Title

Translating gene drive science to promote linguistic diversity in community and stakeholder engagement.

Journal

Global public health, 15(10)

ISSN

1744-1692

Authors

Cheung, Cynthia
Gamez, Stephanie
Carballar-Lejarazú, Rebeca
et al.

Publication Date

2020-10-01

DOI

10.1080/17441692.2020.1779328

Peer reviewed

Translating Gene Drive Science to Promote Linguistic Diversity in Community and Stakeholder Engagement

Cynthia Cheung [a], Stephanie Gamez [b], Rebeca Carballar-Lejarazú [c], Victor Ferman [d], Váleri N. Vásquez [d,e,f,g], Gerard Terradas [b,h], Judy Ishikawa [b], Cynthia E. Schairer [i], Ethan Bier [b,h], John M. Marshall [d,e], Anthony A. James [c,j], Omar S. Akbari [b,h], and Cinnamon S. Bloss [a,i]*

[a] *The Qualcomm Institute, Calit2, UC San Diego, La Jolla, CA USA;* [b] *Section of Cell and Developmental Biology, UC San Diego, La Jolla, CA, USA;* [c] *Department of Microbiology and Molecular Genetics, UC Irvine, Irvine, CA, USA;* [d] *Division of Biostatistics & Epidemiology, School of Public Health, UC Berkeley, Berkeley, CA, USA;* [e] *Innovative Genomics Institute, UC Berkeley, Berkeley, CA, USA;* [f] *Energy and Resources Group, UC Berkeley, Berkeley, CA, USA;* [g] *Berkeley Institute for Data Science, UC Berkeley, Berkeley, CA, USA;* [h] *Tata Institute for Genetics and Society, UC San Diego, La Jolla, CA, USA;* [i] *Department of Family Medicine and Public Health, School of Medicine, UC San Diego, La Jolla, CA, USA;* [j] *Department of Molecular Biology & Biochemistry, UC Irvine, Irvine, CA, USA*

* Address for Correspondence: Cinnamon S. Bloss, Ph.D.
UC San Diego, 9500 Gilman Drive, MC 0811
La Jolla, California 92093-0811
cbloss@eng.ucsd.edu
Phone: (858) 534-9595

Translating Gene Drive Science to Promote Linguistic Diversity in Community and Stakeholder Engagement

Information about genetic engineering (GE) for vector control in the United States is disseminated primarily in English, though non-English speakers are equally, and in some geographic regions even more affected by such technologies. Non-English-speaking publics should have equal access to such information, which is especially critical when the technology in question may impact whole communities. We convened an interdisciplinary workgroup to translate previously developed narrated slideshows on gene drive mosquitoes from English into Spanish, reviewing each iteration for scientific accuracy and accessibility to laypeople. Using the finalized stimuli, we conducted five online, chat-based focus groups with Spanish-speaking adults from California. Overall, participants expressed interest in the topic and were able to summarize the information presented in their own words. Importantly, participants asked for clarification and expressed scepticism about the information presented, indicating critical engagement with the material. Through collaboration with Spanish-speaking scientists engaged in the development of GE methods of vector control, we translated highly technical scientific information into Spanish that successfully engaged Spanish-speaking participants in conversations about this topic. In this manuscript, we document the feasibility of consulting Spanish-speaking publics about a complex emerging technology by drawing on the linguistic diversity of the scientific teams developing the technology.

Keywords: language translation; gene drive; genetically engineered mosquitoes, Spanish speakers; public opinion

Translating Gene Drive Science to Promote Linguistic Diversity in Community and Stakeholder Engagement

La información sobre nuevos métodos de ingeniería genética (GE, del inglés “genetic engineering”) para el control de vectores, es difundida predominantemente en inglés. Sin embargo, es necesario que las personas que no hablan ni entienden inglés tengan el mismo acceso a dicha información dado que las tecnologías basadas en GE pueden afectar a comunidades enteras. Convocamos a un grupo interdisciplinario de siete científicos y traducimos al español el material informativo previamente desarrollado en inglés. Utilizando este material, llevamos a cabo cinco grupos de discusión con adultos residentes del estado de California. En general, los participantes expresaron interés en el tema y pudieron sintetizar la información presentada con sus propias palabras. Además, los participantes pidieron aclaraciones y expresaron escepticismo sobre la información presentada, lo que indica compromiso crítico con el material. A través de la colaboración con científicos de habla hispana, quienes también trabajan en el desarrollo de métodos de GE para el control de vectores, traducimos información científica altamente especializada del inglés al español, la cual involucró con éxito a hispanohablantes en conversaciones sobre este tema. En este artículo, discutimos la utilidad de traducir materiales científicos para ser usados en consultas públicas sobre el control de vectores.

Introduction

English has long been recognized as the *lingua franca* of science (Montgomery, 2013; Piqué-Noguera, 2013) in the Western world. As such, complex information about emerging technological developments, particularly in the United States (US), is often disseminated via English-language outlets. The impact of new technologies, however, and the publics who may be affected by them, are not easily delimited by language (United States Census Bureau, 2015). Efforts to include non-English-speakers in science and technology research in the US have often been limited to the post-hoc translation of findings (as opposed to during the formative or implementation stages of research), citing logistical barriers such as cost and time burden (Santos Jr et al., 2015).

The translation of complex scientific information into another language is not without complications. Several methodological challenges exist, such as achieving conceptual equivalence between translations, locating translators or interpreters with appropriate linguistic, subject matter and technical competencies, selecting the point in the research process at which the translation should occur, and navigating cultural colloquialisms or idiomatic expressions (Hilton & Skrutkowski, 2002; Magaña & Matlock, 2018; Santos Jr et al., 2015; Squires, 2009). In the context of novel vector control methods that employ genetic engineering (GE), translation is further complicated by issues related to scientific literacy (National Science Board, 2018;

Pew Research Center, 2015), public trust in genetic science (Barnett et al., 2007; Connor & Siegrist, 2010), and the polarizing nature of GE and the use of genetically modified organisms (GMOs) more generally (Bloss et al., 2017; Pew Research Center, 2016).

