#InvasiveAlienSpecies Assessment

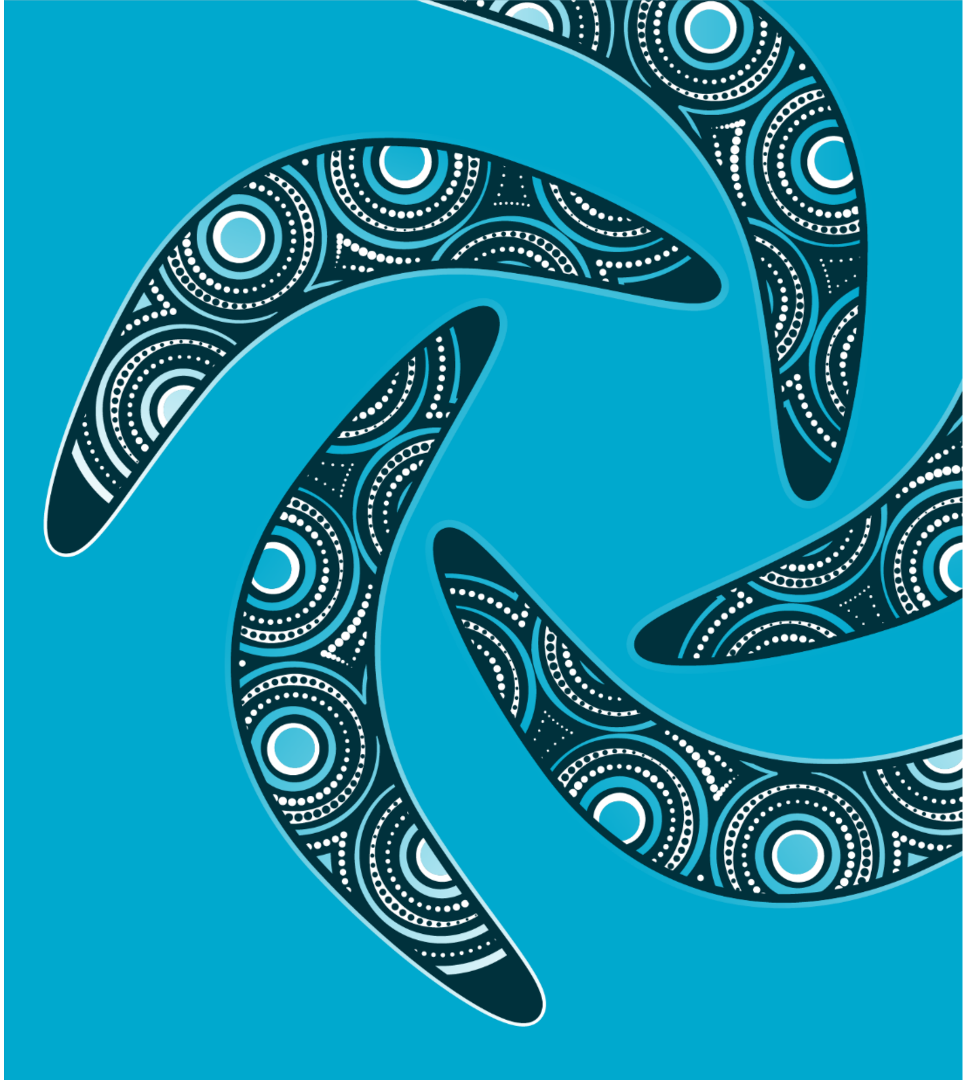
UN environment programme

unesco

Food and Agriculture Organization of the United Nations

UNDP

I would like to begin by acknowledging the Traditional Owners of the land on which I live and work, the Ngunawal people, and pay my respect to their Elders past and present.



A multidisciplinary team of 86 experts & 200 contributing authors from 47 countries across all regions

Developed over 4 years

Over 13,000 documents reviewed (incl. grey literature)

Engagement with Indigenous & local knowledge

First full review of indigenous & local knowledge via 3 dialogue workshops with ILK experts

External review

3 times

#InvasiveAlienSpecies Assessment

1. What are invasive alien species?

Invasive alien (IAS) species are one of 5 major drivers of biodiversity loss

Alien species are organisms that have been introduced by human activities to new regions

IAS are a subset of alien species, known to have established & spread with negative impacts on nature & people

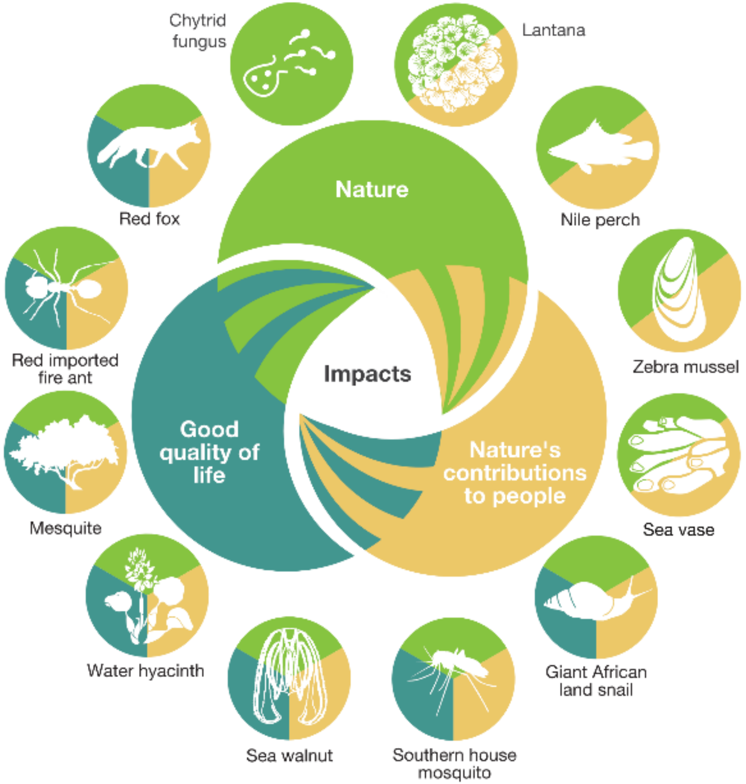
2. Introductory Findings of the assessment

People and nature are threatened by invasive alien species in all regions of Earth

