I have seen it once" at best. Notably, we find that the only local-scale product that is well known by decision-makers of the capital city, Santander and Córdoba is the Agro-climatic Forecasting Platform (COL_L_AFP). This platform provides information for some 30 different localities in 9 departments across the country. Apart from the COL_L_AFP, local information products are only known in the local scale for which they were developed. For instance, the Córdoba agro-climatic bulletin (COL_L_ABC) is very well known in Córdoba, but not even heard of in Santander. The reverse is valid for the Santander agro-climatic bulletin (COL_L_ABS).

Decision-makers' use of the information products

Fig. 5 shows the uses of information products structured by actions and decisions mentioned by the interviewees across temporal scales (daily, monthly, seasonal) for both countries. Information products are used for three purposes, namely, (1) obtaining advice on agricultural activity planning, (2) receiving early warning of extreme climate events or food security alerts, and (3) organization planning. There are substantial similarities between the type of decision-making supported by information products in the two countries. For agricultural planning, products exist in both countries that are intended to support the (re)programming of field activities, selection of crop varieties, programming of planting and harvesting, and the sale of products. In both countries, most of these products contain local-scale information, reflecting the scale at which such decisions are taken. Early warnings of both flooding (daily timescale) and drought (monthly to seasonal) are given by information products in both countries. Finally, with regard to organizational planning, we note a strong focus in Guatemala toward the provision of information products for humanitarian actions that address food insecurity. By contrast, in Colombia, products are used for the design of project proposals and technical assistance programs, the formulation of research guidelines, and deciding on insurance against crop losses.

[Figure 5 near here]

Decision-makers' perceptions of the usability of the information products

In Guatemala, the mean System Usability Scale (SUS) score for the assessed products varies between 72.5 for the Early Warning System bulletin (GTM_L_EWS) and 90.2 for the Monthly Meteorological Bulletin

(GTM_N_MMB, Fig. 6). According to the qualitative scale proposed by Bangor et al. (2009), two products are 'Excellent,' twelve are 'Good,' and one is 'OK.' The highest scoring products are focused on a single theme and provide primary information. The standard deviations show a substantial variation among the scores, which suggests that the interviewees have variable experiences of using the products and that these may not be satisfying the full range of users' requirements. To some extent, the variation may also reflect the subjective nature of the categories used to assess the utility of the products.

In Colombia, the range of the mean SUS value for products is wider than in Guatemala, varying from 46.25 for the Monthly Bulletin of Agricultural Inputs (COL_N_MBI) to 92.00 for Agroclimatic Bulletin of Santander (COL_L_ABS, Figure 6). The latter is the only product whose mean is close to the 'Best imaginable level' of 100 (Bangor et al., 2009). From the remaining products, ten are scored as 'Excellent,' one is 'Good,' and the least scored product is 'OK.' The two lowest-ranked products were also those with the lowest level of use among interviewed persons (COL_N_MBI, COL_L_EWS; Table 2). As in Guatemala, the product scores does not show any pattern related to scale, theme or publishing organization. However, we note that the top-5 ranked products (from COL_L_ABS with a SUS mean score of 92.00 to COL_L_ACB with a mean score of 80.42) are co-produced bulletins or mobile applications, that is, products where the design is user-friendly and/or that enables direct information transfer to users.

[Figure 6 near here]

The SUS average scores are generally well supported by the qualitative assessments made by comments from the interviewees. We noted, however, that the number of comments that accompany the negative statements of the SUS questionnaire was about double the number of comments that accompany positive statements, in both countries. This suggests that the interviewees tend to use the negative statements of the SUS to express criticism and suggestions (see a summary of comments in Supplementary Table S2).

Characteristics of 'ideal' information products

We synthesized suggestions from interviewees for an ideal information product into a single set of characteristics for both countries. The 'ideal' characteristics are classified according to the constraints that they overcome following Patt & Gwata (2002) in Table 3 (also see Supplementary Table S2) namely credibility, legitimacy, scale, cognition, procedures, choices, and content.

[Table 3 near here]

In both countries, the most frequently mentioned desirable characteristics mentioned by interviewees corresponded to different aspects of procedure. Procedures included timely distribution, frequent publication, convenient delivery mechanism/channel (i.e., presentation in public settings, use of mobile phone applications, voice messaging, and radio), and the options of two-way (user-provider) communication and downloadable source information. In Guatemala, the second most frequently mentioned desired characteristic was cognition. Interviewees indicated that the ideal product should be in plain language, logically structures, provide a synthesis of key messages with the help of visual aids (maps, graphs, and their corresponding interpretation), and integrate various types of information (climatic, agronomic, food security). For Colombia, the second most frequently mentioned desired characteristic was credibility, including the use and comparison of trusted sources, and the appropriate explanation of methods, results and uncertainty levels. Less frequently mentioned as desired characteristics, but still considered relevant, were legitimacy and scale. Interviewees in both countries identified the incorporation of local feedback as an important process concerning legitimacy, whereas aggregation of information was the only desired characteristic identified with respect to scale. Differences between countries indicate that most limiting factors are context-specific, reflecting evolving needs for improvement as countries develop better climate services. Users consistently identified specificity (i.e. choices) in the recommendations as an important characteristic of an ideal information product. This desired characteristic is challenging to address since enhanced organizational capacities may be required in order to produce context-specific recommendations. The kind of specific recommendations that users would like to find on the information products might also require enhanced content, i.e. the incorporation of more specific types of data that are not available at present (see "Contents" in Table 3). Similarly, changes in the scale of analysis may also be required in order to provide site- and/or sector-specific recommendations.

The desirable characteristics of information products identified by the interviewees are consistent with the comments they provided when evaluating the products available with the SUS questionnaire, whether these accompanied any negative or affirmations. This is clearly seen by organizing the results of both exercises according to the scheme proposed by Patt and Gwata (2002) mentioned above (see Table 3 and Supplementary Table S2). The results of both exercises are also consistent with the results and recommendations of previous research on the usability of climate services (Lemos et al., 2012).

3.4 Organizational feedback regarding information product assessment

Obtaining feedback from technicians and scientists involved in the generation of the products that were the subject to our assessment was an essential final step in our research. In both countries, it allowed providers to appreciate users' perspectives on the information they are providing and on the ways in which the information is being provided. All the representatives of information providers we spoke to found the network analysis a novel approach that helped them to understand the broad context in which their information products exist and how they interact with other products. They also said that network analysis could help identify thematic and functional gaps (e.g. links with local networks), which could be addressed by collaborating with other organizations. Over and above these novel features, the assessment was seen as a useful and replicable process that provided confirmation of challenges information providers already knew about and how existing products could be improved. In this sense, results from the assessment process could be used to justify planned changes in current information products. Supplementary Text S2 provides an overview of the feedback from information providers and how it was obtained.

4 Discussion

4.1 Tailored climate information for agriculture and food security Guatemala and Colombia

We designed and applied an approach for assessing information products related to existing climate services for agriculture and food security. Across Guatemala and Colombia, our findings indicate that there are a substantial number of periodically published information products that specifically address these thematic areas. The products contribute in different ways to decision-making processes at both national and local scale, providing both monitoring as well as forecast information. These findings have important implications for the provision of climate services in the two countries.

A first finding, emerging from the inventories and in-depth review of the information products, is that most of them seem to be produced following a 'loading-dock' model, in which users are barely involved in the process of product design and implementation (Brasseur and Gallardo, 2016; Cash et al., 2006; Vogel et al., 2017). Exceptions in Colombia are the Córdoba (COL_L_ABC) and Santander (COL_L_ABS) agro-climatic bulletins, where the local technical agro-climatic committees enable the effective and coordinated co-production, translation, transfer, and use of agro-climatic risk management information (Loboguerrero et al., 2018). In Guatemala, the Jocotán Bulletin of Nutritional and Food Security (GTM_L_BSJ), is prepared by the Municipal Commission for Food and Nutritional Security (COMUSAN), a coordination platform involving several organizations. However, our findings indicate that these co-produced products tend to have higher usability scores compared to those produced by single organizations, even though co-produced products play a very different role in the networks in the two countries. This is an interesting finding since the product implementation process was not a principal focus of the initial usability assessment. We consider that this point should be further analyzed (e.g. through interviews with representatives of the organizations that co-produce information products).

Second, our analysis relates to the relationships between information products. In both countries, the number of connections is relatively low in relation to the total number of potential connections between products. To some extent, this relatively low connectivity among products may reflect the limited coordination among the organizations which produce them. These gaps in integration between stakeholders and information sources have previously been identified for Colombia and elsewhere (Buizer et al., 2012; Loboguerrero et al., 2018), and can be seen especially in Guatemala, where two products (Forecast Maps for 24, 48 and 72h [GTM_N_FMH]; and Price Bulletin [GTM_N_PB]) are entirely disconnected from the rest, and thus are not part of the network (and therefore omitted from Figures 2, 3, and 4) although they contain information that is not in other products. While it is possible that these products share connections in other contexts, it is clear that they are potentially useful, yet not used, to inform climate-related decision-making in Guatemala. In other cases, a lack of connectivity with other information products considered in this study is a result of the specialized nature of the information product and its target user group. This can be seen, for instance, in the Coffee Bulletin in Colombia (COL_L_ACB), which, as its name indicates, mainly targets the coffee sector. This product may have different connections that would be revealed by analysis of a specialized coffee information products network. Thus, while there are opportunities to enhance organizational coordination and integration in the generation of information products, it is critical to understand the role of each product in the information network and leverage that role in any coordination initiatives.

