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PRELIMINARY PUBLICATION

Current and proposed insect targets for gene drive development

A horizon scanning survey

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Summary of findings

- Gene drives are under development or have been proposed for 41 insect targets from six different orders.[1,2] This has increased by nine since our previous survey in April 2022.
- While 15 of the proposed targets are vectors of human disease,[3] in particular malaria, the majority are agricultural pests,[4] 22 in total. These include five livestock pests or livestock disease vectors, which partially overlap with human disease vectors.
- There is substantial effort going towards developing gene drives in the mosquito genera *Aedes* and *Culex*, which are not vectors of malaria.
- The crop pests 'spotted winged drosophila' (*Drosophila suzukii*) and the 'diamondback moth' (*Plutella xylostella*) are also the focus of substantial gene drive development efforts.
- Only five species are proposed as targets because of wider biodiversity impacts or combined economic loss and biodiversity impacts,[5] as well as one for forest management purposes and one for conservation, the latter again overlapping with human disease vectors.[6]
- The majority of gene drive proposals are based on eradication/suppression approaches. Only a very few are projects that are aiming to modify characteristics of insects in the wild.
- At the present time no projects are close to producing a usable and proven 'product'. But some are closer to potential field trials, pending on regulation, risk assessment and further (technical) developments.
- CRISPR-based homing gene drives have been shown to function with reasonable efficiency in several members of the order *Diptera* (true flies), especially within the mosquito genera *Anopheles* and *Aedes*, and within the genus *Drosophila*. However it is notable that within another member of the *Diptera*, the mosquito *Culex quinquefasciatus*, a homing gene drive so far operates only at very low efficiency.
- It remains unclear how applicable homing CRISPR/Cas gene drives will be in insects outside of the *Diptera*. In non-dipteran insects there is only one example of a such a gene drive showing any level of functionality: a very low efficiency system constructed in the diamondback moth (*Plutella xylostella*).

Contextualisation

The emergence of gene drive technology opens-up unprecedented prospects of modifying, suppressing, or even eliminating wild species to serve human purposes. The consequences of choosing to go down this path are very difficult to foresee, especially in the longer term. To help frame further discussion on this topic, we have updated our survey of gene drive development in insects, screening the scientific literature up until September 2023. The survey also includes development of so-called 'x-shredders', a sex ratio distortion system with close similarities to gene drive technology.

We do not cover issues regarding risks, difficulties in performing robust risk assessments, or the lack of proven methods to confine, halt or reverse engineered gene drives.

Our survey gives an overview of:

- What research has taken place or is ongoing.
- Which species and taxa are current or proposed targets for gene drive development, and which types of gene drives are being put forward.
- How far along developments have progressed and what the next stages of experimentation might be.

Summary of proposed insect targets

	Taxonomic Group	Taxonomic level	Common name	Number of proposed targets
	CULICIDAE	family	mosquitoes	12
	DIPTERA	order	flies - here excluding mosquitoes	11
	LEPIDOPTERA	order	moths, butterflies and skippers	2
	HEMIPTERA	order	true bugs	5
	COLEOPTERA	order	beetles and weevils	5
	HYMENOPTERA	order	sawflies, bees, wasps and ants	5
	THYSANOPTERA	order	thrips	1
	total			**41**

Methodology

Please see end of document.

1 The vast majority of the targets identified in the literature are single species or species complexes, however some early stage proposals relate to broader taxonomic groups, namely the *Glossina* genus (Testse flies - row 23), the *Scolytinae* subfamily (Bark beetles - row 32) and the order *Thysanoptera* (Thrips - row 41).

2 Many experimental gene drive systems are being developed and tested in the model organism *Drosophila melanogaster*. Because we are not aware of any plans to target this organism in the wild, a survey of work in this species is not included here.

3 All 12 mosquito species listed in rows 1.1-12, the flies in rows 22 and 23, and the bug *Rhodnius prolixus* in rows 28.1-28.2.

4 Targets impacting crops are detailed in rows 13-16, 19, 24-27, 29-31, 33-35, 38, 41; targets impacting livestock are listed in rows 17, 18, 20, 21 and 23.

5 Targets impacting wider biodiversity (and economics) are detailed in rows 36-41.

6 Proposed targets for forestry are bark beetles in row 32, and for conservation is the mosquito *Culex quinquefasciatus* in row 12, a vector for bird malaria as well as for human and animal diseases.

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) Institution	Funders
CULICIDAE (mosquitoes)							
1.1	***Anopheles gambiae*** African malaria mosquito Sub-Saharan Africa  (Sinka et al 2012)	Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Population suppression	Autosomal sex distorter -'X-shredder' (I-PpoI based) [1] Synthetic sex ratio distortion system	i. Galizi et al. 2014, ii. Facchinelli et al. 2019, iii. Bernardini et al. 2019	1 2 3 4 5 6 7 8 9	A. Crisanti Imperial College London, UK + M.Q. Benedict CDC, USA	Gates Foundation (via NIH); European Research Council
1.2			Homing CRISPR Gene drive targeting doublesex (*dsx* gene) or dsxF CRISPR gene drive	i. Kyrou et al. 2018 ii. Hammond, Pollegioni, et al. 2021 iii. Garrood et al. 2021, Taxiarchi et al. 2021	1 2 3 4 5 6 7 8 9	A. Crisanti Imperial College London, UK	Gates Foundation Open Philanthropy DARPA BBSRC
1.3			Autosomal sex distorter - 'X-shredder' (CRISPR based) [1] CRISPR-Cas9 sex ratio distortion system	Galizi et al. 2016	1 2 3 4 5 6 7 8 9	A. Crisanti Imperial College London, UK	Gates Foundation (via NIH)
1.4			Homing CRISPR + Sex Distorter (X-shredder) (male-biased) Sex-distorter gene drive (SDGD)	i. Simoni et al. 2020 ii. Garrood et al. 2021	1 2 3 4 5 6 7 8 9	A. Crisanti Imperial College London, UK	Gates Foundation