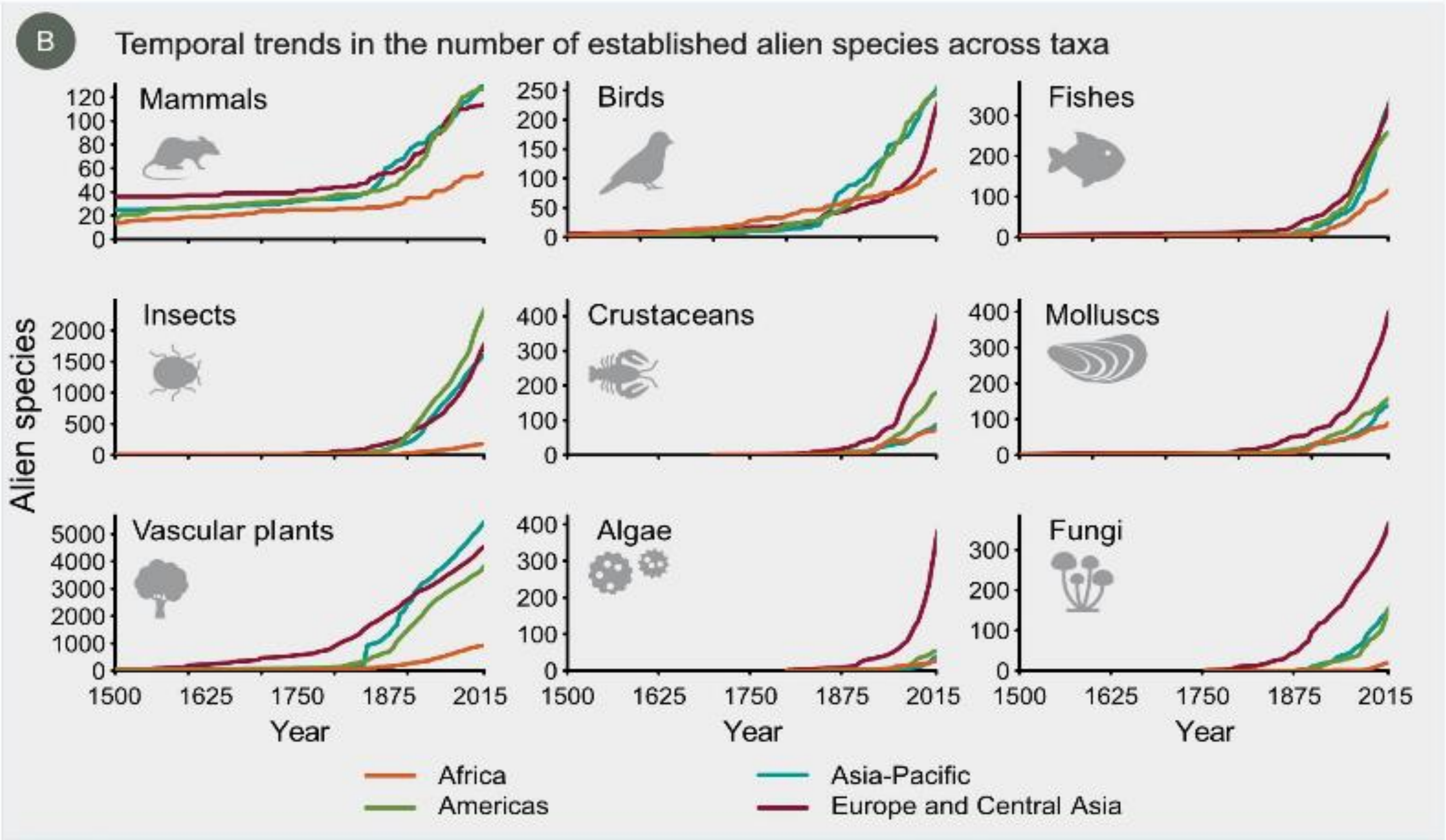
37,000 established alien species have been introduced by human activities worldwide

200 new alien species every year

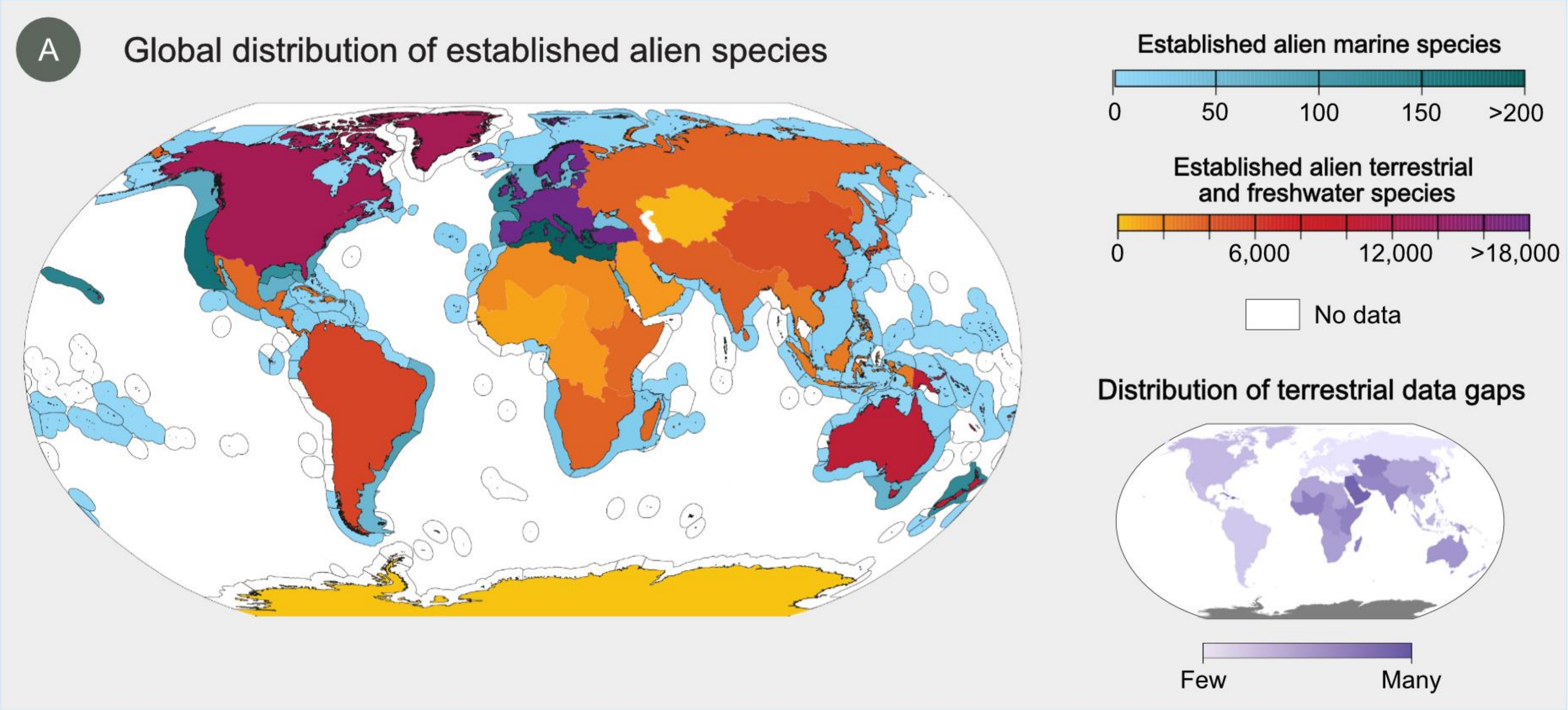
3500 invasive alien species, with negative impacts on nature, and also on people