Third, our analysis reveals that in both contexts (Guatemala, Colombia), we find a product that acts as a 'global' information provider. In both cases this global provider is a climate-only information product that virtually all other products refer to; however, in Guatemala it is a Central American product (the Regional Seasonal Climate Outlook [GTM_R_CACP]), whereas in Columbia it is a national-scale one (the Monthly Climate Prediction Bulletin [COL_N_MBCP]). It is likely that information flow in both contexts would be more restricted if these products did not exist. More importantly, any investment in improving the credibility, legitimacy, scale, cognition, procedures, and content of these highly central products would result in improvements in all the other products that refer to them, and therefore, probably, also to improvements in decision-making processes at both national and local scales. It is notable that both these central products are produced under the leadership or with the involvement of the national meteorological services and are either a direct result of (Guatemala) or input to (Colombia) the Climate Outlook Forum process (Ogallo et al., 2008). Moreover, in both cases these products provide seasonal information, to support seasonal decision-making, and there are recently published studies documenting their forecasting skills that underpin their credibility (Alfaro et al., 2018; Esquivel et al., 2018). In contrast, the Regional Outlook on Food and Nutritional Security (GTM_R_RFAF), occupies, unexpectedly, a less central position in the Guatemalan network. Hence, a further question raised by our results is whether agricultural and food security stakeholders have access to the information they need to effectively link climate forecasts to decision-making processes (Buizer et al., 2012; Loboguerrero et al., 2018) or whether there is a lack of skill in integrating climate information in a way that is meaningful to agricultural decision-makers (Briley et al., 2015). This question could be investigated by researching user capacities and needs, and the extent to which the latter are met by the available information products and the information they provide.

4.2 Towards an operational agro-climatic information products assessment

Strengths, limitations, and performance of the assessment approach

This study outlines an approach to the assessment of CS based on a combination of network analysis and user-centered analysis. In the following sections, we briefly examine the strengths and limitations of the approach and consider how it could be improved.

The typology of evaluations of development projects, programs, and policies proposed by the Organization for Economic Cooperation and Development (OECD, 2002) is useful for delimiting the scope of potential application of our approach, i.e. what it can and cannot be used for. Our approach can be applied to explore the relevance of the CS (e.g. their use and usability by decision-makers with different objectives) and their efficacy in contributing to the flow of information between products (e.g. by revealing the complementary roles of different information products as part of an information network). In this way, our approach can contribute towards remedying deficiencies identified in these respects: one could think about targeting improvements in usability in specific information product or identifying entry points for new climate services (e.g. improved seasonal forecasts) in the information network. On the other hand, our approach does not provide information on efficiency in the use of resources (e.g., time and money required to co-produce information products), nor on the impact of products in terms of behavioral change and downstream development impacts (e.g. avoidance of losses and damage to crop harvests). Nor does the approach consider the sustainability of measures that could be taken to improve the CS (e.g. organizational and policy changes that facilitate the use of CS). Taking all of the above into account, we propose the principal applications of our approach are (i) as a diagnostic tool to identify opportunities for improved provision of CS with an information network (diagnostic assessment); and (ii) to explore the effects of actions taken by projects, programs and policies with the aim of improving the provision and usability of CS.

Our experience of the design and implementation of the assessments in Guatemala and Colombia, in addition to findings reported in the literature on the evaluation of user-centered programs and development processes focused on innovation (see for example Guijt and Woodhill, 2002; Birachi et al., 2013), suggest that the approach proposed here will be especially useful for strengthening internal self-assessment processes, oriented towards learning from experience and reflecting on the lessons learned. In any case, the success of this and other assessment approaches will always depend on the quality of the design of the evaluation process, as well as the existence of organizational structures that provide a context that is conducive to their application (Rodríguez Aríza and Monterde-Díaz, 2014). Aspects of our approach that contribute towards satisfying these conditions include the iterative nature of the process, the participation of stakeholders throughout the study, the production of data that is comparable across different contexts (see previous section), and its novelty, which was confirmed in meetings that were held to share the results with CS providers in the concluding phase of the study. Staff of these organizations found it interesting to see their products analyzed from the perspective of the broader network of products of which they formed part; our presentation of these results generated lively discussions about how to improve communication flows. Furthermore, the verification of the levels of use of individual products and the SUS scores provided useful insights for CS providers on the effectiveness of their products and ways they could be improved.

The application of the approach in Guatemala and Colombia demonstrated its capacity to generate comparable results in different contexts, while the Methods section of this study provides a transparent description of a standardized method for generating comparable results in future applications.

Suggestions for the future development of the approach

A number of changes were incorporated into the methodology between the assessments in Guatemala and Colombia, specifically changes in the order of the interview questions. However, in hindsight, we also consider that some steps in the method were too time-consuming. Specifically, the detailed review of each information product to determine which other products it cited took considerable time, as few products include a reference list. Furthermore, the time required to conduct the interviews and analyze the results could be reduced by limiting the number of open-ended questions, to eliminate the overlap between the comments on the SUS scores and the identification of characteristics of ideal products. There is also scope to improve the graphical presentation of the results to make them more accessible to non-experts. Studies using the assessment approach could explore these and other opportunities to improve both the design and the application of the methodology.

The approach could be improved by making more efficient use of resources when carrying out the assessment. Where evaluations include a large number of products and are done regularly, it is desirable to automate and simplify as many elements as possible (e.g. Jarvis et al., 2015). To increase efficiency in the use of available resources, it may be possible to conduct online or interactive-voice-response surveys, instead of face-to-face interviews. While this reduces time, it may also reduce response rates, requiring the survey to be sent to a larger number of personalized contacts (Cook et al., 2000). Moreover, keeping the respondents engaged is recognized as a challenge in online surveys (Heerwegh and Loosveldt, 2008) and occasional face-to-face interaction may still be required. For the information product network analysis, automation of citation searches may be possible, including the identification of elements copied from other information products. Such automated searches become more attractive if they have the capacity to cover several countries and scales. Building infographic layouts that convey statistical and graphical results in a more friendly way will also contribute to more efficient communication of the results.

The proposed approach leaves flexibility for integrating improvements and increase the effectiveness on the assessment, either based on lessons learned or in response to specific characteristics of the context. For example, given the importance of co-production processes revealed by this study, we consider it essential to include in the assessment approach a specific procedure to generate information on this topic, using standard principles such as those proposed by Vincent et al. (2018) or Bremer et al. (2019).

Considerations in operationalizing the assessment approach

In operationalizing our assessment approach, it will be essential to ensure that the methodological procedure adopted corresponds to the objectives of the assessment. Organizations leading the assessments could decide to simplify our approach and focus on a specific aspect depending on their own area(s) of interest and availability or resources. For instance, a government might be interested in understanding how connections between products or group of products evolve over time. In that case, only the cluster, network, and migration analyses are needed, and the assessment can concentrate on a desk review of citations and references. On the other hand, a farmers' organization may be interested in knowing whether an information product is used by their target group of extension agents or farmers and whether or not these people find the information product suitable for use. In this case, only the use and usability aspects of the assessment may be required. Depending on the available resources, the cluster, network, and migration analysis can be performed with an inventory that includes all available products, and a subsequent selection can be made for the decision-makers' assessment.

Any such assessments should mimic the ideal process of elaboration of the information products and should, therefore, be carried out as far as possible in coordination and collaboration between relevant organizations. If various organizations conduct product assessments in parallel for the same geographic or thematic areas, they should coordinate their efforts to maintain a common framework for assessment and reporting and share data and results.

5 Conclusions

Substantial progress has been made in Guatemala and Colombia in terms of climate variability management, suggesting a transition from reactive crisis response to proactive risk management. Product networks tend to integrate themes or disciplines. However, while climate-only information products are well connected and play a central role in the identified networks, work is needed to develop applied agriculture and food security information products to enable integration of multiple fields of knowledge and perspectives into decision-making processes. Furthermore, the results of the network analysis indicate that further opportunities for information flow exist that are not yet being taken advantage of; as evidenced, for example, by the disconnection of local information products from national-scale products in Guatemala. On the other hand, the results of our user-centered assessment point to the need for major improvements to most existing products in order to respond to the requirements of current and potential users. Brevity and clarity of language are highlighted as desirable in both countries, as well as use of trusted and publicly-available data, and non-paper-based delivery formats. Opportunities to improve CS were revealed by both analytical methods applied in this study. Network analysis identified the potential benefit to the network as a whole of investing in the further development of products that have a strong influence on other products. The user-centered analysis identified a range of potential improvements to individual products. More importantly, any investment in improving the credibility, legitimacy, scale, cognition, procedures, and content of these highly central products would result in improvements in all the other products that refer to them, and therefore, probably, also to improvements in decision-making processes at both national and local scales.

Our approach helped to elucidate general configurations of networks, for example by revealing the role of regional and national seasonal climate outlooks as 'global information providers'; as well as identifying areas where there is scope for improvement, for example by improving the connectivity of the regional food and nutritional security outlook in Guatemala. It also helped to identify measures that could be taken to improve the usability and use of existing products. The results of our user-centered assessment suggest that, while sector-specific data is available and capacities exist in both countries, information management does not always meet users' requirements. Enhanced or novel products are required to address constraints identified by the broad range of users interviewed here, most notably in terms of cognition, procedures, and credibility. When generating new products or improving existing ones, it is important to include a range of users' and organizational perspectives through the adoption of more user-driven design processes, in order to fully realize the potential for transforming existing data into useful information products that address users' needs. A user-centered design process and clarity regarding the broader information ecosystem will avoid developing products that (i) are disconnected, unusable or do not end up in the hands of users; (ii) are redundant, or (iii) that do not address existing information needs.

Our results were shared with the information providers, generating a first feedback loop between information producers and users. Moreover, the fact that our analysis included users and products at multiple scales helped to capture both the broad range of existing products and a representative cross-section of users' perspectives. The use of standardized questions and a standardized metric (SUS), helped to make comparisons possible across scales and themes. This standardization will also be essential to sustain comparability across time and space when the assessment is repeated and when it is replicated in other countries. Accumulated insights into climate information products and networks may lead to the establishment of benchmarks that can guide quality management. We believe that only through systematic assessment of CS for agriculture and food security can we know whether they are effective in providing high-quality, actionable information to improve the decisions of farmers, extension agents, agricultural organization managers, international cooperation agencies, governments, and others. Such systematic understanding can then help to prioritize actions and co-develop new products. Our systematic assessment approach provides a sound basis for coordinated efforts towards this end.