GE techniques for vector control have been in use for some time, but the idea of using a genetic trait with preferential inheritance (*gene drive*) as a biocontrol mechanism is relatively new (Burt, 2003). In the last few years, researchers have made considerable advances in the basic science and development of gene drive and its use as a genetic tool to make specific, persisting edits to the DNA in an organism's genome, including a proof-of-concept in fruit flies and mosquitoes (Gantz & Bier, 2015). The speed of these revolutionary scientific advances has largely outpaced the regulatory processes meant to govern them, leaving ample space for scientists and publics alike to espouse a wide spectrum of beliefs and opinions about the science. Communication about gene drive and other GE technologies for vector control has been challenging due to both the rapid pace of the science as well as a lack of agreement on or use of common scientific language within the field (Brossard et al., 2019; Yeo & Brossard, 2017). One example of this challenge can be seen in the different terms used to refer to the same concept (e.g., 'CRISPR gene drive' versus 'mutagenic chain reaction' (Gantz & Bier, 2015; Noble et al., 2017; Unckless et al., 2015) or 'self-sustaining drives' versus 'global drives' (Alphey et al., 2013; Collins, 2018)). Moreover, amidst ongoing calls for discussion about regulation, ethics, and public

engagement (National Academies of Sciences & Medicine, 2016; Oye et al., 2014), gene drive science continues to advance with little consensus among scientists in the field about what might constitute the correct course of action (Bohannon, 2015; Esvelt & Gemmell, 2017). In this sense, a primary challenge of making this kind of information accessible to lay audiences in diverse languages is the rapid development of a field where there is still evolving scientific consensus.

By the same token, many guidelines exist for the cross-cultural adaptation of research tools into other languages, but there is little consensus about what constitutes the ‘gold standard’ for such adaptations (Epstein et al., 2015). For example, blind back-translation, where a translator naïve to the original document reverse translates the translated document back into the source language, is often upheld as a methodological best practice to ensure equivalence between original and translated documents. However, as McDermott and Palchanes point out, blind-back-translation “does not assure the quality of conceptual equivalence that is necessary for scientific inquiry” (McDermott & Palchanes, 1994). In the case of GE techniques for vector control, it is debatable whether such a translation might even be possible, given the lack of formal consensus about the scientific terms in English as well as a reliance upon English terminology for which there is currently no equivalent in the target language.

Logistical and methodological barriers notwithstanding, it is important that non-English-speaking publics have equal access to public decision-making about emerging technologies. Therefore, it is necessary to make technical information available in a variety of languages so that members of all affected communities may participate in informed decisions that include consideration of the risks and merits (Pew Research Center, 2015). In the US, making this kind of information available in Spanish is especially important, given that Spanish is the most common non-English language spoken in US homes (Gonzalez-Barrera & Lopez, 2013). California, in particular, boasts a population of roughly 15.5 million Hispanic and Latino individuals (United States Census Bureau), 75% of whom speak a language other than English at home and 34% of whom self-identify as speaking English less than ‘very well’ (California Senate Office of Research, 2017), again highlighting the importance of Spanish-language information accessibility. Despite this, to our knowledge, public engagement efforts and the solicitation of public opinion about the use of GE for vector control in the US to date have only been conducted with English-speaking publics (Adalja et al., 2016; Bloss et al., 2017).

Here we present a method of translating informational materials about GE vector control approaches that were developed in English into Spanish and evaluate the utility of the translation based on qualitative responses from focus group participants.

Methods

This work is part of a larger program evaluation that aims to assess California residents' attitudes toward developing GE technologies to control the invasive mosquito vector of disease, *Aedes aegypti* (*Ae. aegypti*). Specifically, we sought input on GE methods being developed within a program of research entitled Team California Safe Gene Drives (TC-SGD) and known colloquially as "Team California". This research program is led by scientists at the University of California and is funded by the US Defense Advanced Research Projects Agency (DARPA) as part of the Safe Genes Program (Defense Advanced Research Projects Agency (DARPA), 2017). This work was reviewed and designated non-human subjects research by UC San Diego's Institutional Review Board (#170944).

Materials

We created a series of four narrated slideshows, originally developed in English, which were designed to communicate information about *Ae. aegypti* in California and ongoing research and development of GE vector control techniques within the context of the Safe Genes Program (see Table 1). Slideshow 1 discusses the history of mosquito control in California, relays the concerns that public health officials have about *Ae. aegypti*, and explains some of the challenges of controlling the mosquitoes given their distinctive habits and preference for biting humans. Slideshow 2 describes two techniques for mosquito control (GE sterile males (specifically, using the

precision-guided Sterile Insect Technique (pgSIT) method (Kandul et al., 2019)) and GE mosquitoes with GD), highlighting what members of the public might experience if either option were utilized in their community. Slideshow 3 introduces the concept of GD to modify mosquito populations to be disease-resistant (often described as ‘replacement drives’ in the scientific literature) and contrasts it with GD to suppress mosquito populations (often described as ‘suppression drives’ in the scientific literature). Lastly, Slideshow 4 compares three specific types of GD systems (self-limiting, threshold-dependent, and self-sustaining drives), which differ in terms of how they are designed to spread through a wild population. Detailed information describing the initial development of these slideshows, as well as the design and methods of the larger program evaluation, are reported elsewhere [Schairer et al. (under review)].

Translation Process

As this project was being conceptualized, there was some scepticism about whether a Spanish translation of the gene drive research program under TC-SGD would be possible. As previously mentioned, there were two distinct sets of challenges related to this translation, the first being methodological and the second being the rapidly evolving and potentially controversial nature of the subject matter. A common methodological concern was whether the science could adequately be explained in Spanish, given that some terms in English do not have a straightforward equivalent (e.g., ‘gene drive’ has been

translated as ‘genética dirigida’ on a common knowledge acquisition website (Wikipedia), but the term is not commonly used in Spanish language media outlets). To address these concerns, we enlisted the help of Spanish bilingual and biliterate individuals with understanding of the subject matter.

Specifically, we established an interdisciplinary working group comprised of seven English-Spanish bilingual natural and social scientists with broad expertise in biology, genetics, public health, Latin American studies, computer science, and mathematical modeling. In order to avoid undue preference for local jargon, we included individuals with fluency in Latin Spanish as well as Castilian Spanish. In addition to fluency in Spanish, each member of the working group is proficient in written and spoken English and has extensive experience communicating scientific findings in English. Members of the workgroup spanned five labs across three University of California (UC) campuses (see Appendix A).