1 Engineered sex ratio distorter systems that are NOT gene drives

	Species **Geographic range** (of target species)	**Intended use** **Intended direct effect** (of gene drive)	**Type of gene drive** (our categories) **Developer's name for gene drive system**	**Publications** (where research is described)	**How close is strain/system to *experimental* releases in the wild?**	**Project leader** (corresponding author on publications) **Institution**	**Funders**
1.5	***Anopheles gambiae*** African malaria mosquito Sub-Saharan Africa  (Sinka et al 2012)	Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Population suppression	Homing CRISPR CRISPR-Cas9 gene drive system targeting female reproduction	i. Hammond et al. 2015, ii. Hammond et al. 2017 iii. Garrood et al. 2021 iv. Pescod et al. 2023[2]	1 2 3 4 5 6 7 8 9	A. Crisanti Imperial College London, UK	Gates Foundation (via NIH); European Research Council
1.6			Homing CRISPR CRISPR-Cas9 gene drive system targeting female reproduction	i. Hammond, Karlsson, et al. 2021 ii. Garrood et al. 2021 iii. Taxiarchi et al. 2021 iv. iv. Pescod et al. 2023[2]	1 2 3 4 5 6 7 8 9	A. Crisanti Imperial College London, UK	Gates Foundation
1.7		Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Population modification	Homing CRISPR 'Cas9/guide RNA (gRNA)–based gene-drive systems' 'autonomous gene-drive system'	i. Carballar-Lejarazú et al. 2020 ii. Carballar-Lejarazú et al. 2022 iii. Terradas et al. 2022 iv. Carballar-Lejarazú et al 2023	1 2 3 4 5 6 7 8 9	A. James UC Irvine, USA	Gates Foundation; UC Irvine
1.8		Population modification (to stop pathogen development within mosquito)	Split homing CRISPR variant (targeting CP, AP-2, and Aper-1) Integral gene drive (IGD)	Hoermann et al. 2021	1 2 3 4 5 6 7 8 9	N. Windbichler Imperial College London, UK	Gates Foundation

2 Pescod et al (2023) carried out further work to characterise the performance of these systems in different strains of *An. gambiae* at the Liverpool School of Tropical Medicine.

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) Institution	Funders
1.9	***Anpoheles gambiae***	Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Population modification (to stop pathogen development within mosquito)	Split homing CRISPR variants (targeting Gam1 and CP) Integral gene drive (IGD)	Hoermann et al. 2022	**1 2 3 4 5** 6 7 8 9	N. Windbichler Imperial College London, UK	Gates Wellcome Trust
1.10		Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Population modification	Homing CRISPR variant Describe a 'CRISPR/ Cas9 integral gene drive allele'	Ellis et al. 2022	**1 2 3 4 5** 6 7 8 9	N. Windbichler Imperial College London, UK	Gates Foundation
2	***Anopheles arabiensis*** Sub-Saharan Africa and a small part of Arabian peninsula - see map  (Sinka et al 2012)	Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Population suppression	Autosomal sex distorter -'X-shredder'[1] Synthetic sex ratio distortion system	Bernardini et al. 2019	**1 2 3 4 5 6** 7 8 9	A. Crisanti Imperial College London, UK	Gates Foundation

1 Engineered sex ratio distorter systems that are NOT gene drives

	Species **Geographic range** (of target species)	**Intended use** **Intended direct effect** (of gene drive)	**Type of gene drive** (our categories) **Developer's name for gene drive system**	**Publications** (where research is described)	**How close is strain/system to *experimental* releases in the wild?**	**Project leader** (corresponding author on publications) **Institution**	**Funders**
3.1	***Anopheles coluzzii***	Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Population suppression	Autosomal sex distorter -'X-shredder' (I-PpoI based) 'synthetic sex ratio distortion transgene'	Pollegioni et al, 2023	**1 2 3 4 5 6** 7 8 9	P. Pollegioni National Research Council, Terni, Italy [A Crisanti - also an author now at University of Padova, Italy]	Gates Open Philanthropy
3.2		Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Population modification	Homing CRISPR 'Cas9/guide RNA (gRNA)–based gene-drive systems' 'autonomous gene-drive system'	Carballar-Lejarazú et al, 2023	**1 2 3 4 5 6** 7 8 9	A. A. James UC Irvine, USA	Gates UC, Irvine
4.1	***Anopheles stephensi*** Asian malaria mosquito Indian subcontinent and parts of middle east - see map  (Sinka et al 2012)	Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in India and surrounding regions) Population modification to 'interrupt parasite transmission'	Homing CRISPR Cas9 mediated gene drive system for population modification	i. Gantz et al. 2015 ii. Pham et al. 2019	**1 2 3 4 5** 6 7 8 9	E. Bier & A. James UC San Diego, USA UC Irvine, USA	NIH; Sarah Sandell and Michael Marshall; W. M. Keck Foundation; TATA Institute; Gates Foundation; UC Irvine