Acknowledgments

(Please see this section in the final published version of this article: https://www.sciencedirect.com/science/article/pii/S2405880719300780?via%3Dihub#ak005).

Supplementary Material

Text S1. Interview format for decision-makers and considerations for its application in Colombia.
Text S2. Communication of the results of the assessment process.
Table S1. Numbers of interviewees that contributed to the assessment of information products presented here, according to institution type and location.
Table S2. Summary of positive (+) and negative (–) characteristics of current information products as gathered from interviewees in both Guatemala and Colombia, classified according to common constraints of this kind of products (Patt and Gwata, 2002).

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Table 1. Information products assessed for Guatemala and Colombia. The code includes the country abbreviation, the product scale (L - local, N - national, R - regional) and the acronym of the product name. Main theme: CL - climate, CR - crops, AC – agroclimatic, FS - food security; frequency: D - daily, M - monthly, S - seasonal; type: M - monitoring, F – forecasting.

Code	Publication	Publishing organization name and type	Co-production process	Main theme	Frequency	Type
GTM_L_BSJ	Bulletin SAN, Jocotán	COMUSAN – local government platform	Yes	FS	M	M
GTM_L_EWS	Early Warning System	Copanch´orti´ - local governments platform		CL	M	F
GTM_L_MCR	Monthly Climate Report			CL	M	M
GTM_N_MBRP	Reserves and Prices Monthly Bulletin	FAO – international cooperation		FS	M	M
GTM_R_CACP	Central America Seasonal Climate Outlook	FCAC-CRRH-SICA – regional intergovernmental platform		CL	S	F
GTM_N_FSP	Food Security Outlook	FEWS NET – international cooperation		FS	M & S	F
GTM_N_PB	Price Bulletin			FS	M	M
GTM_N_DM	Daily Maps	INSIVUMEH – governmental organization		CL	D	M
GTM_N_FMH	Forecast Maps for 24, 48 and 72 H			CL	D	F
GTM_N_MMB	Monthly Meteorological Bulletin			CL	M	M
GTM_N_MPB	Monthly Perspective Bulletin			CL	M	F
GTM_N_SPB	Seasonal Perspective Bulletin			CL	S	F
GTM_N_CMS	Crop Monitoring System	MAGA – governmental organization		CR	M	M
GTM_N_FFNS	Food and Nutrition Security Forecast	SESAN – governmental organization		FS	S	F
GTM_R_RFAF	Regional Forum for the Application of Forecasts for Food and Nutritional Security	OBSAN-R-SICA – intergovernmental platform		CR	S	F
COL_L_ACB	Coffee Agroclimatic Bulletin	Coffee Federation – producers association		AC	M	F
COL_L_ABC	Córdoba Agroclimatic Bulletin	FENALCE – producers association	Yes	AC	M	F
COL_L_ABS	Santander Agroclimatic Bulletin		Yes	AC	M	F
COL_L_AFP	Agroclimatic Forecasting Platform	CIAT – international cooperation		AC	M	F
COL_R_CABC	Climatic Analysis Bulletin CIIFEN	CIIFEN – international cooperation		CL	M	F
COL_N_MBI	Agricultural Inputs Bulletin	DANE – governmental organization		CR	M	M
COL_N_AF	Agrometeorological Forecast	IDEAM – governmental organization		AC	S	F
COL_N_AMF	App My Forecast			CL	D	F
COL_N_DHB	Hydrometeorological Bulletin			CL	D	M
COL_N_MBCP	Bulletin on Climate Prediction			CL	M	F
COL_L_EWS	Bogotá Early Warning System	IDIGER – governmental organization		CL	D	M
COL_N_C	Celuagronet	MADR – governmental organization		CR	D	F
COL_N_NAB	National Agroclimatic Bulletin		Yes	AC	M	F

Table 2. Medians of knowledge ratings for information products grouped by work location of respondents interviewed in Guatemala and Colombia. Categories: 1 - I have never heard about this product before, 2 - I have heard about it before, 3 - I have seen it once, 4 - I have consulted it before but I do not use it frequently, and 5 - I use it and consult it frequently. Different letters show significant differences (Kruskal-Wallis test), α = 0.05 (**) or 0.01 (***). The sample (n) of people from Guatemala City who evaluated local products is lower than the total number of interviewees because these products were later incorporated into the process. For full titles of products see Table 1.

Product code	median		n	median		n	median		n	*p*
(a) Guatemala	Guatemala City			Dry Corridor						
GTM_L_BSJ	3		2	4		23	-		-	n.s.
GTM_L_EWS	1.5		2	2		23	-		-	n.s.
GTM_L_MCR	1.5		2	2		23	-		-	n.s.
GTM_N_CMS	5	a	17	2	b	23	-		-	***
GTM_N_DM	4		17	4		23	-		-	n.s.
GTM_N_FFNS	5	a	17	2	b	23	-		-	***
GTM_N_FMH	4		17	4		23	-		-	n.s.
GTM_N_FSP	5	a	17	2	b	23	-		-	***
GTM_N_MBRP	5	a	17	2	b	23	-		-	***
GTM_N_MMB	4	a	17	3	b	23	-		-	**
GTM_N_MPB	5	a	17	3	b	23	-		-	**
GTM_N_PB	5	a	17	2	b	23	-		-	***
GTM_N_SPB	5	a	17	3	b	23	-		-	***
GTM_R_CACP	4	a	17	2	b	23	-		-	***
GTM_R_RFAF	3	a	17	1	b	23	-		-	***
(b) Colombia	Bogotá, D.C.			Santander			Córdoba			
COL_L_ABC	3	a	16	5	b	8	1	c	8	***
COL_L_ABS	2	a	16	1	b	8	5	c	8	***
COL_L_ACB	3	a	16	1.5	ab	8	2	b	8	**
COL_L_AFP	4	a	16	4	a	8	2	b	8	**
COL_L_EWS	2	a	16	1	b	8	1	b	8	***
COL_N_AF	4		16	3.5		8	3.5		8	n.s.
COL_N_AMF	4		16	2		8	2.5		8	n.s.
COL_N_C	3		16	4.5		8	3.5		8	n.s.
COL_N_DHB	4		16	4		8	4		8	n.s.
COL_N_MBCP	4		16	4		8	3		8	n.s.
COL_N_MBI	2		16	1.5		8	1.5		8	n.s.
COL_N_NAB	5		16	5		8	3.5		8	n.s.
COL_R_CABC	3.5		16	2.5		8	3		8	n.s.

Table 3. Desirable characteristics of information products to overcome constraints (Patt and Gwata 2002) that limit its usability according to respondents interviewed in Guatemala and Colombia.

Constraints	Characteristics
Credibility	- Use of trusted sources and sources comparison. - Explanation of monitoring and forecasting methodologies and assumptions. - Explanation of forecasting uncertainty level.
Legitimacy	- Incorporation of local feedback. - Inventory of actions taken in response to the provision of the agro-climatic information.
Scale	- Information aggregated at first- or second-level administrative divisions of the country.
Cognitive capacity	- Plain language, links to a glossary when necessary. - Logical structure with key messages at the beginning, and synthesis sections for extension agents and farmers. - Visual aids (e.g., diagrams, photos, infographics) with clear captions. - Integration of climatic, agronomic and food security variables in the analysis.
Procedures	- Timely distribution for planning and decision-making. - High frequency of publication. - Links to original data and downloadable maps. - The apps should allow two-way communication - Appropriate delivery mechanisms (e.g., local meetings presentations, interactive maps or apps with climate forecast and crop recommendations, concise radio messages about key decisions, WhatsApp messages with the link to the products).
Choices (recommendations and other information to influence decisions)	- Concrete and practical recommendations based on explicit assumptions or scenarios. - Agroclimatic calendars for planning. - Drought impacts on coffee, livestock and drinking water, also relevant for food security. - List of current and planned organizational responses. - Maps with clear spatial references (e.g., areas vulnerable to drought or food insecurity).
Contents	- Climate: relative humidity observations, ENSO situation and forecast, mid-summer drought forecast, hurricane season forecast, dry spells monitoring, frost forecast, early flood warnings, maps of climate vulnerability. - Agriculture: evapotranspiration data, water requirements for crops, phenology, seed availability, pest and disease warnings, loss and damage estimates, farmer technical assistance budget, crops market prices, availability of financial instruments (e.g. loans and insurances). - Food security: population at risk and affected, acute and chronic malnutrition, access to drinkable water, food reserves, cost of the basic food basket.

Figure 1. Overview of the assessment approach. Research questions (left side) are presented alongside the methodological approach (center) adopted at each step of the analysis and the tools used for information gathering (right).