The group engaged in a four-month process of iterative translation and review of materials. First author CC led the translation effort by performing the initial one-way translation of all documents into Spanish. Workgroup members then individually reviewed the translated materials either alongside the English materials (first four reviewers) or as stand-alone materials (final two reviewers). Materials were reviewed for conceptual accuracy, accessibility to a lay audience (e.g., using as little academic Spanish or technical jargon as possible),

ease of reading, consistency of terminology, and general comprehensibility. With each draft, reviewer suggestions were synthesized and incorporated as appropriate (Figure 1). After reviews and revisions were complete, the narrated slideshows were recorded and shown to one monolingual-Spanish and four English-Spanish bilingual community members (i.e., individuals who were not part of the workgroup or larger research team). Actionable feedback provided by the community members was discussed and incorporated as appropriate. Lastly, the slideshows were re-recorded by a native Spanish speaker. Each narrated slideshow underwent at least four rounds of review, with the latter two (more technical) slideshows undergoing at least one additional review. Because we conducted the English-language focus groups prior to the Spanish-language groups, we first developed and finalized the slideshows in English. As such, we note that ours constituted an asymmetrical translation, which is a translation that privileges or remains loyal to the original language.

Design

Participants were recruited by Ipsos (formerly GFK) and FocusVision using their probability-based online panel (GFK KnowledgePanel). Individuals were invited to participate in 90-minute, chat-based focus groups via an online platform where they viewed the finalized Spanish-language slideshows and responded to a series of forced choice polling questions and open response prompts. Twenty-nine Spanish-speaking adults from 29 unique California zip codes

participated in five focus groups between March and April 2019. To evaluate the effectiveness of these translated slideshows, here we present comments from focus group participants that reflect their comprehension and level of engagement with the content. Quotes from text chat have been edited for grammar and spelling, but not content. We note that this paper is focused on presenting data related to the effectiveness of the translation. Results from the overarching program evaluation to assess Spanish-speaking California residents' attitudes toward developing GE technologies will be reported elsewhere.

Results

Workgroup Translation of Slideshows

As previously mentioned, our translation was asymmetrical by design and as such, the content of our translated slideshows remained loyal to the original English-language version of the materials. Given this design choice, the iterative changes made to the translated script were primarily grammatical and/or related to word choice. For example, Polling Question #2 in Slideshow 1 (refer to Table 2) was first translated word-for-word into Spanish: "As far as you know, is there a public agency in your area that deals with mosquitoes?" became *¿Por lo que sabe usted, hay una agencia pública en su área que trabaja con los mosquitos?* Although this translation was technically accurate, one reviewer pointed out that the way it was phrased ("*agencia pública en su área que trabaja con los mosquitos*")

implied that we were inquiring about a public agency that simply worked with mosquitoes, but not necessarily in the field of mosquito control. The translation was thus changed to better clarify the meaning of the question: *¿Por lo que usted sabe, hay alguna agencia pública en su área que trabaje en el control de los mosquitos?* Later, another reviewer suggested to change the phrasing of the question to make it more conversational in nature: *¿Conoce de alguna agencia pública, en el área donde vive, que trabaje en el control de los mosquitos?* The translation process consisted of many of these types of minor changes to clarify meaning and simplify the language used.

In addition to making a number of more minor changes of the type described above, another issue that necessitated further discussion was that of naming conventions (e.g., whether to label the GE technologies in English ("GE sterile male technique") or to translate the labels into Spanish (*machos estériles genéticamente diseñados*)). Within our workgroup, some members thought it would be best to leave the terms in English, whereas others felt it might be more appropriate to present the terms in both languages:

> Reviewer 1: I think it would be best to leave the terms in English. That way when they hear it outside of this [focus group] they won't be confused. Maybe it may help for a one-time only literal translation of that but continue using the English phrase in my opinion.
>
> Reviewer 2: I think that ideally you should keep the terms in

> both languages. You have to consider that in some houses the adults have very poor English and that the new generations are the translators. On the other hand, a lot of old people feel more comfortable if the information is only in Spanish…but the activities carried by the authorities will be held in English. If you really want to avoid confusion I think the best way to go is to put the terms ONLY in English even for the first time.
>
> Reviewer 3: If space is a factor then I concur with the one-time literal translation (English term followed by Spanish translation) and then using the English term thereafter until the summary at the end, when both terms can be used side by side again.

In deciding how to label and present the information, we considered that our audience could be Spanish monolingual or bilingual in English/Spanish, communication about these technologies in the future would likely be in English, and using both English and Spanish every time could be wordy and distracting. When it came time for our native speaker to record the script, it became clear that switching between Spanish and English sounded awkward. To keep the flow of the narrative as simple as possible, we presented the technologies first in both English and English-Spanish hybrid (e.g., “Sustained Gene Drive o Gene Drive Sostenido”) with all subsequent mentions in the English-Spanish hybrid (e.g., “Gene Drive Sostenido”) (Figure 2).

Feedback from Spanish-speaking Participants

When the slideshows were piloted with community members prior to the focus groups, the feedback received suggested that only minor grammatical changes were necessary. However, we noted that there were some comments from these individuals about the technical complexity of the topic, particularly the material covered in Slideshow 4. Community members were sceptical that participants would understand the scientific concepts in Slideshow 4 without being cognitively overwhelmed. This underscored our primary concerns, which were that 1) participants would find the information unclear or confusing or that 2) participants might perceive these new approaches, labeled with English terminology, to be inherently foreign and reject them outright. While there is some indication that participants had some difficulty comprehending Slideshow 4, for the most part, focus group participants were able to reflect the information back in their own words and ask sophisticated questions, suggesting that the information was comprehensible. Furthermore, participants expressed interest in learning more about the topic of GE techniques for vector control, demonstrating that they carefully considered the information.

For example, Slideshow 1 presented basic information about mosquitoes, including the history of *Ae. aegypti* in California. After viewing this slideshow, comments from nearly all participants indicated an understanding of the challenges posed by *Ae. aegypti*

and reasons to be concerned about them. For example, after being asked what was most surprising about what they just heard, comments included, "*Como le decía con poca agua estancada en las hojas de las plantas basta para la reproducción de los mosquitos*" (Just a little bit of stagnant water on the leaves of plants is enough for the reproduction of these mosquitoes; 2055) and "*Nada le sirve contra el Aedes aegypti*" (Nothing works to control *Ae. aegypti*; 2064).

Respondents also appeared to deliberate on the information provided by making comments that suggest they anticipated a need to discuss how *Ae. aegypti* might be controlled (the topic of Slideshow 2):

> 873: *No tomamos en cuenta el mal que causan los mosquitos, porque pensamos que sólo le sucede a otras personas y lo tomamos como parte de la vida*. (We don't often consider the real harms posed by mosquitoes and mosquito-borne disease because we think it only happens to other people and consider it a part of life.)
>
> 919: *Pues es preocupante, en mi país hay mucha transmisión de enfermedades y muy poco control*. (Well this is worrisome, in my country there is a lot of disease transmission and very little control.)
>
> 912: *Lo importante sería saber cómo los podemos controlar*. (The important thing is to know how to control them.)