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?									Project leader (corresponding author on publications) Institution	Funders
4.2		Reduction of transmission of malaria pathogen by this vector Population modification – proof of principle	Homing CRISPR HDR based autonomous gene drive rescue system (HDR = homology directed repair)	i. Adolfi et al. 2020 ii. Terradas et al. 2022	1	2	3	4	5	6	7	8	9	A. James UC Irvine, USA	NIH; TATA Institute; UC Irvine; DARPA
5.1	***Anopheles funestus***  (Sinka et al 2012)	Reduction of transmission of malaria pathogen by this vector (to reduce morbidity and mortality from malaria in Sub-Saharan Africa) Unspecified	Unspecified – probably would be derived from systems developed by Gates Foundation in *An. gambiae* NA – preliminary study only	Ogola et al. 2019	1	2	3	4	5	6	7	8	9	D.P. Tchoussassi International Centre of Insect Physiology and Ecology, Kenya	Gates Foundation (via NIH) DFiD Sida SDC Kenyan Govt
5.2		Morbidity and mortality from malaria in sub-Saharan Africa Not specified but does talk about 'control' of this vector	Probably homing CRISPR – cites these drives as showing 'the most promise' NA – preliminary study only	Quinn et al. 2021	1	2	3	4	5	6	7	8	9	T. Nolan Liverpool School of Tropical Medicine, UK	BBSRC
6	***Anopheles albimanus***	Reduction of transmission of pathogens (including malaria and lymphatic filariasis) by these vectors in North America Use of the term 'vector control' in abstract implies population suppression	Probably homing CRISPR 'gene drives utilizing CRISPR-cas9' -likely indicating homing CRISPR	Henderson et al. 2022	1	2	3	4	5	6	7	8	9	J.L. Rasgon Pennsylvania State University, USA	NIH USDA Pennsylvania Department of Health Dorothy Foehr Huck and J. Lloyd Huck NSF
7	***Anopheles crucians***				1	2	3	4	5	6	7	8	9		
8	***Anopheles freeborni***				1	2	3	4	5	6	7	8	9		
9	***Anopheles quadrimaculatus***				1	2	3	4	5	6	7	8	9		

	Species **Geographic range** (of target species)	**Intended use** **Intended direct effect** (of gene drive)	**Type of gene drive** (our categories) **Developer's name for gene drive system**	**Publications** (where research is described)	**How close is strain/system to *experimental* releases in the wild?**	**Project leader** (corresponding author on publications) **Institution**	**Funders**
10.1	***Aedes aegypti*** Yellow fever mosquito '…predicted to occur primarily in the tropics and sub-tropics, with concentrations in northern Brazil and southeast Asia including all of India…'(Kraemer et al. 2015)	Reduction of transmission of arboviruses (e.g. yellow fever, chikungunya, dengue, and Zika) Population modification	Split homing CRISPR gene drive CRISPR based split gene drive (Verkuijl et al (2022) conclude that in some cases the mechanism may be meiotic drive rather than homing drive)	i. Li, Yang, et al. 2020 ii. Buchman et al. 2019 iii. Buchman et al. 2020 iv. Verkuijl et al. 2022	**1 2 3 4 5** 6 7 8 9	O. Akbari UC San Diego, USA + L. Alphey Pirbright Institute, UK	DARPA; UC Davis; US Centers for Disease Control and Prevention BBSRC NIH
10.2	↓	Reduction in transmission of arboviruses (e.g. yellow fever, chikungunya, dengue, and Zika) by this vector. Population modification/ replacement	Homing CRISPR Single locus autonomous CRISPR/ Cas9 gene drive	Reid et al. 2022	**1 2 3 4 5** 6 7 8 9	A. W. E. Franz University of Missouri, USA	NIH
10.3	↓	Presumably to reduce impacts on human health from Yellow fever and dengue transmission by this vector species, however the authors do not make this explicit NA - Technology development	Split homing CRISPR 'Split drive' / 'Split homing-drive'	Anderson et al, 2023	**1 2 3 4 5** 6 7 8 9	L Alphey Pirbright Institute, UK	DARPA Wellcome Trust BBSRC
10.4	↓	Reduction of disease-transmission by this vector species Population suppression	Homing CRISPR 'homing-based gene drive' - preliminary research	Chae et al, 2023	**1 2 3** 4 5 6 7 8 9	Z. N. Adelman Texas A&M University, USA	NIH-NIAID TexasA&M USDA