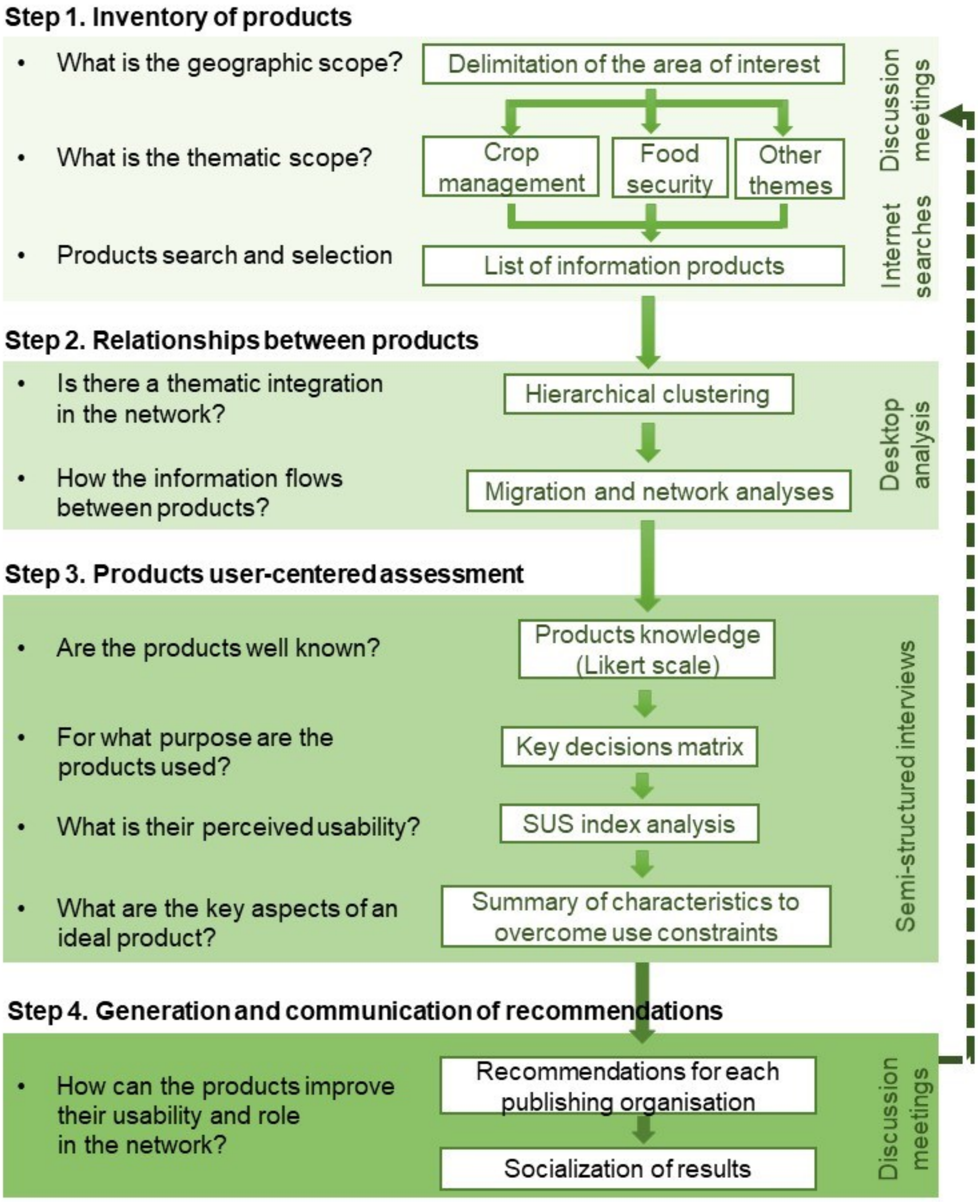


Figure 2. Dendrograms showing the results of cluster analysis of information products with relevant information on (a) drought management for agriculture and food security in Guatemala, available in 2015; (b) agro-climatic information in Colombia, available in 2018. The dendrograms group the information products according to the patterns of citation between pairs of products. Colors indicate the group of products for a statistical solution of three cluster in Guatemala and two clusters in Colombia. In Guatemala the grouping is principally determined by geographical scale; in Columbia the grouping is principally determined by the production processes, i.e. co-produced products vs. those produced by a single organization. Products are identified by product codes; for their full names see Table 1.

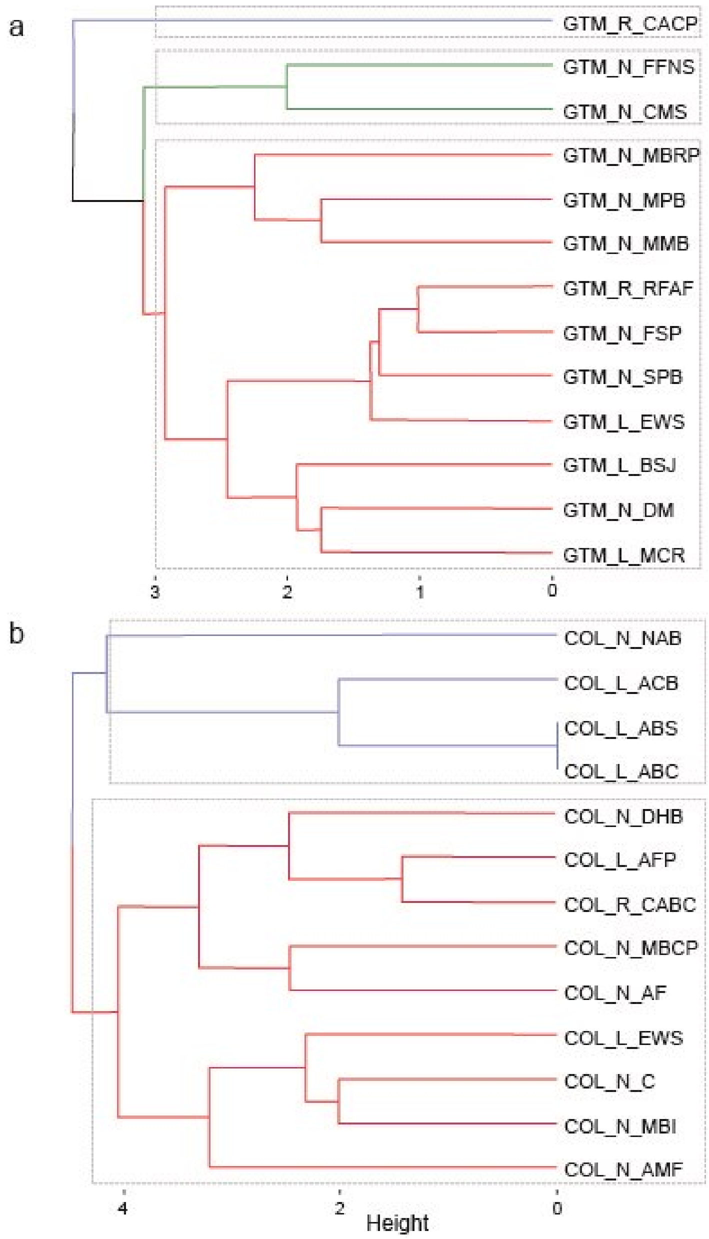


Figure 3. Networks of information products and their relationships as sources and receivers of information in (a) Guatemala, and (b) Colombia. Each node represents an information product, an arrow represents a confirmed relationship between two products: the source and the destination. The shape of the node corresponds to the main theme of the product; the color indicates the type of publishing organization, and the size is proportional to the number of direct relationships it has with other nodes. The position of each node in the diagram is related to its function in information exchange: The closer a node is to the center of the diagram, the more important it is as a provider of information; while the closer it is to other nodes, the more easily can it exchange information with them. The diagram also identifies 'intermediary' products that have a role in transferring information between two otherwise unconnected products. Products are identified by product codes; for their full names see Table 1.

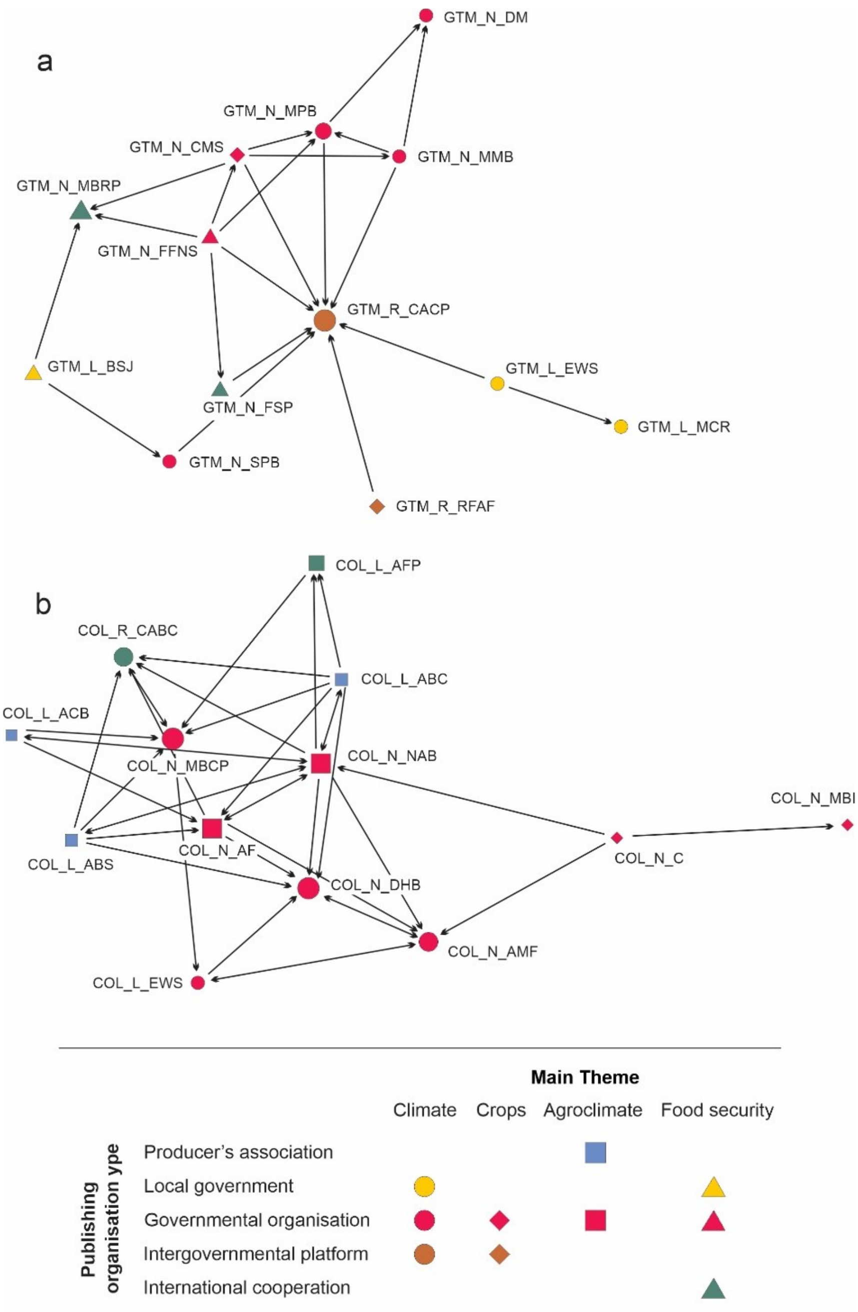


Figure 5. Objectives and decisions supported by information products in Guatemala and Colombia across temporal scales. Objectives are shown on the left, whereas decision topics are shown as white boxes within each objective. Products are identified by product codes; for their full names see Table 1. Monitoring products are shown in the standard font; forecast products are shown in italics.