In other groups, participants were moved to “*aprender qué maneras se puedan prevenir…y qué hacer*” (learn about ways they can be prevented… and what to do; 857) and think about other practical actions: “*Me hace pensar que ¿talvez la limpieza cuidadosa diaria será necesaria en zonas donde se encuentran estos mosquitos? Talvez mantener ventanas y puertas con* "*screens*" (This makes me think that perhaps careful daily cleaning might be necessary in areas where these mosquitoes are found? Maybe keeping screens on windows and doors; 1016).

Slideshows 2 and 3 describe two GE technologies for mosquito control (GE sterile males and GD) and two uses for GD (replacement of the mosquito population and suppression of the mosquito population). Many participants had heard of the sterile male technique, but very few participants were familiar with the concept of gene drive. One deemed the idea of gene drive “*muy raro y preocupado*” (very strange and worrisome; 886). Despite the novelty of the concepts, however, participants were able to reflect information back in a way that demonstrated their understanding and careful consideration of the information presented. For example, one participant stated that “*En una ocasión ví un vehículo soltando moscas, creo que estaban haciendo algo parecido a lo que aprendí el día de hoy, pero hasta hoy lo entendí*” (one time I saw a vehicle releasing flies, I think doing something similar, but I didn’t understand it until today; 916). This comment demonstrates that the information was clear enough for this respondent to apply it and use it to make

sense of a previous experience. Another participant stated "*Nunca había escuchado de ingeniería genética, pero según su video la 2da tecnología [Gene Drive] es más efectiva, parece ser menos costosa y mayor durabilidad y mejor desarrollado para combatir los insectos*" (I've never heard of genetic engineering before, but according to the video, the second technology is more effective; it seems to be more cost-effective, durable, and better developed to fight mosquitoes; 853). This participant's response indicates a consideration of the costs and benefits of each of the two GE options and anticipates themes that would be brought up in the final slideshow, which was focused on different types of GD systems.

The questions asked by participants were also indicative of their critical engagement with the information. For example, the information presented did not explicitly discuss risks to human health or ecological safety, but these questions were independently raised in almost every focus group. Participants commonly asked, "*¿Cómo afectaría la cadena alimenticia?*" (How would this affect the food chain?; 2056) and expressed concern that the consumption of GE mosquitoes would lead to genetic changes in their predators: "*Las 2 teorías como dije están muy bien teóricamente, pero creo que sí afectaría a los demás animales en el caso de las ranas y sapos, también tendrían cambios genéticamente*" (The two options are good in theory, but I think that it would affect other animals and in the case of frogs and toads, they would also have genetic changes; 2022). Notably, some participants who were originally naïve to the concepts

of GE and gene drive were later able to ask sophisticated questions about the information presented:

- 1017: *¿Cómo reaccionarán los mosquitos hembras con estos mosquitos modificados? ¿Se aparearán de la misma manera? … Puesto que se crearían nuevos mosquitos, ¿qué tipo de defensas podrían desarrollar los hijos de mosquitos silvestres con mosquitos modificados? ¿Podrían transmitir enfermedades a los animales?*" (How would [wild-type] female mosquitoes react to these modified mosquitoes? Do they mate the same way? Given that new mosquitoes would be created, what kind of defenses could the progeny of wild mosquitoes and modified mosquitoes develop? Could they transmit diseases to animals?)
- 2036: *¿Cómo se controla la población en una área? Estos vuelan de zona a zona, estado a estado, y el efecto que causa si mosquitos en una area (donde existen) y se eliminan los mosquitos afectara otros especies de animales; como murciélagos.* (How is the population controlled in a given area? These fly from place to place, state to state, and the effect of mosquitoes being eliminated (from a specific area), could affect other animals such as bats.)
- 1016: *En teoría parecen ser soluciones viables, pero mi pregunta es, este mosquito llegó a nuestro ecosistema de afuera así que ¿cómo sabemos que no regresaría con tanto movimiento entre los humanos en nuestros viajes?* (In theory, these are viable solutions, but my question is: this mosquito

came to our ecosystem from far away, so how will we know that it won't come back given so much movement from human travel?)

In each of these examples, questions were asked in a way that indicates that the participant absorbed the information and was then able to imagine potential problems that could arise.

Despite a generally high level of comprehension, however, it was clear that as the subject matter grew increasingly technical, participants did begin to lose track of the information. Specifically, participants expressed confusion after Slideshow 4, which describes three types of gene drive systems that differ as a function of how they are controlled (self-limiting, threshold-dependent, and self-sustaining drives, referred to in the slideshow as Gene Drive Limitado, Gene Drive Híbrido, and Gene Drive Sostenido, respectively). One participant commented that she was "*muy confundida con esta información*" (very confused with the information) but "que bueno que hay opciones" (how good that there are options; 865). Similarly, another participant responded that "*esta mierda confusa la verdad pero suena como buenas ideas*" (this [is] confusing shit, truth be told, but it sounds like they are good ideas; 857). These comments suggest that for some participants, the science may have gotten too technical in the last slideshow or that more time was needed to process the information.

As stated above, in addition to comprehension, another concern

was that participants might perceive such a technology (labeled in English) to be inherently foreign and reject it outright. Our respondents demonstrated a range of attitudes toward the use of GE methods of vector control. We did not observe any indication that participants dismissed the concepts based on the foreignness of the terms (e.g., ‘gene drive,’ which was used in English throughout the slideshows):

- 911: *GDS [gene drive sostenido] sería más conveniente y menos costoso a la población, ya que al final el costo cae en nosotros.* (Self-sustaining gene drive would be most convenient and least expensive for the population, given that at the end the cost will fall on us.)
- 873: *Los tres sistemas tienen su pro/con pero tomando en cuenta costos y vidas tendría que utilizarrse el sistema cual sea mejor para la localidad designada y el riesgo de la población.* (The three systems have their pros and cons, but considering cost and lives, we should use each system dependent on the area and risks of the population.)
- 870: *Hay varias clases de combatir al mosquito pero ninguna es 100 por ciento efectiva, como que debe haber una combinación de entre todas.* (There are various ways to combat mosquitoes but none are 100% effective, so there should be a combination of all of these.)