The threats from biological invasions are increasing markedly in all regions of Earth



Few regions of the world have not be been colonized by invasive alien species

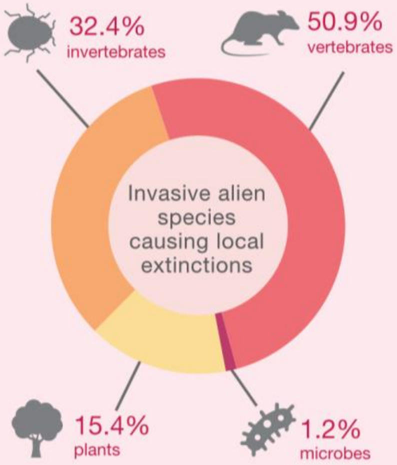


Extinctions

Contributed to 60%

Invasive alien species have contributed solely or alongside other drivers of change to 60% of recorded **global extinctions**, of which 90% occurred on islands[a]

218 invasive alien species caused 1,215 **local extinctions** of native species

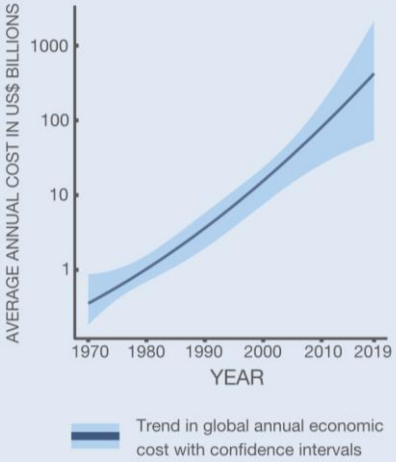


Economic cost

x 4 every decade

The **economic cost** of biological invasion species increased fourfold every decade[b]

In 2019, the estimated global annual **economic cost** of biological invasions was $423 billion