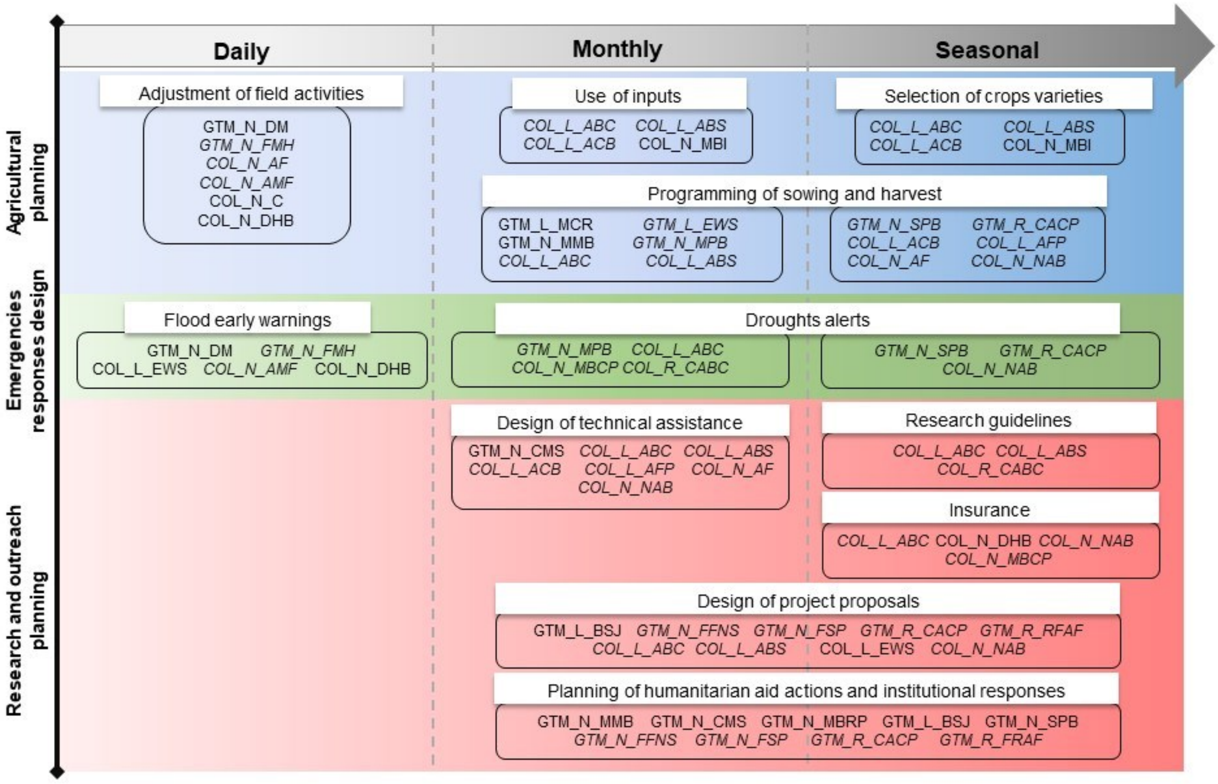
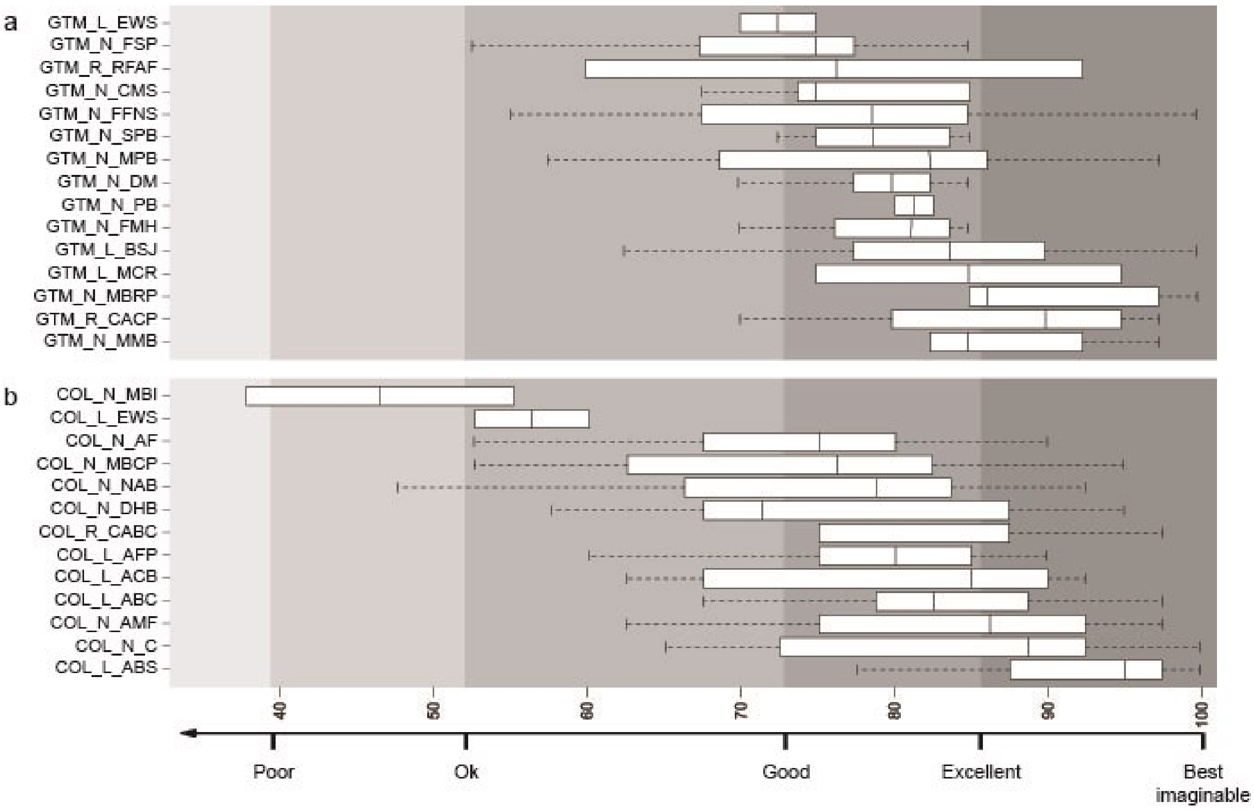


Figure 6. Variation in the System Usability Score (SUS) across information products in (a) Guatemala and (b) Colombia. The thick vertical line indicates the median, boxes extend to the interquartile range, and whiskers extend to 5 % and 95 % of the distribution. Products are identified by product codes; for their full names see Table 1.



5 Discusión general de resultados

Pregunta 1. ¿Cómo se caracteriza la vulnerabilidad al cambio climático de las familias agricultoras a pequeña escala en América Central, con especial atención a los factores que diferencian su capacidad de adaptación?

Sub-pregunta 1.1 A escala regional y local, ¿cómo impacta el cambio climático los medios de vida de las familias agricultoras a pequeña escala?

En los capítulos 2 y 3, uno a escala regional y el otro a escala local respectivamente, proponemos metodologías para estimar el impacto del cambio climático en los medios de vida de las familias agricultoras a pequeña escala; la primera, basada en información pública, y la segunda, en el conocimiento local.

Los cambios estimados en la aptitud climática de las combinaciones de cultivos a nivel municipal variaron ampliamente entre los países, y dentro de cada país, estimándose mayores pérdidas en las zonas bajas. Los resultados, a esta graduación gruesa, sugirieron que los medios de vida basados en café, banano y frijol tendrán un mayor impacto del cambio climático, pues la mayor parte de los municipios de estos países perderán aptitud climática para sostenerlos; mientras que los medios de vida basados en cultivos menos sensibles al aumento de la temperatura y al cambio de los patrones de lluvia, como sorgo, maíz, arroz de secano (gramíneas) y yuca (tubérculo) tendrían menos pérdidas de aptitud climático o incluso podrían aumentarla. Sin embargo, estas ganancias de aptitud se ubicaron generalmente en lugares donde los cultivos no forman parte de la seguridad alimentaria (por ejemplo, yuca en las zonas bajas de El Salvador) o en lugares donde habría competencia por otros usos del suelo como zonas urbanas o zonas de reserva hídrica. Por otro lado, esta ganancia de aptitud fue sobreestimada porque la metodología no incorpora el efecto de eventos extremos crecientes como las sequías.

Los medios de vida agrícolas de estas familias estuvieron basados en el cultivo de café con frutales y otros árboles de sombra, granos básicos (maíz y frijol) y ganadería, apoyados con medidas de manejo de agua, suelo y recursos forestales. Las personas en las cinco microcuencas percibieron las mismas tendencias de cambio en el clima, como el aumento de la temperatura a lo largo de todo el año y principalmente en estaciones secas, cambios en los patrones de lluvias, intensificación y extensión del periodo seco o canícula y vientos más intensos.

Los impactos documentados afectaron negativamente a todos los medios de vida, y se expresaron como reducción en la cantidad y calidad de las cosechas y aumento de costos de producción. En este caso, el trabajo con técnicas participativas permitió identificar impactos causados por eventos extremos, como lluvias intensas o erráticas. En zonas de mayor altitud se documentaron algunos impactos positivos, como la producción de frutas en épocas con mayor demanda de mercado, o el aumento de la calidad del grano de café. Aunque las personas no manifestaron que los cambios en el clima fueran a hacer insostenibles sus medios de vida, algunos ganaderos mencionaron que ya no podían producir maíz por efecto de la intensificación de la estación seca y la canícula.