The above quotes demonstrate that the use of English terms did not

inhibit participation in the group. On the contrary, participants seemed unaffected by the use of both English and Spanish terms, as evidenced by their use of the combined English-Spanish terms and their use of abbreviations (e.g., ‘GDS’ for Gene Drive Sostenido) in conversation.

Discussion

Through collaboration among Spanish-speaking scientists engaged in the development of GE methods of vector control, we sought to produce a high-quality, thought-for-thought translation of informational materials about GE vector control approaches. Qualitative responses from participants suggest that the translated materials successfully engaged Spanish-speakers in conversations about this topic.

Given the novelty of the specific GE vector control approaches in question, there were initially many concerns about the prospect of conducting a translation and whether it should be pursued. Concerns included whether the material could be translated, whether the information would be accessible to Spanish-speakers, and whether the use of some English terminology would lead participants to perceive the technology as foreign and reject it outright. In the scope of this project, however, these initial concerns did not emerge as significant problems. Participants in our groups were interested in the subject matter and responded in ways that were consistent with comprehension of and engagement with the information. In only a

handful of cases, especially when the information became exceedingly technical (e.g., in Slideshow 4), did participants respond with confusion. In general, however, respondents seemed to understand and then discuss the new concepts, asking insightful questions and expressing scepticism about ideas with which they did not agree.

Our approach has some limitations. In order to engage participants about GE technologies, our materials included a substantial educational component. However, as this study was an evaluation of the program of research (versus human subjects research focused on participants), we did not collect demographic information about our respondents. It is therefore unknown whether participant understanding of or reception to the material presented varied by demographic characteristics (e.g., education). Additionally, information about GE and GD systems was framed in light of public health concerns about mosquito-borne illness. Given this framing, we followed guidelines from national public health agencies for making translated informational materials clear and effective (McGee & McGee & Evers Consulting). We recognize that translation practices vary widely across disciplines, however, and that different or specific guidelines for linguistic adaptations may exist based on the academic discipline from which the source document originates.

As previously noted, however, there is no consensus about the ‘gold standard’ for translation of research tools into other languages

(Epstein et al., 2015), and it is well accepted that good translators translate ideas at the conceptual level rather than word-for-word (Hendzel, 2012), making it imperative for the translator to understand the ideas and concepts being conveyed. Accordingly, we employed subject matter experts with Spanish-language fluency rather than language experts with subject matter knowledge to perform the translation. Given that GD for vector control is a niche field, it is unclear whether individuals in the latter group even exist. Furthermore, due to the rapid progress in the field, it would have been difficult to go through the process of having to educate and train an outside language expert translator. Instead, we leveraged the expertise of selected scientists engaged in the work of developing the GE systems who speak both English and Spanish as well as the languages of GE and science. We consider the multilingualism and technical competence of our translation team to be distinct strengths of our approach, as the workgroup was comprised of several bilingual and bicultural Spanish speakers who are also foremost experts on the subject matter presented. By incorporating the expertise of GD scientists, we created scientifically accurate materials that could be used in online focus groups with Spanish-speaking lay people.

Conclusion

The importance of conducting community and stakeholder engagement (CSE) ‘early and often’ is well-accepted, but there is little agreement about the proper form of CSE early in technological

development (Schairer et al., 2019), nor agreement or standard practices for how such work should best be conducted to effectively reach linguistically diverse publics. For emerging technologies like GE for vector control, timely communication in linguistically heterogenous populations presents a unique challenge. For a variety of reasons, there is scant information about this topic available in lay Spanish (e.g., of the fact sheets provided by the United Nations Convention on Biological Diversity about the Cartagena Protocol, only two are available in languages other than English (*Convention on Biological Diversity: Fact Sheets and Banners*)). However, GE for vector control, including GD approaches, is controversial and has the potential to alter conditions around the world. It is therefore vital to engage with various publics prior to the deployment of any novel vector control strategy, and data suggest there are important and distinct insights to be learned from linguistically and culturally diverse groups (Chaet et al., 2016).

Policy makers, scientists, and public health professionals alike have underscored the importance of CSE to better understand public needs and concerns about the implementation of genetic tools for vector control (Esvelt et al., 2014; National Academies of Sciences & Medicine, 2016; Oye et al., 2014; Resnik, 2014). Providing basic information to support public deliberation and debate about these technologies that are accessible to linguistically diverse populations is critical for democratic decision-making. Conversely, disparate availability of information may have implications for governmental

decision-making with regard to regulation, science policy, and funding. For example, lack of participation in the decision-making process due to language barriers may raise social justice concerns and lead to a situation where some communities unfairly experience benefits or burdens associated with the technology.

Despite considerable progress over the last century (Sturgis & Allum, 2004), science communication still struggles to reach beyond the ivory tower (Seiler et al., 2013) and make research insights available to linguistically and educationally diverse lay populations. As information becomes increasingly accessible to laypeople by way of the internet, the method by which scientists and researchers communicate their science to the public must evolve accordingly. Effective science communication in any language requires interdisciplinary collaboration and the inclusion of individuals with a diversity of expertise (National Academies of Sciences & Medicine, 2017). The strategy of involving both social scientists and GD scientists in the work of translation thus presents an opportunity for ongoing and iterative dialogue between communities, stakeholders, and the designers of GE vector control approaches. Our work demonstrates the feasibility of this approach for consulting Spanish-speaking publics about emerging technology and potential for using the linguistic diversity of scientists as a resource in conducting such work. There are, however, over 200 languages and dialects spoken in the state of California alone (Joint Working Group for California's Language Access Plan, 2015) and unique lessons to be learned from

other diverse groups. Future work in this field might test these methods among other heterogeneous populations.

Acknowledgements

The authors acknowledge the community members who participated in the focus groups.

Funding details. This work was supported by the Defense Advanced Research Projects Agency (DARPA) Biological Technologies Office (BTO) Program (Contract No. HR0011-17-2-0047; PI: Akbari). The funder had no role in the collection, analysis, or interpretation of these data.

Disclosure statement. The authors declare that they have no competing interests.

Data availability statement. The datasets used during the current study are available from the corresponding author on request.

References

Adalja, A., Sell, T. K., McGinty, M., & Boddie, C. (2016). Genetically Modified (GM) Mosquito Use to Reduce Mosquito-Transmitted Disease in the US: A Community Opinion Survey. *PLOS Currents Outbreaks*.