	Species **Geographic range** (of target species)	**Intended use** **Intended direct effect** (of gene drive)	**Type of gene drive** (our categories) **Developer's name for gene drive system**	**Publications** (where research is described)	**How close is strain/system to *experimental* releases in the wild?**	**Project leader** (corresponding author on publications) **Institution**	**Funders**
11.1	***Aedes albopictus***	Reduction in transmission of arboviruses (e.g. yellow fever, chikungunya, dengue, and Zika) by this vector. Population suppression	Homing CRISPR CRISPR/Cas9 gene-drive system	Zhao et al. 2022	**1 2 3 4** 5 6 7 8 9	X-G Chen Southern Medical University, China A James University of California Irvine, USA	National Natural Science Foundation of China National Key Research and Development Program of China NIH
12.1	***Culex quinquefasciatus*** Southern house mosquito  (Samy et al 2016)	Reduction of transmission of vector borne diseases in humans, mammals and birds (e.g. avian malaria) Proof of principle	Split homing CRISPR 'Split-gene-drive'	i. Harvey-Samuel et al. 2023 (Not yet peer reviewed) ii. Feng et al. 2021 iii. Anderson et al. 2020 iv. Anderson et al. 2019 v. DARPA 2017	**1 2 3 4 5** 6 7 8 9	L. Alphey Pirbright Institute, UK [+ K. Esvelt MIT, USA On DARPA grant award]	DARPA; BBSRC; Welcome Trust UCSD NIH TATA
12.2	↓	↓	Unspecified - CRISPR based NA – preliminary study only	Li, Li, et al. 2020	**1 2 3** 4 5 6 7 8 9	O. Akbari UC San Diego, USA	In part: UC San Diego Start Up Funds

	Species **Geographic range** (of target species)	**Intended use** **Intended direct effect** (of gene drive)	**Type of gene drive** (our categories) **Developer's name for gene drive system**	**Publications** (where research is described)	**How close is strain/system to *experimental* releases in the wild?**	**Project leader** (corresponding author on publications) **Institution**	**Funders**
DIPTERA (flies)							
13.1	***Drosophila suzukii***[3] Spotted wing drosophila (SWD) Bangladesh, Korea, Thailand. Spread into: Japan, Brazil, Argentine, Chile, Mexico, United States (esp. California), Canada, and Europe (esp. France) see map  (Polo et al. 2016) (EPPO 2022)	Reduction of damage to soft fruit crops (e.g. cherries) caused by this species Here providing proof of concept for MEDEA in *D. suzukii* for population suppression/ replacement	MEDEA Synthetic *Medea* gene drive system	Buchman et al. 2018	**1 2 3 4 5** 6 7 8 9	O. Akbari UC San Diego, USA	California Cherry Board
13.2	***Drosophila suzukii***	Reduction of damage to soft fruit crops (e.g. cherries) caused by this species Population suppression	Split homing CRISPR 'CRISPR/Cas9-based split homing gene drive targeting doublesex'	Yadav et al, 2023	**1 2 3 4 5** 6 7 8 9	M. J. Scott North Carolina State University, USA	NIH *(full list of funders to follow in final version)*
13.3		Reduction of damage to soft fruit crops (e.g. cherries) caused by this species Population suppression	Propose homing CRISPR NA – preliminary study only	Ni et al. 2021	**1 2 3** 4 5 6 7 8 9	J. Huang Zhejiang University, China	Zhejiang Provincial Fund for Distinguished Young Scholars Fundamental Research Funds for the Zhejiang Provincial Universities

3 Wolf et al (2023) published an experimental study investigating the potential for *D. suzukii* to hybridise with closely related species. The aim was to establish strategies for assessing the risk of gene drive elements impacting non-target species via hybridisation.

	Species **Geographic range** (of target species)	**Intended use** **Intended direct effect** (of gene drive)	**Type of gene drive** (our categories) **Developer's name for gene drive system**	**Publications** (where research is described)	**How close is strain/system to *experimental* releases in the wild?**	**Project leader** (corresponding author on publications) **Institution**	**Funders**
13.4	***Drosophila suzukii*** Spotted winged drosophila	Reduction of economic costs caused by consumption of fruit crops by this species. Population suppression	NA - Stakeholder engagement study NA- Stakeholder engagement study	Kokotovich et al. 2022	**1** 2 3 4 5 6 7 8 9	A.E. Kokotovich North Carolina State University, USA	USDA *(full list of funders to follow in final version)*
14.1	***Ceratitis capitata*** Mediterranean fruit fly (medfly) Africa, Mediterranean area Australasia, North and South America (FAO/IAEA 2017)	Reduction of damage to fruit crops caused by this species Population suppression	Autosomal sex distorter - 'X-shredder' CRISPR based sex distortion	Meccariello et al. 2021	**1 2 3 4 5** 6 7 8 9	N. Windbichler Imperial College London, UK	BBSRC BARD
14.2	↓	↓	Homing CRISPR gene drive Cas9 based sex conversion suppression gene drive (note no constructs yet tested in *C. capitata*)	KaramiNejadRanjbar et al. 2018	**1 2 3** 4 5 6 7 8 9	E. Wimmer University of Gottingen, Germany	DAAD Excellence Foundation for the Promotion of the Max Planck Society IGI UC Berkeley DARPA
14.3	↓	↓	Preliminary study only, but development of CRISPR methods in this species points towards CRISPR based gene drive design NA – preliminary study only	Sim et al. 2019	**1 2 3** 4 5 6 7 8 9	S.M. Geib Daniel K. Inouye US Pacific Basin Agricultural Research Center, USA	USDA
15	***Anastrepha ludens*** Mexican fruit fly Mexico, Central America and parts of US (CABI 2022)	Reduction of damage to fruit crops caused by this species Population suppression	Preliminary study only, but development of CRISPR methods in this species points towards CRISPR based gene drive design NA – preliminary study only	Sim et al. 2019	**1 2 3** 4 5 6 7 8 9	S.M. Geib Daniel K. Inouye US Pacific Basin Agricultural Research Center, USA	USDA