Como se desprende de las secciones correspondientes de los capítulos 2 y 3, el impacto actual y potencial del cambio climático en los medios de vida de las familias agricultoras a pequeña escala está afectando y continuará afectando negativamente los medios de vida de las familias agricultoras a pequeña escala, aunque de manera diferente. La adaptación a estos cambios debería impulsar un amplio rango de niveles de adaptación, considerando incluso la adaptación transformacional para prevenir conflictos de uso de la tierra en áreas donde se espera que aumente la aptitud para ciertos cultivos, y para enfrentar que algunos medios de vida actuales no sean viables, sin medidas de adaptación, en las zonas donde actualmente se desarrollan con las prácticas tradicionales.

Sub-pregunta 1.2 A escala regional y local, ¿cuáles factores diferencian la capacidad adaptativa de los diferentes medios de vida de las familias agricultoras a pequeña escala?

En los capítulos 2 y 3, también propusimos una caracterización de la capacidad adaptativa de los diferentes medios de vida de las familias agricultoras a pequeña escala, utilizando información pública y conocimiento local respectivamente.

En el Capítulo 2 contrastamos dos maneras de caracterizar esta capacidad adaptativa a gradación gruesa. La primera se basó en la construcción de un índice de capacidad adaptativa que consideró diez criterios y once indicadores. La definición de estos criterios e indicadores se basó en el enfoque de medios de vida y los estructuró en tres condiciones para la capacidad adaptativa: 1) la satisfacción de necesidades básicas, 2) recursos para la innovación, es decir, recursos que permitan definir la necesidad y tipo de cambios necesarios para adaptar los medios de vida, y 3) recursos para la acción, es decir, recursos para poner en práctica la innovación. La segunda caracterización de la capacidad adaptativa utilizó esta estructura de indicadores para agrupar municipios con patrones similares de capacidad adaptativa en cada país, es decir que presentaban condiciones similares en el desempeño de los indicadores, usando una técnica estadística de conglomerados.

El índice de capacidad adaptativa mostró un gradiente de valores, ubicando los municipios con mayores valores del índice cerca a zonas urbanas y rutas de comercio, mientras los valores más bajos los tuvieron los municipios ubicados en el Corredor Seco, principalmente en el oriente de Guatemala, el occidente de Honduras y el norte y oriente de El Salvador, o en áreas de frontera agrícola.

El análisis complementario definió grupos de municipios con diferentes tipos de capacidad adaptativa. Es decir, no solo si su capacidad adaptativa es relativamente mayor o menor, sino qué indicadores hacen que sea mayor o menor, lo cual permitiría definir estrategias y medidas de adaptación diferentes y más apropiadas para cada grupo.

Los indicadores de satisfacción de necesidades básicas (capital humano como salud, educación básica y equidad, y capital construido como acceso al agua y a vivienda digna) estuvieron relacionados con una capacidad adaptativa mayor de los municipios. Estos indicadores de satisfacción de necesidades básicas incluyeron el acceso al agua potable (en Honduras y Nicaragua), la proporción de población rural en edad escolar que asiste a centros de educación (en todos los países), viviendas rurales construidas con materiales duraderos (en todos los países), y el índice de equidad de género, basado en el acceso de hombres y mujeres a la educación (en todos los países). Encontramos que los grupos de municipios con menos satisfacción de necesidades básicas tienden también a tener menor desempeño de los indicadores para innovación y acción, lo que nos sugiere que en estos grupos de municipios los programas de adaptación deberían abordar también la atención a las necesidades básicas.

Los indicadores relacionados con una mayor capacidad adaptativa, relacionados con los recursos para innovación (capital humano expresado como conocimiento para la producción agrícola, natural y construido) y puesta en práctica de la innovación (capital financiero y capital humano expresado como fuerza de trabajo), incluyeron la densidad de carreteras (en Guatemala, El Salvador y Nicaragua), la población rural económicamente activa con empleo no agrícola (en todos los países), y la relación de dependencia demográfica referida a la población rural, indicador relacionado con la migración y la fuerza de trabajo (en todos los países). Estos indicadores, que apoyan la adaptación, pueden apoyar la priorización de programas de adaptación que aprovechen estas ventajas. En particular, la diversificación de los ingresos, reflejada por el indicador de población rural económicamente activa con empleo no agrícola ha mostrado antes estar asociado a la reducción de pobreza de las familias agrícolas en estudios previos.

El análisis señaló también que los grupos de municipios que mayor inversión han recibido en incentivos agrícolas como asistencia técnica y préstamos (capitales financiero y político) no tienen necesariamente una capacidad adaptativa mayor. Esto se explica porque estos factores no garantizan oportunidades para la diversificación de ingresos, resaltando que las políticas de adaptación deben ir más allá de los incentivos agrícolas. Un ejemplo de esto es que los grupos de municipios con proporciones más altas de unidades de producción agrícola que reciben asistencia técnica y préstamos, generalmente con una alta proporción de la tierra agrícola dedicada al cultivo del café, tienen una capacidad adaptativa intermedia.

A escala local, la caracterización de la capacidad adaptativa consideró tanto las características de los recursos de la comunidad, como la puesta en práctica de medidas de adaptación. Todas estas medidas implementadas fueron consistentes con los impactos percibidos. Esta información permitió establecer diferencias en el capital humano entre medios de vida y lugares, porque se sostienen en el conocimiento para identificarlas y la fuerza de trabajo para ponerlas en práctica. Las familias ganaderas a pequeña escala en las microcuencas de Chiapas, principalmente las que están más cerca a centros poblados, habían puesto en práctica varias medidas de adaptación apropiadas, como la diversificación de pastos, y ensilaje. También las familias productoras de café identificaron medidas apropiadas y las implementaron en las microcuencas de El Salvador y Costa Rica. Por otro lado, familias productoras de granos básicos en El Salvador y una microcuenca de México mostraron dificultades en identificar medidas de adaptación apropiadas. Generalmente estas familias, que se consideran las más vulnerables en el Corredor Seco en América Central, son arrendatarios en El Salvador o avecindados en México (personas que acceden a una porción de tierra a través de un acuerdo con un miembro de la comunidad) y trabajan para otras familias para así obtener dinero en efectivo; esto muestra una limitación en el acceso al capital natural para la producción (suelo y agua).

A diferencia de la escala regional, a escala local fue posible incluir el capital cultural en la caracterización de los medios de vida. Relacionamos el capital natural con la percepción del cambio climático como un proceso real y progresivo (es decir, no con la percepción de “otro año malo”) y con una reacción activa (no pasiva) para enfrentar un proceso de adaptación. Esto puede tener relación con que en todos los lugares elegidos para realizar la investigación hubo una demanda expresa de alguna organización local y que, por lo tanto, el problema de la adaptación al cambio climático ya estaba establecido como tema de discusión en el lugar.

A esta escala, también pudimos incluir el capital social en la caracterización de capacidad adaptativa de los medios de vida, y en este caso sí encontramos diferencias. Todos los grupos, excepto las familias productoras de granos básicos en la microcuenca en El Salvador y las familias productoras de café en una de las microcuencas de Chiapas, tuvieron algún nivel de organización para la implementación de medidas de adaptación, pero esta organización tuvo el único propósito de cumplir con los requisitos para recibir asistencia técnica, capacitación e incentivos financieros de entidades gubernamentales y ONG. Familias ganaderas en una microcuenca de Chiapas tuvieron un nivel de organización más desarrollado, lo que permitió la compra y gestión de insumos de manera compartida, mostrando la puesta en práctica de acuerdos para realizar esfuerzos más allá de la finca individual, como el riego colectivo.

El capital político y el acceso al capital financiero relacionado (incentivos en efectivo distribuidos por entidades gubernamentales y ONG) también influyó en la capacidad adaptativa de los diferentes medios de vida. En la peor situación estuvieron otra vez las familias productoras de granos básicos en El Salvador y productoras de café en dos lugares de México, que no accedieron a ningún tipo de apoyo o incentivo. Lo que es importante considerar respecto a las familias ganaderas en Chiapas, o los productores de café en El Salvador es que estos programas no toman en cuenta las necesidades locales y, por lo tanto, no necesariamente responden a las necesidades de adaptación de las familias agricultoras. Los representantes de las familias productoras, de todos los medios de vida y lugares dijeron que, si pudieran influir en la ayuda que reciben, harían que esta esté enfocada en obtener créditos para añadir valor a sus productos agrícolas.

Sub-pregunta 1.3 A escala local, ¿cómo se caracterizan las principales medidas de adaptación?

A escala local, las principales medidas de adaptación implementadas y propuestas se distribuyen en un gradiente entre la adaptación progresiva y la transformacional y en diferentes capitales. La mayoría de las medidas de adaptación propuestas en la etapa de planificación de las ELACC corresponden a los niveles incremental y de sistema. Solo se identificaron dos medidas transformadoras, ambas relacionadas con la conservación y restauración de los servicios ecosistémicos a nivel de cuenca y los mecanismos financieros correspondientes. Por otro lado, la clasificación de las medidas de adaptación muestra que son complementarias según su afinidad con diferentes capitales, y que existe conciencia en las plataformas de planificación de la importancia de fortalecer no solo el capital natural y construido sino el fortalecimiento de los capitales blandos para la viabilidad. y sostenibilidad.

Pregunta 2 ¿Cuáles son las principales características de los servicios climáticos para apoyar la adaptación de las familias agricultoras a pequeña escala a las sequías en Guatemala?

Sub-pregunta 2.1 ¿Cómo se caracteriza la oferta de los servicios climáticos para la gestión de sequías para la agricultura y la seguridad alimentaria en Guatemala, en términos de integración disciplinaria y relaciones entre productos?