Alphey, L., McKemey, A., Nimmo, D., Neira Oviedo, M., Lacroix, R., Matzen, K., & Beech, C. (2013). Genetic control of Aedes mosquitoes. *Pathogens and global health*, *107*(4), 170-179.

Barnett, J., Cooper, H., & Senior, V. (2007). Belief in public efficacy, trust, and attitudes toward modern genetic science. *Risk Analysis*, *27*(4), 921-933. https://doi.org/10.1111/j.1539-6924.2007.00932.x

Bloss, C. S., Stoler, J., Brouwer, K. C., Bietz, M., & Cheung, C. (2017). Public response to a proposed field trial of genetically engineered mosquitoes in the United States. *JAMA*, *318*(7), 662-664. https://doi.org/10.1001/jama.2017.9285

Bohannon, J. (2015). '*Chain reaction*' *spreads gene through insects*. Retrieved March 28 from https://www.sciencemag.org/news/2015/03/chain-reaction-spreads-gene-through-insects

Brossard, D., Belluck, P., Gould, F., & Wirz, C. D. (2019). Promises and perils of gene drives: Navigating the communication of complex, post-normal science. *Proceedings of the National Academy of Sciences*, 201805874.

Burt, A. (2003). Site-specific selfish genes as tools for the control and genetic engineering of natural populations. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *270*(1518), 921-928.

California Senate Office of Research. (2017). *A Statistical Picture of Latinos in California: 2017 Update*. Retrieved February 21 from https://latinocaucus.legislature.ca.gov/sites/latinocaucus.legislature.ca.gov/files/forms/Statistical%20Picture%20of%20Latinos%20in%20California%20-%202017%20Update.pdf

Chaet, A. V., Morshedi, B., Wells, K. J., Barnes, L. E., & Valdez, R. (2016). Spanish-Language Consumer Health Information Technology Interventions: A Systematic Review. *Journal of medical Internet research*, *18*(8), e214-e214. https://doi.org/10.2196/jmir.5794

Collins, J. P. (2018). Gene drives in our future: challenges of and opportunities for using a self-sustaining technology in pest and vector management. (Ed.),^(Eds.). BMC proceedings.

Connor, M., & Siegrist, M. (2010). Factors Influencing People's Acceptance of Gene Technology: The Role of Knowledge, Health Expectations, Naturalness, and Social Trust. *Science Communication*, *32*(4), 514-538. https://doi.org/10.1177/1075547009358919

Convention on Biological Diversity: Fact Sheets and Banners. Retrieved June 21 from http://bch.cbd.int/protocol/cpb_factsheets.shtml

Defense Advanced Research Projects Agency (DARPA). (2017). *Building the Safe Genes Toolkit*. Retrieved March 25 from https://www.darpa.mil/news-events/2017-07-19

Epstein, J., Santo, R. M., & Guillemin, F. (2015). A review of guidelines for cross-cultural adaptation of questionnaires could not bring out a consensus. *Journal of clinical epidemiology*, *68*(4), 435-441.

Esvelt, K. M., & Gemmell, N. J. (2017). Conservation demands safe gene drive. *PLoS biology*, *15*(11), e2003850.

Esvelt, K. M., Smidler, A. L., Catteruccia, F., & Church, G. M. (2014). Emerging technology: concerning RNA-guided gene drives for the alteration of wild populations. *Elife*, *3*, e03401.

Gantz, V. M., & Bier, E. (2015). The mutagenic chain reaction: A method for converting heterozygous to homozygous mutations. *Science*, *348*(6233), 442. https://doi.org/10.1126/science.aaa5945

GFK KnowledgePanel. *Be Sure with KnowledgePanel*. Retrieved May 8 from https://www.gfk.com/fileadmin/user_upload/dyna_content/US/documents/GfK_Fact_Sheet_-_Knowledge_Panel_-_Overview.pdf

Gonzalez-Barrera, A., & Lopez, M. H. (2013). *Spanish is the most spoken non-English language in U.S. homes, even among non-Hispanics*. Retrieved April 4 from https://www.pewresearch.org/fact-tank/2013/08/13/spanish-is-the-most-spoken-non-english-language-in-u-s-homes-even-among-non-hispanics/

Hendzel, K. (2012). Translation is Not About Words. It's About What the Words are About. http://www.kevinhendzel.com/translation-is-not-about-words-its-about-what-the-words-are-about/

Hilton, A., & Skrutkowski, M. (2002). Translating instruments into other languages: development and testing processes. *Cancer nursing*, *25*(1), 1-7.

Joint Working Group for California's Language Access Plan. (2015). *Strategic Plan for Language Access in the California Courts* (http://www.courts.ca.gov/documents/CLASP_report_060514.pdf

Kandul, N. P., Liu, J., Sanchez C, H. M., Wu, S. L., Marshall, J. M., & Akbari, O. S. (2019). Transforming insect population control with precision guided sterile males with demonstration in flies. *Nature Communications*, *10*(1), 84. https://doi.org/10.1038/s41467-018-07964-7

Magaña, D., & Matlock, T. (2018). How Spanish speakers use metaphor to describe their experiences with cancer. *Discourse & Communication*, *12*(6), 627-644.

McDermott, M. A. N., & Palchanes, K. (1994). A literature review of the critical elements in translation theory. *Image: The Journal of Nursing Scholarship*, *26*(2), 113-118.

McGee, J., & McGee & Evers Consulting. *Toolkit for Making Written Material Clear and Effective*. Centers for Medicare & Medicaid Services. Retrieved March 6 from https://www.cms.gov/Outreach-and-Education/Outreach/WrittenMaterialsToolkit

Montgomery, S. L. (2013). *Does science need a global language?: English and the future of research*. University of Chicago Press.

National Academies of Sciences, E., & Medicine. (2016). *Gene Drives on the Horizon: Advancing Science, Navigating Uncertainty, and Aligning Research with Public Values*. National Academies Press.

National Academies of Sciences, E., & Medicine. (2017). *Communicating science effectively: A research agenda*. National Academies Press.

National Science Board. (2018). *Chapter 7: Science and Technology: Public Attitudes and Understanding* (https://www.nsf.gov/statistics/2018/nsb20181/report/sections/science-and-technology-public-attitudes-and-understanding/public-knowledge-about-s-t

Noble, C., Olejarz, J., Esvelt, K. M., Church, G. M., & Nowak, M. A. (2017). Evolutionary dynamics of CRISPR gene drives. *Science advances*, *3*(4), e1601964.