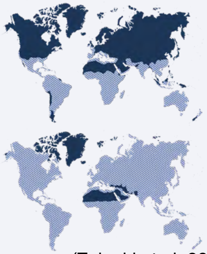
	Species / Geographic range (of target species)	Intended use / Intended direct effect (of gene drive)	Type of gene drive (our categories) / Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) / Institution	Funders
16.1	***Bactrocera dorsalis*** Oriental fruit fly	Reduction of damage to vegetable, fruit and nut crops caused by this species	Preliminary study only, but development of CRISPR methods in this species points towards CRISPR based gene drive design	Sim et al. 2019	**1 2 3** 4 5 6 7 8 9	S.M. Geib Daniel K. Inouye US Pacific Basin Agricultural Research Center, USA	USDA
	 (CABI 2022)	Population suppression	NA – preliminary study only				
16.2	↓	↓	Some form of CRISPR based gene drive	Zhao et al. 2019	**1 2 3** 4 5 6 7 8 9	R. Yan Hainan University, China	
			NA – preliminary study only				
17	***Cochliomyia hominivorax*** New world screwworm	Reduction of disease and death of livestock caused by this species in South America and Caribbean	Propose homing CRISPR	i. Scott et al. 2020 ii. Paulo et al. 2019 iii. Novas et al. 2023	**1 2 3** 4 5 6 7 8 9	M.J. Scott North Carolina State University, USA	NCSU FAPESP USDA-ARS COPEG STRI Institut Pasteur de Montevideo IADB INIA
	 (CABI 2022)	Population suppression	'autonomous CRISPR/ Cas9-based homing gene drive'				
18	***Lucilla cuprina*** Australian sheep blowfly	Reduction of disease and death of livestock caused by this species in Australia and New Zealand	Probably homing CRISPR (in line with proposals for *C. hominivorax*)	Paulo et al. 2019	**1 2 3** 4 5 6 7 8 9	M.J. Scott North Carolina State University, USA	FAPESP USDA-ARS COPEG STRI
	Throughout the world (needs warmer weather conditions)	Population suppression	NA – preliminary study only				

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) Institution	Funders
19	***Bactrocera oleae*** Olive fruit fly  (CABI 2022)	Reduction of harm to olive harvests caused by this species Population suppression	Homing CRISPR NA – preliminary study only	Koidou et al. 2020	**1** **2** **3** 4 5 6 7 8 9	J. Vontas Foundation for Research & Technology, Hellas, Greece	
20	***Lucilla sericata*** Green bottle fly Throughout the world	Reduction of disease and death of livestock caused by this species Population suppression	Propose Homing CRISPR NA – preliminary study only	Davis et al. 2021	**1** **2** **3** 4 5 6 7 8 9	M.J. Scott North Carolina State University, USA	DARPA
21	***Wohlfahrtia magnifica*** Spotted flesh fly (or screw worm fly)	To reduce impacts on livestock health from myiasis caused by this parasitic fly species. Population suppression	Homing CRISPR Cas9-based homing gene drive system	Jia et al, 2023	**1** **2** **3** 4 5 6 7 8 9	P. A. Burger University of Veterinary Medicine Vienna, Austria	Chinese Scholarship Council (CSC) National Natural Science Foundation of China Austrian Science Funds (FWF)
22	***Lutzomyia longipalpis* species complex** Sand Fly Primarily central and South America (Sosa-Estani and Leonor Segura 2015)	Reduction in transmission of *Leishmania infantum* by this vector (to reduce occurrence of visceral leishmaniasis disease) Population modification	Propose homing CRISPR NA – preliminary study only	Wellcome 2017	**1** **2** 3 4 5 6 7 8 9	M. Yeo London School of Hygiene and Tropical Medicine, UK	Wellcome

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) Institution	Funders
23	***Glossina* genus** Tsetse flies  (FAO in Kariithi et al. 2013)	Reduction in transmission of trypanosome parasites by this vector (to reduce occurrence of sleeping sicknessin humans and livestock, esp. European cattle breeds.) Not stated – proposal only	NA – proposal only NA – proposal only	Bier 2022	**1** 2 3 4 5 6 7 8 9	E. Bier UC San Diego, USA	NIH; Allan Frontiers Group Gates Foundation; TATA trusts

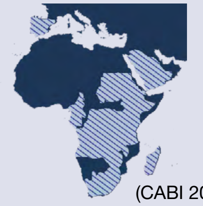
LEPIDOPTERA (moths, butterflies and skippers)