En el Capítulo 4 exploramos la integración disciplinaria de quince productos disponible públicamente, que diseminaban, en el momento de hacer la investigación, información climática, agronómica y de seguridad alimentaria relevante para la gestión de sequías para la agricultura y la seguridad alimentaria en Guatemala. El resultado de la técnica estadística utilizada no agrupó los productos por temas o disciplinas. El primer grupo incluyó la Perspectiva Regional del Clima, una publicación estacional (trimestral) producto de la colaboración entre los servicios meteorológicos nacionales de América Central. El segundo grupo incluyó el Sistema de Monitoreo de Cultivos y el Pronóstico de Seguridad Alimentaria y Nutricional, productos nacionales elaborados respectivamente por el Ministerio de Agricultura, Ganadería y Alimentación y la Secretaría Nacional se Seguridad Alimentaria y Nutricional, que agregan información climática, agronómica y de seguridad alimentaria y nutricional de diferentes fuentes. El tercer grupo combinó productos enfocados en diferentes temas escalas geográficas.

Exploramos las relaciones de productos mediante un análisis de redes sociales. La Perspectiva Regional del Clima estuvo en el centro de la red, siendo el producto proveedor más importante de información climática. El Sistema de Monitoreo de Cultivos y el Pronóstico de Seguridad Alimentaria y Nutricional se ubicaron como productos bien conectados, cumpliendo un rol de intermediación e integración disciplinaria en la red.

Estos resultados afirman entonces que, en el momento de la investigación, hubo una oferta de servicios climáticos con integración disciplinaria al menos incipiente, compuesta de productos de información que cumplieron diferentes roles en la provisión e integración de información. Sin embargo, el bajo número de relaciones entre productos, tomando en cuenta el potencial de conexiones en la red, reflejaron limitaciones en la coordinación y visión de conjunto entre las organizaciones encargadas de su elaboración. Estas limitaciones fueron evidenciadas, por ejemplo, por la desconexión de dos productos nacionales, uno con mapas de pronósticos climáticos a corto plazo y un boletín de reporte de precios de productos agrícolas. Estos productos no citaron otros productos (lo cual es lógico pues presentan información primaria), pero no fueron citados por otros, aunque contenían información única y útil. Otro ejemplo fue la ausencia de conexión de productos elaborados a nivel local. Dos productos diseminaban variables del clima provenientes de estaciones meteorológicas gestionadas por una mancomunidad, en ese momento no integradas a la red nacional. Considerando su ubicación en una zona montañosa, la información de estas estaciones locales pudo haber provisto información muy valiosa para la toma de decisiones. Sin embargo, el otro producto local, un boletín coproducido por una mesa interinstitucional en un municipio de esa mancomunidad, no usó esa información.

También llamó la atención la posición marginal y baja conectividad de la Perspectiva Regional de Aplicación de los Pronósticos Climáticos a la Seguridad Alimentaria y Nutricional, un boletín ligado a la Perspectiva Regional del Clima y basado en un mecanismo complementario de colaboración regional de expertos. Por lo anterior, la posición y conectividad de este no pareció estar causada por la ausencia de coordinación o difusión; más bien, el análisis sugirió examinar el nivel de la vinculación efectiva de pronósticos climáticos con información agronómica y de seguridad alimentaria a nivel regional (coproducción) a una escala apropiada para los diferentes usuarios.

Sub-pregunta 2.2 ¿En qué grado conocen y usan, para qué usan y cómo perciben la oferta de servicios climáticos las personas encargadas de la agricultura y la seguridad alimentaria ante las sequías en Guatemala?

En el Capítulo 4 sintetizamos en qué grado conocen y usan la oferta de servicios climáticos las personas encargadas de la agricultura y la seguridad alimentaria ante las sequías en Guatemala. En este país, diez de los quince productos de información a escala nacional y regional publicados estacionalmente fueron significativamente más conocidos y usados por personas que trabajaban en la ciudad capital siendo preferidos los productos que integran información de diferentes disciplinas. Por el contrario, las personas que trabajaban en el Corredor Seco conocían y usaban más los productos nacionales orientados a una sola disciplina y preparados para el corto plazo (diarios o mensuales) y los productos locales. Varias personas de este último grupo comentaron que conocen los productos que integran información a nivel nacional pero que prefieren recopilar información de diferentes fuentes, analizarla, para después elaborar sus propias conclusiones y recomendaciones.

Posteriormente, sintetizamos para qué usaron los productos climáticos las personas que gestionan esfuerzos de adaptación de la agricultura y enfrentan las crisis de seguridad alimentaria. Las personas que usaron los productos para al menos tres objetivos diferentes, a saber, (1) obtener asesoramiento sobre la planificación de la actividad agrícola (con mayor énfasis entre personas que trabajaban en el Corredor Seco), (2) recibir alertas tempranas de eventos climáticos extremos (inundaciones y sequías) y de seguridad alimentaria, y (3) planificación organizacional. Estos usos estuvieron relacionados a tres escalas temporales (diaria, mensual, estacional) diferentes. Para la planificación agrícola, hubo productos en Guatemala destinados a apoyar la (re) programación de las actividades de campo, la selección de variedades de cultivos, la programación de siembra y cosecha y la venta de productos. Estos productos contuvieron información a escala local, relacionada a la escala a la que se toman tales decisiones. El contraste con el caso de Colombia permitió identificar otras oportunidades de uso de los servicios climáticos a esa escala, como decisiones oportunas para la aplicación de insumos (por ejemplo, fertilizantes) y la selección adecuada de variedades y cultivos. Finalmente, con respecto a la planificación organizacional, hubo un fuerte enfoque en Guatemala hacia la provisión de productos de información para programar acciones humanitarias para abordar la inseguridad alimentaria (productos mensuales y estacionales). Otra vez, el contraste con Colombia permitió identificar oportunidades no aprovechadas de los servicios climáticos, como el diseño de propuestas de proyectos y programas de asistencia técnica, la formulación de lineamientos de investigación y el acceso a instrumentos de transferencia de riesgo, como seguros contra pérdidas de cultivos.

Finalmente, las personas calificaron siempre de manera positiva los productos que más usaron, aunque hubo una variación sustancial entre las puntuaciones, lo que sugiere que las personas entrevistadas tuvieron experiencias diversas usando los productos y que estos pueden no satisfacer la gama completa de sus necesidades para tomar decisiones. Los productos que fueron mejor calificados fueron los que se centraron en un solo tema o disciplina y que proporcionaban información primaria.

Sub-pregunta 2.3 ¿Cuáles son las principales recomendaciones para mejorar los servicios climáticos desde las necesidades de los usuarios y su producción?

En el Capítulo 4 sintetizamos finalmente las recomendaciones que los usuarios hicieron para que los productos respondan mejor a sus necesidades. Clasificamos estas características de acuerdo con los desafíos comunes a estos productos propuestos por Patt y Gwata (2002). Las principales recomendaciones para satisfacer las necesidades de las personas usuarias en Guatemala fueron:

En cuanto a *procedimientos*, el principal desafío abordado en Guatemala:
- La distribución oportuna para la planificación y toma de decisiones.
- Una mayor frecuencia de publicación.
- Mecanismos apropiados de difusión, haciendo énfasis en presentaciones en reuniones locales para discutir a profundidad los mensajes clave, pero aprovechando también medios no convencionales como aplicaciones de mensajería instantánea.

En cuanto a *capacidad cognitiva* o transmisión del conocimiento, el segundo desafío en importancia en Guatemala, las recomendaciones también se refirieron al nivel local, y estuvieron relacionadas con la difusión limitada de la información entre técnicos extensionistas y familias productoras:

- El uso de un lenguaje simple, y enlaces a glosarios para la explicación de términos técnicos.
- El uso de una estructura más simple, con la inclusión de mensajes clave al inicio, y secciones de síntesis para extensionistas y familias productoras.
- La inclusión de ayudas visuales, como diagramas y fotos con explicaciones claras.
- La integración de variables climáticas, agronómicas y de seguridad alimentarias en el análisis; es decir, no solo presentarlas por separado, sino señalar sus relaciones e implicancias para elaborar conclusiones y recomendaciones significativas y claras.

En cuanto a *credibilidad*:

- El uso de fuentes reconocidas y la comparación de fuentes de información. En particular, las personas usuarias señalaron que las fuentes simplemente no son señaladas.
- La explicación de los métodos utilizados para el monitoreo y pronóstico de variables climáticas, agronómicas y de seguridad alimentaria, así como la mención de los supuestos y metodologías que están detrás de los pronósticos y su nivel de incertidumbre.

En cuanto a *legitimidad,* las principales recomendaciones provinieron también de personas entrevistadas en el Corredor Seco y se centraron en la incorporación de los resultados de la revisión de los productos de información realizados a nivel nacional por técnicos locales siguiendo los mecanismos de retroalimentación establecidos.

En cuanto a *escala*, una recomendación común, también de personas entrevistadas en el Corredor Seco incidieron en la desagregación de la información a nivel departamental (segundo nivel administrativo) y municipal (tercer nivel administrativo). En particular, propusieron soluciones simples y viables como la difusión de enlaces electrónicos a los mapas con que presentan variables climáticas, o la formulación de recomendaciones desagregadas al menos a nivel departamental.

En cuanto a las *opciones para toma de decisiones* ofrecidas por los productos, las principales recomendaciones fueron la inclusión de:

- Recomendaciones prácticas para plazos y escenarios concretos, acompañadas de los supuestos que están detrás de su formulación.
- Calendarios agroclimáticos para la planificación a corto plazo.
- Recomendaciones no solo para granos básicos, sino para otros cultivos relevantes para la seguridad alimentaria como el café y también para la gestión del agua potable.
- Mapas con claras referencias a las zonas más vulnerables a sequía y seguridad alimentaria.
- El listado o mapeo de acciones de adaptación o de respuesta a las emergencias, de respuesta en ejecución o programadas por organizaciones nacionales y locales.

A partir de las reuniones de retroalimentación a las organizaciones encargadas de los productos, concluimos de manera conjunta que varias de las recomendaciones relacionadas a procedimientos, capacidad cognitiva, credibilidad, legitimidad y escala, podrían ser abordadas, al menos parcialmente, con recursos de conocimiento y financieros disponibles.