Oye, K. A., Esvelt, K., Appleton, E., Catteruccia, F., Church, G., Kuiken, T., Lightfoot, S. B.-Y., McNamara, J., Smidler, A., & Collins, J. P. (2014). Regulating gene drives. *Science*, *345*(6197), 626-628.

Pew Research Center. (2015). *A Look at What the Public Knows and Does Not Know About Science*. Retrieved April 4 from https://www.pewresearch.org/science/2015/09/10/what-the-public-knows-and-does-not-know-about-science/

Pew Research Center. (2016). *Public opinion about genetically modified foods and trust in scientists connected with these foods*. Retrieved March 1 from http://www.pewresearch.org/science/2016/12/01/public-opinion-about-genetically-modified-foods-and-trust-in-scientists-connected-with-these-foods/

Piqué-Noguera, C. (2013). *English-written abstracts for Spanish publications: A challenge in the globalization of science* (Vol. 19).

Resnik, D. B. (2014). Ethical issues in field trials of genetically modified disease-resistant mosquitoes. *Developing world bioethics*, *14*(1), 37-46. https://doi.org/10.1111/dewb.12011

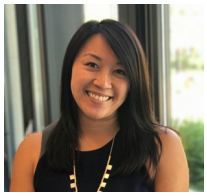
Santos Jr, H. P., Black, A. M., & Sandelowski, M. (2015). Timing of translation in cross-language qualitative research. *Qualitative health research*, *25*(1), 134-144.

Schairer, C. E., Taitingfong, R., Akbari, O. S., & Bloss, C. S. (2019). A typology of community and stakeholder engagement based on documented examples in the field of novel vector control. *PLOS Neglected Tropical Diseases*, *13*(11), e0007863. https://doi.org/10.1371/journal.pntd.0007863

Seiler, T.-B., Engwall, M., & Hollert, H. (2013). Lost in translation? Ways for environmental sciences to communicate about risk

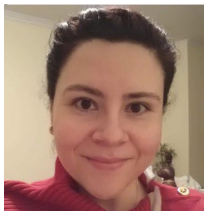
and research. *Environmental Sciences Europe*, *25*(1), 8. https://doi.org/10.1186/2190-4715-25-8
Squires, A. (2009). Methodological challenges in cross-language qualitative research: A research review. *International journal of nursing studies*, *46*(2), 277-287.
Sturgis, P., & Allum, N. (2004). Science in society: re-evaluating the deficit model of public attitudes. *Public understanding of science*, *13*(1), 55-74.
Unckless, R. L., Messer, P. W., Connallon, T., & Clark, A. G. (2015). Modeling the manipulation of natural populations by the mutagenic chain reaction. *Genetics*, *201*(2), 425-431.
United States Census Bureau. *American Fact Finder*. Retrieved February 22 from https://factfinder.census.gov/
United States Census Bureau. (2015). Census Bureau Reports at Least 350 Languages Spoken in U.S. Homes.
Wikipedia. *Genética dirigida* https://es.wikipedia.org/wiki/Gen%C3%A9tica_dirigida
Yeo, S. K., & Brossard, D. (2017). *The (changing) nature of scientist–media interactions: A cross-national analysis*. Oxford University Press: New York.

Appendix A. Spanish Translation Workgroup Bios



Cynthia Cheung is a social scientist who specializes in qualitative research. She holds dual master's degrees in public health and Latin American Studies and completed her undergraduate education in Spanish Literature. She has educational experience from Mexico and Chile and is bilingual and bi-literate in Spanish.

Stephanie Gamez is currently pursuing her PhD in biology. She works in fields related to synthetic molecular biology, genetics, gene drive, and vector biology. Stephanie is a first-generation Mexican-American whose first language is Spanish.



Rebeca Carballar-Lejarazú is a senior scientist of microbiology and molecular genetics. She has experience in insect molecular genetics, vector biology, and the development of insect genetic technologies. Rebeca completed her graduate education in Mexico. She has been living in the US for 8 years and has a First Certificate in English (FCE) by the Cambridge Assessment English. She has written several papers in English published in international high impact journals.

Victor Ferman holds a PhD in Computer Science and works on computational models used to contain and eliminate mosquito-borne disease. Victor completed his undergraduate and graduate education in Mexico, where he also served as an instructor for courses taught in English and Spanish.

Váleri N. Vásquez is a PhD student at the University of California, Berkeley. She uses mathematical models to study gene drive systems. Valerie took undergraduate courses in Spain and was raised speaking Ecuadorian Spanish.

Gerard Terradas holds a PhD in biology and works in fields related to mosquito ecology and mosquito replacement gene drives. Gerard was raised in Spain, completed his terminal degree in Australia, and currently works in San Diego, California.

Judy Ishikawa serves as the head Lab Technician of the Akbari mosquito insectary space, rearing and maintaining *Aedes* and *Anopheles* mosquitoes. Judy's first language is Spanish.

Table 1. Structure of the chat-based focus group sessions.

Sequence	Title/Theme	Slideshow Duration	Slides	Polling Questions	Discussion Prompts
Opening	*Discurso de Apertura* (Opening Remarks)	1:09 min	1	2	3
Slideshow 1	*Mosquitos en California* (Mosquitoes in California)	5:54 min	10	3	2
Slideshow 2	*Ingeniería Genética para el Control de Mosquitos* (Genetic Engineering for Mosquito Control)	6:54 min	8	4	2
Slideshow 3	*Modificando a los mosquitos usando los Gene Drives* (Modifying Mosquitoes with Gene Drives)	3:12 min	5	2	1
Slideshow 4	*Controlando los Gene Drives* (Controlling Gene Drives)	7:39 min	8	4	2
Closing	*Repaso* (Review)	--	--	4	3

Table 2. Example of an exchange to clarify the meaning of the question.

Original text in English	As far as you know, is there a public agency in your area that deals with mosquitoes?
First translation into Spanish	¿Por lo que sabe usted, hay una agencia pública en su área que trabaja con los mosquitos?
Reviewer comment	This expression in Spanish means that the public agency worked with mosquitoes but doesn’t involve anything about “control.”
Text changed to clarify meaning of the questions	¿Por lo que usted sabe, hay alguna agencia pública en su área que trabaje en el control de los mosquitos?
Reviewer edit	¿Conoce de alguna agencia pública, en el área donde vive, que trabaje en el control de los mosquitos?

Figure 1. Iterative translation and review process.