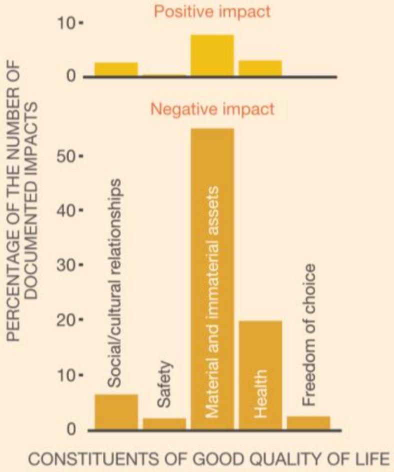


Good quality of life

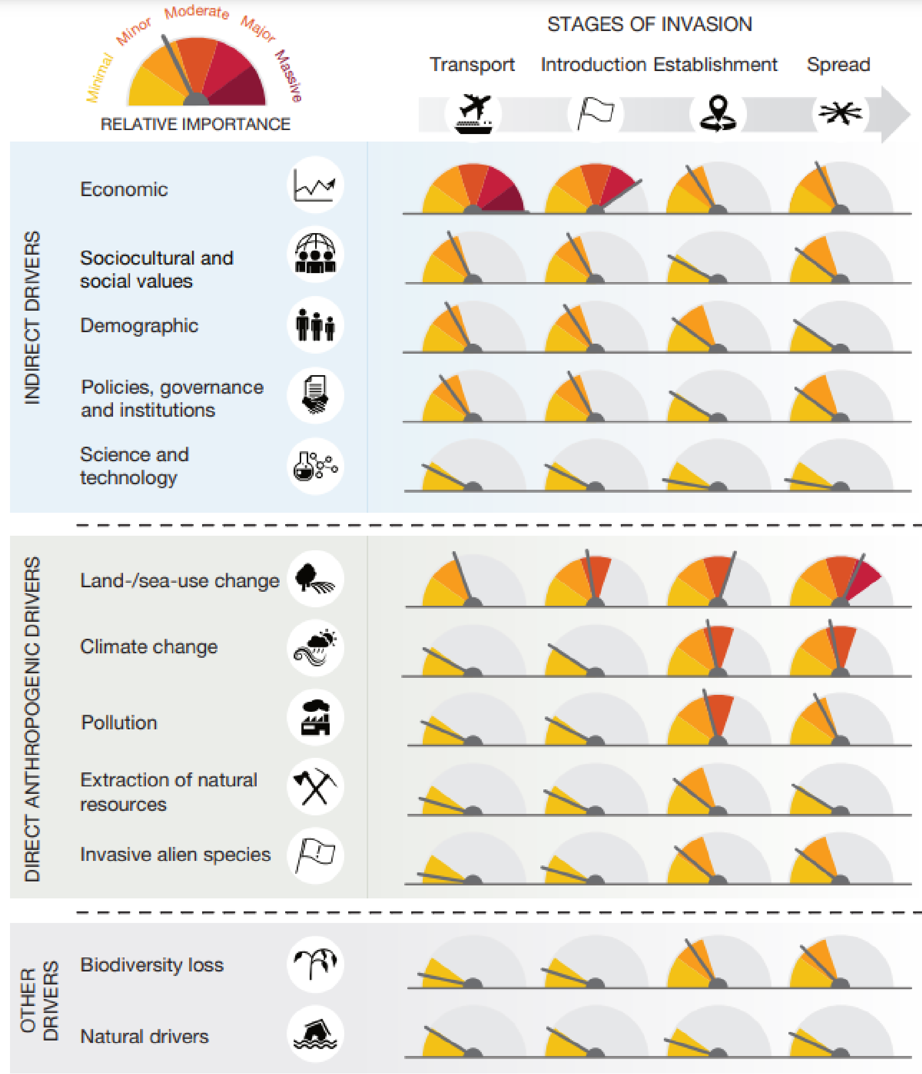
85%

Invasive alien species have a negative impact on **good quality of life** in 85% of cases[c]

Known impact of invasive alien species on **good quality of life**



Many human activities facilitate the transport, introduction, establishment and spread of invasive alien species



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3. Invasive Alien Species Management *Actions*

Invasive alien species Management

“direct or indirect actions taken to address the risks/threats and/or consequences/impacts of invasive alien species within a defined geographic area”

Decision-Support approaches, tools and methods

Includes:

- Stakeholder community of practice & knowledge-sharing frameworks
- Expert elicitation
- Horizon scanning
- Pathway risk analysis
- Impact assessment
- Risk analysis
  - pathway
  - impact
  - management approach
- Economic analyses
  - cost-benefit
  - willingness-to-pay
  - cost-effectiveness analysis (for intangibles)
- Multi-criteria analyses
- Historical case studies (past successes/failures)
- Evidence/scenario synthesis
- Best practice management
- Prioritization (pathways, species & sites)

Prevention and preparedness are the most cost-effective options

- Prevention, where possible, results from effective pathway management:
  - import controls,
  - pre-border, border and post-border biosecurity,
  - rapid response protocols & agreements.

- Prevention is critical in marine and connected water systems where eradication has generally failed, and practical and important on islands.

Prevention & Preparedness requires:

- biosecurity legislation, regulations & policy –appropriate & enforceable
- biosecurity border inspection facilities, quarantine,& diagnostic services
- offshore intelligence gathering & pest risk analysis
- surveillance, detection & diagnostics
- rapid response approaches, plans & agreements
- scientific & technical cooperation
- technology, genomic & digital tools
- adequate & sustained resources
- capacity building
- performance assurance evaluation

International sanitary & risk-based regulations, measures, standards, guidelines & treatments:

International Agreements:

IPPC - International Plant Protection Convention,

WOAH - World Organization of Animal Health, &

IMO – International Maritime Organisation

CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora

Prevention & Preparedness contexts:

A) Terrestrial and closed water systems

- animal and plant commodity trade (Ag, Forestry), wood packaging
- E-commerce pet and plant trade (illegal)
- hitchhiker pests in other freight.

B) Marine and connected water systems

- hull biofouling (poorly regulated) - 70% of problem
- ballast water (international agreements)
- marine debris (pollution/ extreme events)
- pet trade in marine species

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Surveillance & detection tools & technologies targeted)

- Citizen science
- Crowdsourcing/ web-scraping
- Sentinel sites
- Risk mapping
- Remote sensing
- Sensor networks & smart traps

- Volatile detection technologies
- Pheromones & lures
- Ultra-sound/acoustic surveillance devices
- 3D image/X-ray screening
- Environmental DNA
- Track-n-trace next-gen meta-barcoding & genome sequencing

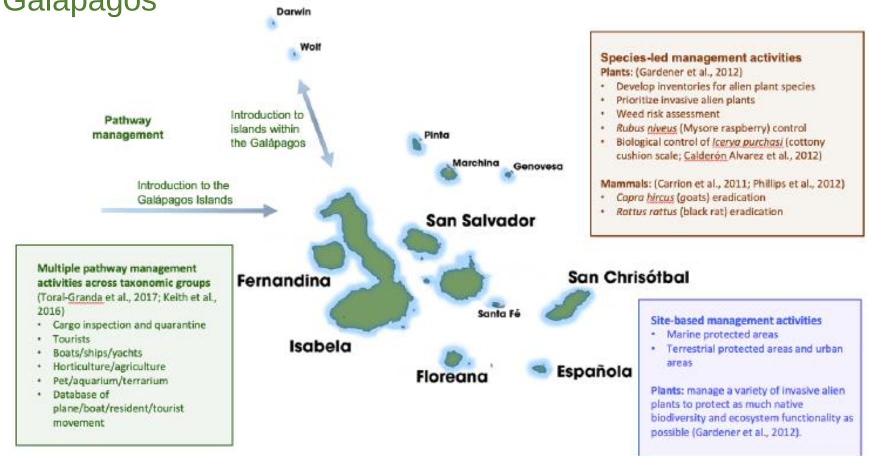
Three management approaches:

(a) introduction pathway management prevention & preparedness addressing IAS arrival & spread