Sin embargo, también concluimos que la implementación de otras recomendaciones implicaría cambios en las capacidades institucionales para generar información, compartirla e interactuar entre sí.

Las principales variables no monitoreadas o reportadas, que fueron mencionadas repetidamente como necesarias para la adaptación de la agricultura a pequeña escala ante las sequías y la gestión de las emergencias de seguridad alimentaria son demográficas (ubicación de las comunidades más afectadas por inseguridad alimentaria y falta de acceso a agua potable), agronómicas (monitoreo del desarrollo de los cultivos, incidencia de pestes y plagas, estimaciones de daños y pérdidas de cosechas) e institucionales (requisitos para el acceso a mecanismos de apoyo, como distribución de semillas, presupuesto y acciones programadas para asistencia a familias productoras, créditos y préstamos). En indagaciones posteriores comprobamos que la información de algunas de esas variables (por ejemplo, estimaciones de daños y pérdidas de cosechas o presupuestos para apoyo a emergencias) sí eran recopiladas, pero no se diseminaron en su momento por factores políticos. Un estudio posterior sobre el uso de información climática para la gestión de sequías y seguridad alimentaria en el Corredor Seco de Guatemala (Müller *et al*. 2020) menciona explícitamente este desafío, causado por estructuras burocráticas, centralización, e intereses políticos que limitan la difusión de datos oficiales de manera oportuna.

Otras recomendaciones hubieran requerido el desarrollo de capacidades adicionales a nivel institucional para innovar el proceso de producción de servicios climáticos, como las siguientes:

- Visión de conjunto de los productos de información disponibles, para identificar y disminuir la duplicidad de esfuerzos, mejorar el flujo de información entre productos, identificar y reducir vacíos funcionales y temáticos, como, por ejemplo, las relaciones con y entre esfuerzos de producción de información a escala local, e invertir en el desarrollo de productos que tienen una fuerte influencia en otros.

- Coproducción de información, integrando a los usuarios, en vez de adición de información a cargo de técnicos exclusivamente. Al momento de realizar la investigación, solo uno de los quince productos de información resultó de un proceso de coproducción impulsado por la demanda local, integrando información de diferentes disciplinas a través de una plataforma de un gobierno municipal en la que participaron técnicos de diferentes entidades de gobierno y ONG y usuarios, para definir recomendaciones adecuadas en escala y plazo para la adaptación de la agricultura y la gestión de emergencias de seguridad alimentaria[3].

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[3] En 2017 se constituyó la Mesa Técnica Agroclimática de Chiquimula, una red interinstitucional que facilita espacios de discusión para la gestión de información agroclimática local y para identificar mejores prácticas de adaptación al cambio climático.

6 Conclusions

The following are general conclusions from the work.

1. We affirm that analysing public information to characterize coarse-grained vulnerability, with particular emphasis on adaptive capacity, provides guidelines to guide the definition and implementation of adaptation measures in four vulnerable countries in Central America. The following are the main contributions of the analysis in this regard:

   – The loss of suitability to sustain the crops that are the basis of small-scale farming households' livelihoods presents a broad spectrum, suggesting that at the regional level, progressive adaptation measures should be combined, where suitability losses allow, and transformational, where climate change is expected to make current livelihoods unsustainable in the future.

   – Projected climate suitability gains also represent a challenge for adaptation because of human, social, and cultural factors related to small-scale agricultural livelihoods and competition for other land uses.

   – The factors related to adaptive capacity, at the coarse-grained level of analysis, show that climate change adaptation policies for the small-scale agricultural sector should go beyond sectoral measures, such as technical assistance incentives and agricultural credits. Income diversification seems to be a much more important determinant for the sector's sustainability.

   – In pressure areas and hotspots (respectively, areas that are becoming more suitable for specific crops and areas where reduced expected suitability for current crop combinations may mean that current crop combinations become economically unviable), proposed adaptation pathways may require responses to climate change at higher levels than production units, which could include restoration of degraded lands, reorganization of land uses in territories, diversification of livelihoods and even migration.

   – Where a relatively low potential climate impact is expected, changes in practices and technologies within current systems (progressive adaptation) are recommended, including adaptation strategies such as changes in planting dates or water harvesting. Relatively small changes within current systems (including adaptation strategies such as changes to drought-resistant crops) may be sufficient.

   – The choice of adaptation measures for small-scale agriculture in the region will depend on natural capital (mainly water and land), social and cultural capital, and access to information.

2. We propose that the livelihoods-based approach is applicable in other countries or regions to identify spatial priorities for adaptation using public information. However, we suggest refining some aspects, such as estimating climate change's impact on crop productivity. This variable would be much easier to communicate and contrast with national statistics. We also propose the inclusion of social, cultural, and natural variables through participatory methods in the characterization of adaptive capacity and a focus on agricultural landscapes rather than administrative divisions.

3. We highlight the complementary use of the adaptive capacity index and the definition of groups of municipalities according to their adaptive capacity at the coarse-grained level of analysis, both tools

based on a structure of criteria and indicators based on the livelihoods approach for the spatial prioritization of adaptation actions. Both procedures show that current adaptive capacity conditions form a gradient between municipalities where cash crops are grown, close to the main urban areas, and municipalities where staple grains predominate on the agricultural frontier. The analysis of conditions for adaptation showed that municipalities with higher satisfaction of basic needs also have high indicator values for resources for innovation and action. This result confirms the consistency of the proposed structure of criteria and indicators to characterize adaptive capacity to show the satisfaction of basic needs as a starting point for adaptation processes.

4. At the fine-grained level of analysis, we highlight the importance of considering the implementation of adaptation measures as part of the characterization of adaptive capacity and the consideration of cultural and social aspects, which could not be measured with the information available at the coarse-grained level of analysis. At this level, we conclude that limited access to natural capital for production (soil and water), differences in social capital to implement adaptation measures beyond the level of the individual farm, and access to financial capital - related to political capital - established the main differences in the adaptive capacity of small-scale farming households' livelihoods.

5. At the local level (fine-grained level of analysis), the primary adaptation measures implemented and proposed are distributed along a gradient between progressive and transformational adaptation and in different capitals in a complementary way. This shows that the people on the planning platforms are aware of the importance of strengthening natural and built capital and the importance of human, cultural, social, and political capitals ("soft" capitals), including climate information management.

6. We affirm that in Guatemala, there are advances in information management to manage adaptation to droughts in small-scale agriculture and the design of responses to food security crises, suggesting a transition from reactive crisis response to proactive risk management. This conclusion is based on the fact that the network of information products analysed integrated climate, agronomic, and food security issues at national and local scales at an early stage.

7. We also argue that these advances are insufficient for those managing agricultural adaptation to drought and food security crises in the Dry Corridor because of limitations in production and distribution procedures, communication, credibility, legitimacy, scale, and recommendations. It is, therefore, a priority to develop information products that integrate different fields and sources of knowledge to support adaptation decisions.

8. We emphasize that there are opportunities to improve information products with available resources. Any investment to improve the limitations noted in the previous paragraph in widely cited products would result in improvements in the products that use them as sources and, therefore, probably also in decision-making. However, we also conclude that investment of resources is needed to innovate the production process to include and integrate information.

9. Finally, we conclude that when generating new products or improving existing ones, it is essential to include user perspectives to harness the potential of available information into useful information products. A user-centred design process and clarity regarding the information ecosystem will avoid investing in products that (i) are disconnected or unused, (ii) are redundant, or (iii) do not address existing information needs. We affirm that only through a systematic evaluation of climate services for agriculture and food security can we know whether they are effective in providing high-quality information to improve the decisions of farmers, extension agents, managers of agricultural

organizations, international cooperation agencies, governments, and other actors in the field of smallholder agriculture adaptation and food security management.

10. The work suggests different lines of future research:

    – *Regarding the characterization of vulnerability and adaptive capacity at regional and national scales*, our study provides inputs to guide the implementation of smallholder agriculture adaptation in four Central American countries. To improve this methodological proposal, it is necessary, on the one hand, to integrate climate change variability for a better estimation of the impact of climate on crops and to deepen the understanding and integration of indicators of social, cultural, and political capitals, as well as the validation of the distribution of different levels of adaptive capacity with case studies and or outcome indicators, i.e., with indicators that are based on adaptive responses.

    – *Regarding the characterization of vulnerability and adaptive capacity at the local scale*, the methodology we propose was helpful for a rapid characterization of vulnerability and adaptive capacity. Relevant topics for future research are in the field of identification of transformative adaptation measures for the most vulnerable livelihoods, including the identification of bottlenecks, partners, and arrangements to implement these measures, and in practical conceptual and methodological proposals to obtain results to influence local development agendas, such as the estimation of cost-benefit ratios for implementing adaptation strategies and measures.

    – *Regarding the evaluation of climate services*: The approach we propose is helpful as a diagnostic tool to identify opportunities for improvement in the provision of climate services to keep the supply of climate information aligned with the needs of users and to make the best use of available information resources. The development and validation of evaluation approaches on the efficiency of the climate service production process (e.g., time and money required to co-produce information products), effectiveness (e.g., changes in adaptation measures), and impact (e.g., reduction of crop losses and damages), as well as its sustainability (e.g., organizational changes to facilitate information sharing, co-production, and use of services), is needed.

Correcciones a referencias y citas

Finalizada la redacción de la tesis doctoral, se advirtieron errores en la redacción de referencias o en su cita en el texto de los capítulos 2, 3 y 4, capítulos que no contienen modificaciones de producción o maquetación (tales como *copy editing*). Varios de estos errores fueron subsanados en las versiones publicadas de dichos capítulos. Se presentan aquí las correcciones a los errores encontrados. Los enlaces a los documentos en línea fueron verificados al 15 de octubre de 2023.

pág.	Dice:	Debe decir:
26	Bárcena et al. 2011	CEPAL 2011
26, 27	CCAD 2010	CCAD and SICA 2010
28	Parry et al. 2007	IPCC 2007
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