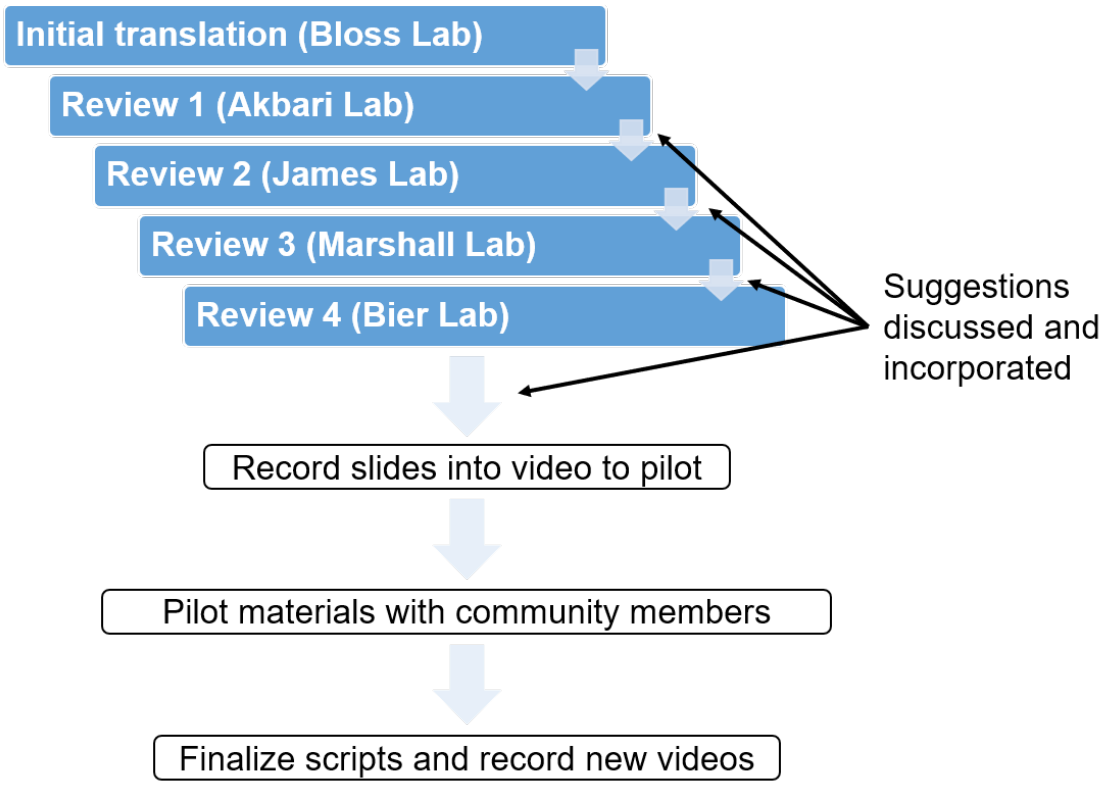
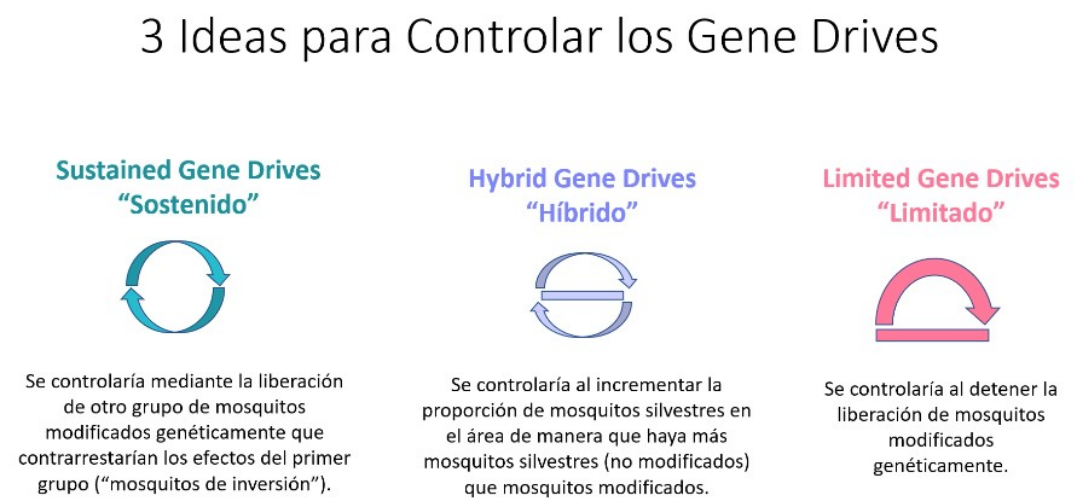
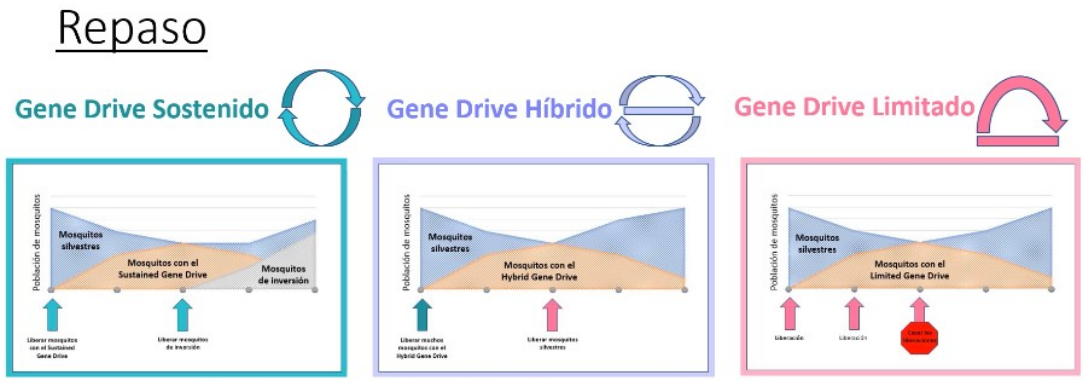


Figure 2. First slide with terms in both Spanish and English; last slide with terms in an English-Spanish hybrid.





Control	Liberar mosquitos de inversión	Liberar mosquitos silvestres	Cesar las liberaciones
Esfuerzo/Coste	Bajo	Moderado	Alto
¿Confinados?	No	Sí	Sí

Figure captions (list)

- Figure 1. Iterative translation and review process.
- Figure 2. First slide with terms in both Spanish and English; last slide with terms in an English-Spanish hybrid.