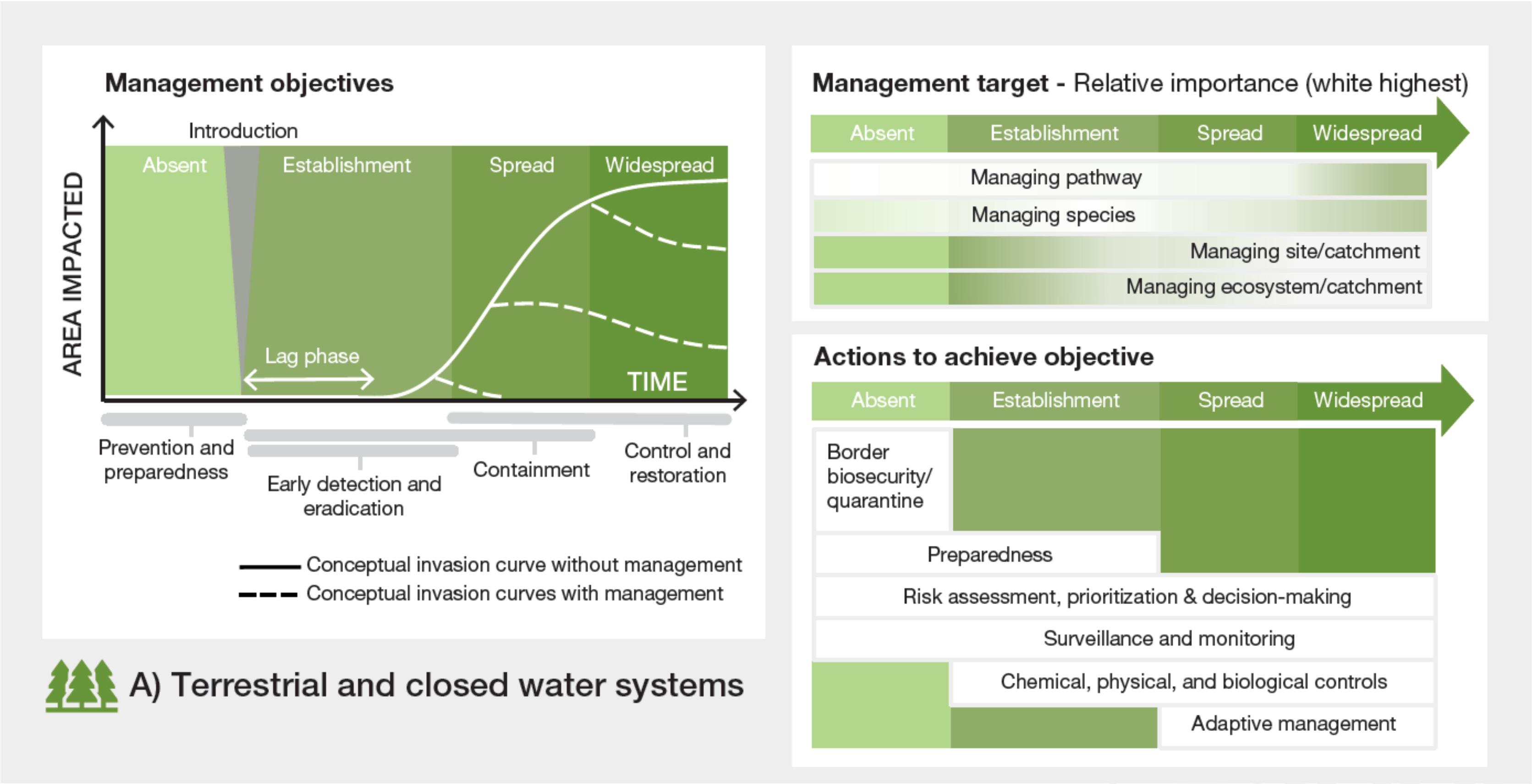
(b) species-led management - surveillance, detection, eradication, containment, & control at either local or landscape scales

(c) site- or ecosystem- based management including restoration at local scales

Integrated management of 1,476 naturalised terrestrial & marine IAS in the Galapagos

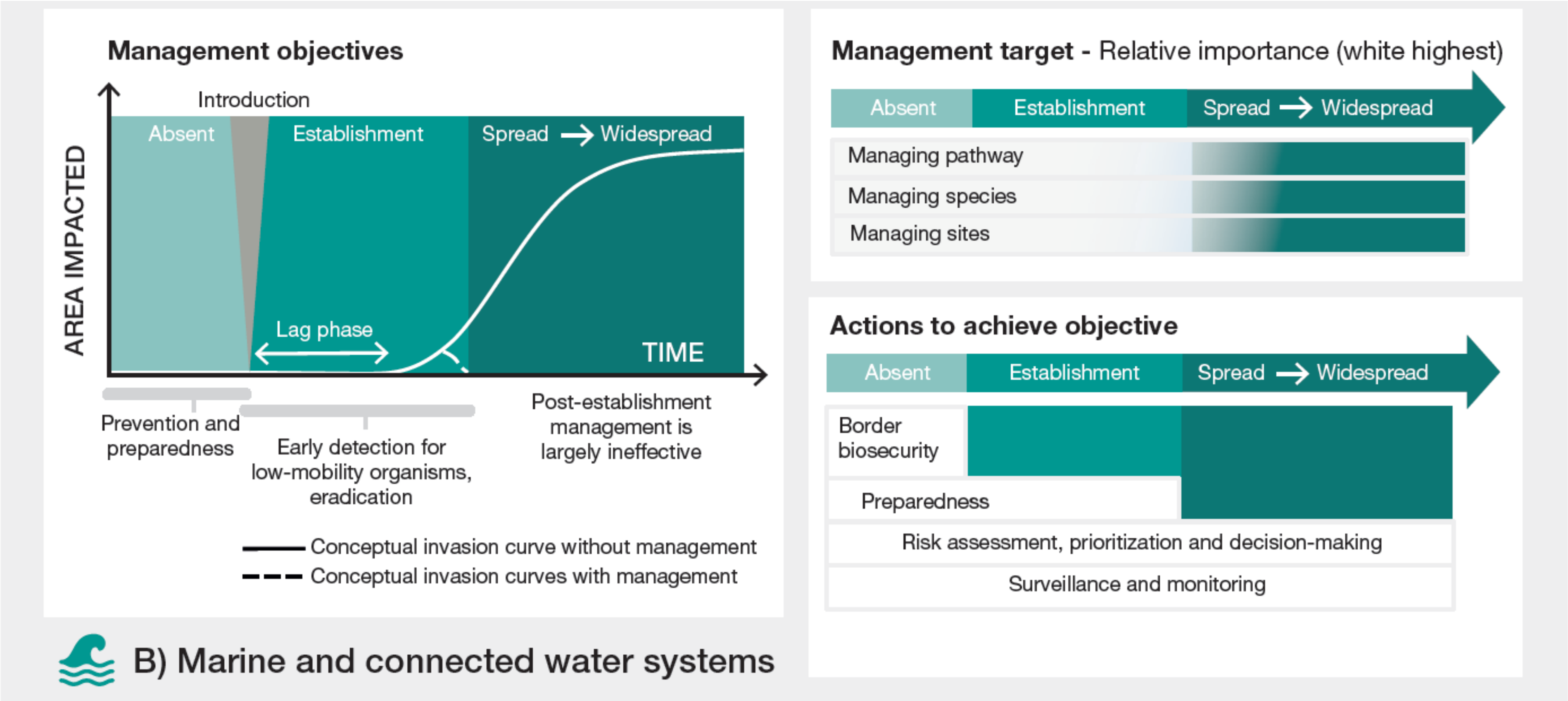


Management along the invasion continuum - terrestrial



Whole suite of management options have been successful and cost-effective

Management along the invasion continuum – marine



Prevention-based pathway management currently only effective management option.