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) Institution	Funders
24.1	***Plutella xylostella*** Diamond back moth	Demonstration of a functional homing CRISPR gene drive system in this species, to allow development of systems for 'genetic control of globally-distributed pest *P. xylostella* Proof of principal for either population modification or suppression (ultimate aim appears to be population suppression)	Homing CRISPR CRISPR/Cas9-based gene drive (CCGD)	Asad et al. 2022	**1 2 3 4 5** 6 7 8 9	G. Yuang Fujian Agriculture and Forestry University, China	National Natural Science Foundation of China Special Key Project of Fujian Province "111" program

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) Institution	Funders
24.2	***Plutella xylostella*** Diamond back moth Top – year round range Bottom – seasonal range  (Zalucki et al. 2012)	Reduction of damage to cruciferous crops by this species Not stated	Split homing CRISPR CRISPR-Cas9 based gene drive in the diamondback moth	Xu et al. 2022	**1 2 3 4** 5 6 7 8 9	M.S. You Fujian Agriculture and Forestry University, China + L. Alphey Pirbright Institute, UK	BBSRC EU Chinese government
24.3		Reduction of damage to cruciferous crops by this species Population suppression	Drive type not specified in detail Proposed system is termed 'RIDL-with-Drive' (RIDL - Release of Insects carrying Dominant Lethal)	Harvey-Samuel et al. 2019	**1 2 3** 4 5 6 7 8 9	L. Alphey Pirbright Institute, UK	EU BBSRC
24.4		Reduction of damage to cruciferous crops by this species Population suppression	Not specified but study uses CRISPR-Cas9 gene knockout methodology, so homing CRISPR seems likely NA preliminary study		**1 2 3** 4 5 6 7 8 9	M.S. You Fujian Agriculture and Forestry University, China	National Natural Science Foundation of China, National Natural Science Foundation of Fujian Province, Major Project of Fujian Province
25	***Plodia interpunctella*** Indian meal moth Present on all continents except Antarctica (CABI 2022)	Reduction of damage to dry food stores (e.g. cereals) caused by this species Not stated – proposal only	NA – proposal only NA – proposal only	Goldsmith et al. 2022	**1** 2 3 4 5 6 7 8 9	C. Goldsmith Texas A&M University, USA	USDA

	Species / Geographic range (of target species)	Intended use / Intended direct effect (of gene drive)	Type of gene drive (our categories) / Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) / Institution	Funders
HEMIPTERA (true bugs)							
26.1	***Diaphorina citri*** Asian citrus psyllid	Reduction in transmission of citrus greening disease, and resulting harm to citrus fruit. This species acts as a vector for *Candidatus Liberibacter* spp. bacteria which cause the disease.	Not stated – no details of design published	Described by Jones et al. 2019 and Turpen 2017 (Report to USDA)	1 2 3 4 x x x x x	T. Turpen	USDA
	Central and South America, India, South East Asia and Saudi Arabia (Grafton-Cardwell et al. 2005)	Population replacement or modification	Not stated – no details of design published			Citrus Research and Development Foundation, Florida, USA	
26.2		As above	Propose homing CRISPR	Wheatley and Yang 2021	1 2 3 4 5 6 7 8 9	Y. Yang	USDA
		Population modification or suppression proposed	NA – proposal only			Pennsylvania State University, USA	Hatch appropriations
27	***Lygus hesperus*** Western tarnished plant bug	Reduction in damage to cotton and other crops caused by this species	Probably CRISPR based – various forms of CRISPR drive cited	Heu et al. 2022	1 2 3 4 5 6 7 8 9	J. Fabrick	Cotton Incorporated
	Mainly western US, also reported in US state of Georgia (CABI 2022)	Population suppression	NA – preliminary study			U.S. Arid Land Agricultural Research Center, USA	
28.1	***Rhodnius prolixus*** Kissing bug	Reduction in transmission of the parasite *Trypanosoma cruzi* by this vector (to reduce occurrence of Chagas disease)	Propose homing CRISPR	Wellcome 2017	1 2 3 4 5 6 7 8 9	M. Yeo	Wellcome
	Venezuala, Columbia and parts of Central America (Sosa-Estani and Leonor Segura 2015)	Population modification	NA – no research published yet			London School of Hygiene and Tropical Medicine, UK	

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?									Project leader (corresponding author on publications) Institution	Funders
28.2		Reduction in transmission of the parasite *Trypanosoma cruzi* by this vector (to reduce occurrence of Chagas disease) Population modification or suppression	Probably homing CRISPR NA – unpublished preliminary study only	Berni et al. 2020	1	2	3	4	5	6	7	8	9	H. Araujo Federal University of Rio de Janeiro, Brazil	Not stated
29	***Bemisia tabaci* species complex** Silverleaf whitefly  (Kriticos et al. 2020)	Reduction of damage to crops caused by transmission of begomoviruses by this vector species Population modification	Homing CRISPR NA – preliminary theoretical study	Li, Aidlin Harari, et al. 2020	1	2	3	4	5	6	7	8	9	B.E. Tabashnik University of Arizona, USA	United States—Israel Binational Agricultural Research and Development Fund
29.2	***Bemisia tabaci***	Reduction of damage to crops via feeding or transmission of viruses (especially begomoviruses) Population modification/ replacement OR Population suppression/ eradication	Probably homing CRISPR 'CRISPR based gene drive'	Mahmood et al. 2022	1	2	3	4	5	6	7	8	9	S Mansoor College of Pakistan Institute of Engineering and Applied Sciences (PIEAS), Pakistan	*Full list of funders to follow in final version*