Species-led management : Eradication

A) Terrestrial and closed water systems

B) Marine and connected water systems

Most attempts fail, but is cost-effective on:

- small islands or similar isolated habitats
- highly localized, slow spreading, easily delimited biological invasions

- Success dependent on:
  - support and engagement of all relevant stakeholders
  - continuous science-based progress evaluation,
  - clear criteria for failure and
  - long-term sustainable investment
- 1500 examples of vertebrate eradications on about 1000 islands
- Eradication of invasive ants has been successful if caught early
- Plant eradications particularly difficult - dormant often hard to detect propagules
- Eradication of IAS in marine systems near impossible

Species-led management – Containment

A) Terrestrial and closed water systems

- Aims to **slow spread in defined area** (generally follows failed eradication)

- **Suppressed reproduction common strategy** to limit long-distance dispersal/movement

Species-led management - Control

A) Terrestrial and closed water systems

Physical/mechanical/chemical

- Short-term efficacy & requires regular application - low cost-effectiveness
- *Mechanical control* – mulching weeds & lethal culling of vertebrate pest animals. Latter has ethical challenges.
- *Chemical control* – chemicals & toxicants. Declining social acceptability and non-target and environmental impacts has tightened regulations & use
- *Grazing* - is also widely used for weeds with some effectiveness in grasslands

Species-led management – Classical Biological Control

A) Terrestrial and closed water systems

- 100+ year history & widely accepted as a long-term & effective for invasive alien **plants, invertebrates** and some **vertebrates** in agricultural & environmental settings.

- Host-specific natural enemies of the IAS from the native range are released following internationally accepted risk assessment to provide ecological suppression in invaded range.

- Not been trialled for marine IAS a - risks less understood than in terrestrial or freshwater ecosystems.

- Biocontrol agents include:
  a) herbivorous invertebrates for weeds,
  b) biotrophic fungi for plant targets & arthropods,
  c) invertebrate predators or parasites for invertebrates
  d) Viruses to control certain invertebrates

Species-led management – Other Control Technologies

A) Terrestrial and closed water systems

- ***Sterile insect technique*** *(SIT):* - mass releases of irradiated infertile males - effective in reducing some insect pest populations
- ***Viral biocontrol of vertebrates:*** - taxon-specific pathogenic virus is used as a biocontrol agent – used to control alien vertebrates in Australia & New Zealand.
- ***RNA Interference:*** - RNAi is an applied modified RNA molecule that inactivates specific genes vital to pest or weed fitness
- ***Genetic-control approaches*** (including gene drive): genetic modification of the IAS to population fitness – generally aims to massively skew sex ratio (generally male-biased) driving populations to extinction. Being developed to manage mosquitoes & rodents.

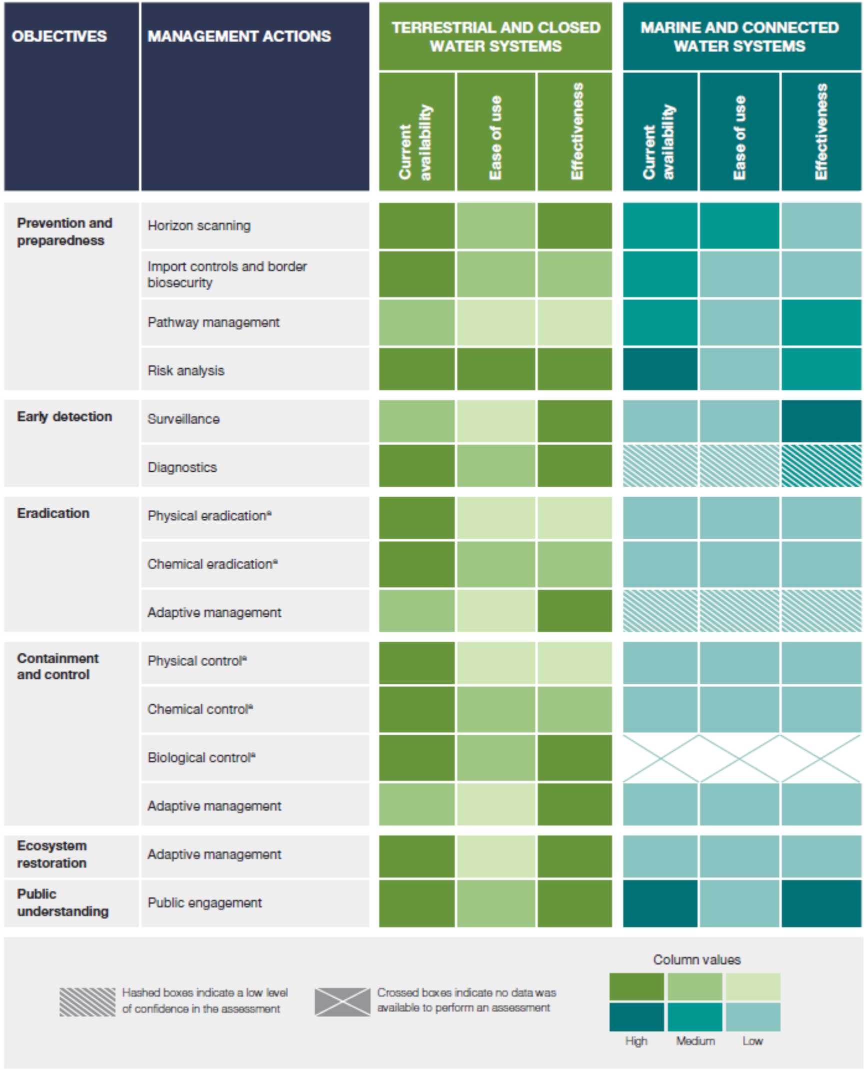
Site-based management (local scales)

- *Remove or suppress IAS* impacts on biodiversity & ecological assets at a priority location or ecosystem

- *Adaptive management approach* including site/ecosystem regeneration (revegetation/restoration)

- Rarely effective in marine environments (too rapid spread in currents)

Objectives & Actions for managing biological invasions



Monitoring & Evaluation

Long-term monitoring of management actions vital to demonstrate beneficial outcomes:

- key part of Adaptive management
- quantifies management & restoration effectiveness & benefits
- early detection of reinvasion
- supported by:
    - cost-benefit,
    - cost-effectiveness, &
    - risk analysis

4. Invasive Alien Species Management

Best practice

Engagement & collaboration with stakeholders & Indigenous Peoples & local communities improves outcomes of management actions for biological invasions

This helps with :

- conflicting perceptions &values
- ethics of management options
- sharing across science local knowledge systems

Stakeholder led *Adaptive Management* -

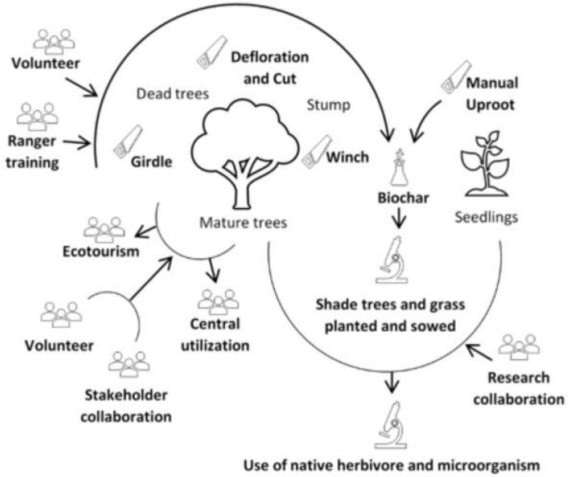
"implementing management using science to understand & improve effectiveness"

Best led by stakeholders & Indigenous Peoples & local communities as promotes consensus, capacity building, & optimized management

Optimises triple-bottom-line benefits by:

- setting biodiversity, cultural & ecosystem service management goals
- inclusive partnerships with affected Indigenous Peoples & local communities & other stakeholders based on:
  - co-designed planning
  - co-developed decision-making
  - co-implemented management. &
  - social learning

Integrating stakeholder engagement & management strategies for *Vachellia nilotica* (gum arabic tree) in Baluran National Park, Indonesia (Zahra et al. (2020), https://doi.org/10.13057/biodiv/d210115



Integrated governance best supports strategic actions to prevent introduction & impact of invasive alien species:

- Enhanced international & regional coordination
- Developing & adopting tractable national IAS strategies
- Sharing efforts & commitment by understanding specific roles of all actors
- Improving policy coherence
- Building engagement across all stakeholders & Indigenous Peoples & local communities;
- Resourcing innovation, research & technology;
- Supporting data information systems and infrastructures

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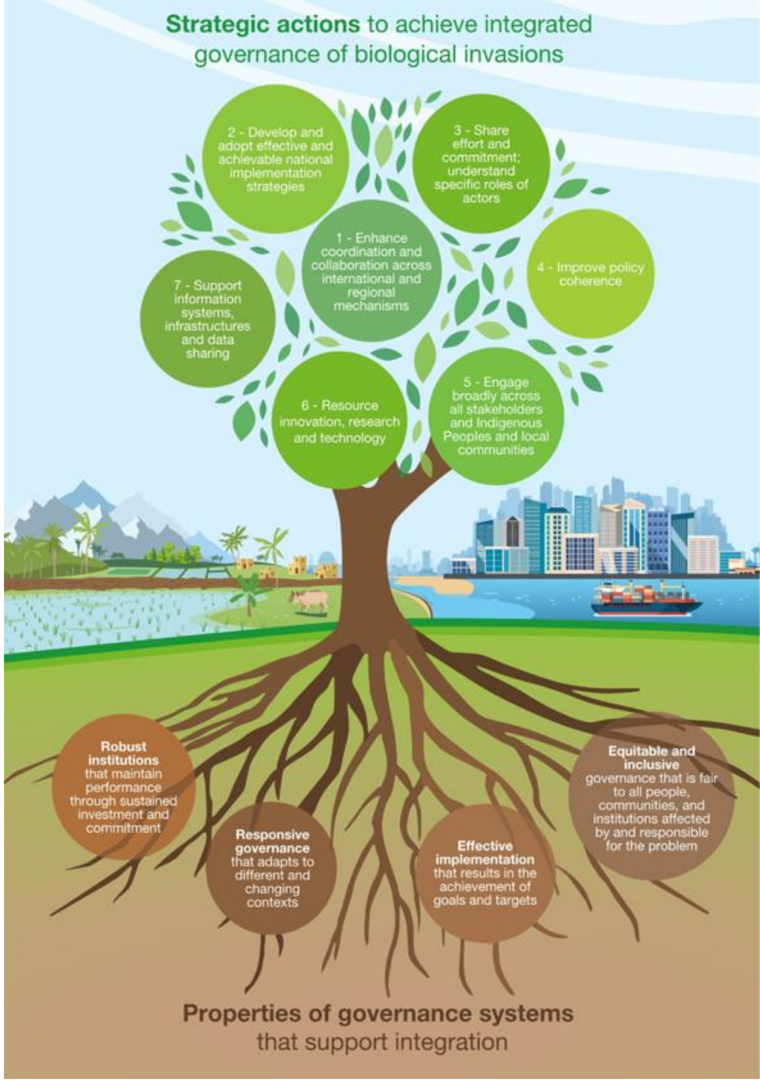


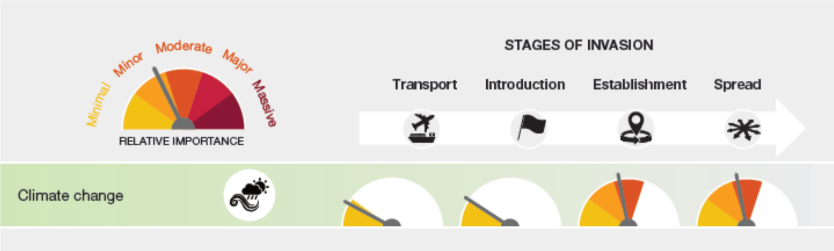
Global Change & Nature Positive (NP) context

Global change – *"anthropogenic planetary-scale changes in the Earth system"*

NP – *" investments halting and reversing current trends of biodiversity loss"*

- Extreme climate events increase ecosystem susceptibility to IAS

- Effective IAS management & ecosystem restoration can build ecosystem resilience to climate change & achieve NP outcomes



Relative importance of climate change as one of the drivers of change in nature that facilitates biological invasions across biomes per different stages of the biological invasion process.