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) Institution	Funders
30	***Trioza eryteae*** African citrus psyllid (vector of citrus greening disease)  (CABI 2022)	Reduction in transmission of citrus greening disease, and resulting harm to citrus fruit. This species acts as a vector for *Candidatus Liberibacter* spp. bacteria which cause the disease. Population modification or suppression proposed	Propose homing CRISPR NA – proposal only	Wheatley and Yang 2021	**1** 2 3 4 5 6 7 8 9	Y. Yang Pennsylvania State University, USA	USDA Hatch appropriations
	COLEOPTERA (Beetles and weevils)						
31	***Tribolium castaneum*** Red flour beetle Present on all continents except Antarctica (IRAC 2019)	Reduction of spoilage of stored grains caused by this species Population suppression	Homing CRISPR NA – preliminary theoretical study	Drury et al. 2017	**1** **2** 3 4 5 6 7 8 9	M.J. Wade University of Wisconsin, USA	NIH Indiana University start- up funds
32	***Scolytinae* subfamily** Bark beetles NA - No single species named as a target yet	Reduction of damage to timber crops caused by this species Population suppression	Homing CRISPR NA – preliminary theoretical study	Liu and Champer 2022 (Note that Li, Aidlin Harari, et al. 2020 also imply these species could be a target)	**1** **2** 3 4 5 6 7 8 9	J. Champer Peking University, China	Peking University SLS-Qidong Innovation Fund

	Species **Geographic range** (of target species)	**Intended use** **Intended direct effect** (of gene drive)	**Type of gene drive** (our categories) **Developer's name for gene drive system**	**Publications** (where research is described)	**How close is strain/system to *experimental* releases in the wild?**	**Project leader** (corresponding author on publications) **Institution**	**Funders**
33	***Listronotus bonariensis*** Argentine stem weevil Indigenous to South America, it has spread to Australia and New Zealand  (EPPO 2022)	Reduction of damage to pasture grass caused by this species Population suppression	Not stated – proposal only NA – proposal only	Dearden et al. 2018	1 2 3 4 5 6 7 8 9	P. Dearden University of Otago, NZ	Not stated
34	***Sitona lepidus*** (synonym - *S. obsoletus*) clover root weevil  (CABI 2022)	Reduction of damage to clover caused by this species (in agricultural contexts) Population suppression	Not stated – proposal only NA – proposal only	Dearden et al. 2018	1 2 3 4 5 6 7 8 9	P. Dearden University of Otago, NZ	Not stated
35	***Anthonomus grandis*** Mexican cotton boll weevil Indigenous to Central America, has spread to USA, Caribbean, Brazil and other South American countries (CABI 2022)	Reduction of damage to cotton crops caused by this species Not stated – proposal only	Not stated – proposal only NA – proposal only	Goldsmith et al. 2022	1 2 3 4 5 6 7 8 9	C. Goldsmith Texas A&M University, USA	USDA

	Species Geographic range (of target species)	Intended use Intended direct effect (of gene drive)	Type of gene drive (our categories) Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) Institution	Funders
HYMENOPTERA (sawflies, bees, wasps and ants)							
36	***Vespula vulgaris*** Common wasp Palearctic species native to Eurasia, invasive in parts of South America, Australia, New Zealand and Hawaii	Reduction of ecological effects of invasive populations of this species in New Zealand and elsewhere (e.g. Australia) Population suppression	Homing CRISPR NA – preliminary theoretical study	i. Dearden et al. 2018 ii. Lester et al. 2020 iii. Lester et al. 2023	1 2 3 4 5 6 7 8 9	P. Dearden University of Otago, NZ + P.J. Lester Victoria University of Wellington, NZ	New Zealand Ministry of Business Innovation and Employment; Victoria University of Wellington
37	***Vespula germanica*** German wasp Predicted distribution - suitable and marginal areas  (de Villiers, Kriticos, and Veldtman 2017)	Reduction of ecological effects of invasive populations of this species in New Zealand and elsewhere (e.g. Australia) Population suppression	Homing CRISPR NA – preliminary theoretical study	i. Dearden et al. 2018 ii. Lester et al. 2020	1 2 3 4 5 6 7 8 9		
38	***Solenopsis invicta*** Red imported fire ant Native to South America. Imported populations in United States, China, Australia, New Zealand and some other SE Asian and Carribean countries (Chen et al. 2020)	Reduction of impacts on agriculture, biodiversity and infrastructure caused by this invasive species Population suppression	Homing CRISPR NA – preliminary theoretical study	Liu and Champer 2022	1 2 3 4 5 6 7 8 9	J. Champer Peking University, China'	Peking University SLS-Qidong Innovation Fund

	Species / Geographic range (of target species)	Intended use / Intended direct effect (of gene drive)	Type of gene drive (our categories) / Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) / Institution	Funders
39	***Vespa velutina nigrithorax*** Yellow legged hornet or Asian Hornet	Reduce impacts from predation of commercial honey bees (and potentially wild pollinators)	Homing CRISPR	Meiborg et al, 2023	**1** **2** 3 4 5 6 7 8 9	A. B. Meiborg Roslin Institute, University of Edinburgh, UK	EMBL Wageningen University USDA BBSRC
		Population suppression	*'homing gene drive'* targeting a *'haplosufficient female fertility gene'* [model other variants, but state this is most likely to be effective]				
40	***Polistes dominula*** European paper wasp	Presumably to reduce biodiversity impacts of invasive populations of this species, however the authors do not make this explicit.	Homing CRISPR	Meiborg et al, 2023	**1** **2** 3 4 5 6 7 8 9	A. B. Meiborg Roslin Institute, University of Edinburgh, UK	EMBL Wageningen University USDA BBSRC
		Population suppression	*'homing gene drive'* targeting a *'haplosufficient female fertility gene'* [model other variants, but state this is the only candidate likely to be effective]				

THYSANOPTERA (Thrips)

	Species / Geographic range (of target species)	Intended use / Intended direct effect (of gene drive)	Type of gene drive (our categories) / Developer's name for gene drive system	Publications (where research is described)	How close is strain/system to *experimental* releases in the wild?	Project leader (corresponding author on publications) / Institution	Funders
41	***Thysanoptera* order** Thrips	Reduction of damage to crops caused by thrips	Homing CRISPR	Liu and Champer 2022	**1** **2** 3 4 5 6 7 8 9	J. Champer Peking University, China	Peking University SLS-Qidong Innovation Fund
	NA - No single species named as a target yet	Population suppression	NA – proposal only				

Abbreviations for funders and other organisations

BBSRC	UK Biotechnology and Biological Sciences Research Council
BARD	United States –Israel Binational Agricultural Research and Development Fund
CDC	Centers for Disease Control and Prevention (Atlanta, US)
COPEG	Panama-United States Commission for the Eradication and Prevention of Screwworm
DAAD	German Academic Exchange Service
DARPA	US Defense Advanced Research Projects Agency
DFiD	UK Department for International Development
FAPESP	São Paulo Research Foundation
Gates	The Bill and Melinda Gates Foundation
IADB	Inter-American Development Bank
IGI UC Berkeley	Innovative Genomics Institute, University of California, Berkeley
INIA	Instituto Nacional de Investigación Agropecuaria
NIH	US National Institutes of Health
NCSU	North Carolina State University
PAF	Philanthropy Advisory Fellowship
SDC	Swiss Agency for Development and Cooperation
STRI	Smithsonian Tropical Research Institute
Sida	Swedish International Development Cooperation Agency
TATA	TATA trusts
UC	University of California
USDA	US Department of Agriculture

Key to technology levels

1 **Gene drive proposed:** a proposal has been put forward in the scientific literature or from another academic source (e.g. funding body)

2 **Gene drive proposed with supporting theoretical work, or preliminary laboratory work funded:** a proposal has been made in the scientific literature supported by theoretical or modelling work, or preliminary laboratory work has been funded but has not yet been published

3 **Preliminary laboratory work:** laboratory research relevant to gene drive construction published (e.g. developing molecular biology methods) with possibility or intention to construct gene drive stated

4 **Active research on gene drive construction:** research on gene drive construction has been funded, but no results yet published OR results published showing non-functional gene drives, or similar very limited progress

5 **Limited proof of concept:** Published results show a gene drive is to some extent functional, however there are outstanding technical issues such as resistance or low efficiency

6 **Laboratory proof of concept:** Taking published results at face value, the system works effectively in small cage trials.

7 **Large cage trials:** Data published on trials in large cages, offering a more accurate simulation of conditions in natural environment.

8 **Potential further contained trials:** After large cage trials, it is not currently clear what further trials may take place prior to experimental releases. One possibility is trials in outdoor cages.

9 **Experimental releases in natural environment:** Field trials are underway with releases in the natural environment. This does not indicate that the technology has been shown to be effective or safe.

X **Abandoned project:** Research to construct a gene drive has been carried out, but has been unsuccessful and to our knowledge is no longer active

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Literature searches

Literature searches from January 2022 through to 30 September 2023 were carried out using the Web of Science database and the search term ‘gene drive’. Literature searches for 2021 and previous years were carried out with the PubMed database using the same search term. Relevant journal articles were identified by systematically screening titles and abstracts from the search outputs. Press releases from academic institutions and other relevant materials on the web were identified using appropriate web searches (e.g. searching for the names of group leaders, target species, and the term ‘gene drive’). We recognise that all relevant material on the web may not have been identified.

Research on the related field of ‘sex ratio distorters’ is also included and identified from the literature using similar methodology.

Criteria for inclusion

Laboratory research in insect species as reported in the academic literature and other sources, such as press releases from funders and universities, have been included. Modelling studies have been included for species where laboratory work on gene drive construction has not yet begun, so modelling studies in *Anopheles gambiae* for example are not included. Proposals for gene drives in insect targets as identified from the natural sciences literature are included. Proposals deriving from other academic literature (such as literature relating to policy or ethics) are included at our discretion, for example if such proposals designate novel targets.

Basis for constructing the data table

Broadly, each entry in the table describes development of a particular gene drive concept in a specific target species or group, as described in the relevant literature. Entries are grouped taxonomically, and then ordered by how far the research has progressed.