Precautionary principle & management

> *"where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should **not be used** as a reason for postponing measures to avoid or minimize such a threat."*
> (CBD 2002)

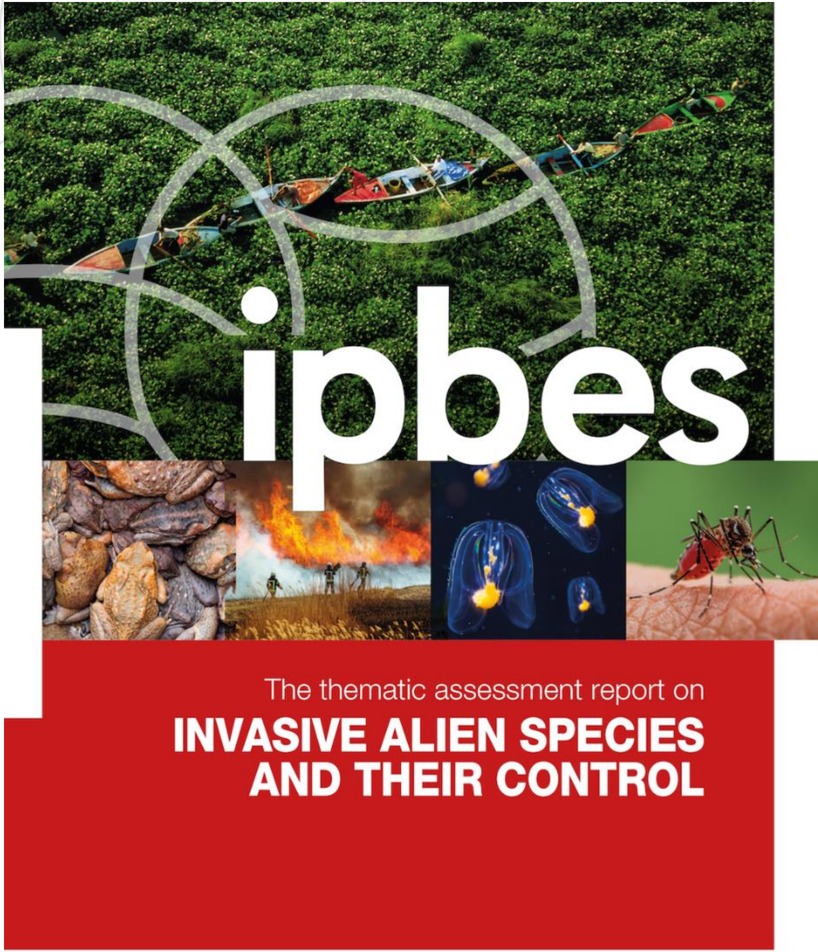
Active capacity-building, priority-setting & management should proceed despite knowledge, data, & management implementation gaps.

Supported by:

- many open-access data bases/sources & analytical tools.
- capturing, sharing, integrating, & analysing data to support decision-making
- stakeholders & Indigenous & local knowledge through effective engagement
- collective addressing of data/knowledge gaps & uncertainty
  (e.g., re global change impacts - *established but incomplete*)

There is compelling evidence for immediate & sustained action

With sufficient resources & long-term commitment, preventing & controlling invasive alien species are attainable goals that will yield significant long-term benefits for people & nature.



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ipbes

The findings of the invasive alien species assessment are contributing to:

- Target 6 of the Kunming-Montreal GBF

- Target 15 Sustainable Development Goals 2030

#InvasiveAlienSpecies Assessment

New technologies for surveillance & genetic management of invasive alien species

Indigenous designed AI for adaptive co-management of weed impacts

- NA wetlands are ‘the supermarkets of the bush’
- Critical biodiversity & cultural values
- Para grass (*Urochloa mutica*) choking these floodplains (e.g. Nardab)
- Magpie geese reduced from 1000’s to 10’s due to lost food & nesting
- Droned & smart Apps making a difference

Njanjma Rangers

Northern Australia Environmental Resources Hub
National Environmental Science Programme

kakadu NATIONAL PARK

Microsoft

THE UNIVERSITY OF WESTERN AUSTRALIA

CHARLES DARWIN UNIVERSITY

Indigenous-led para grass management

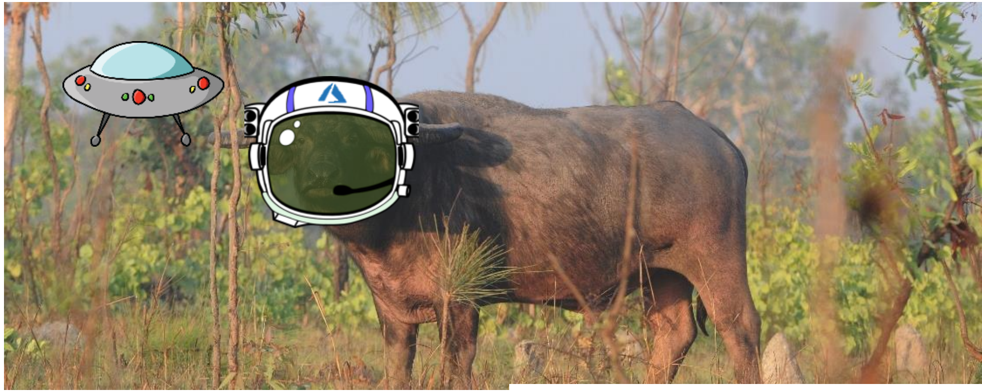
- **Drones** allow collection & review 1000’s hrs of footage of management impact & biodiversity benefit
- **Analytics on phones & tablets** supports control decisions by rangers in real-time & long-term monitoring

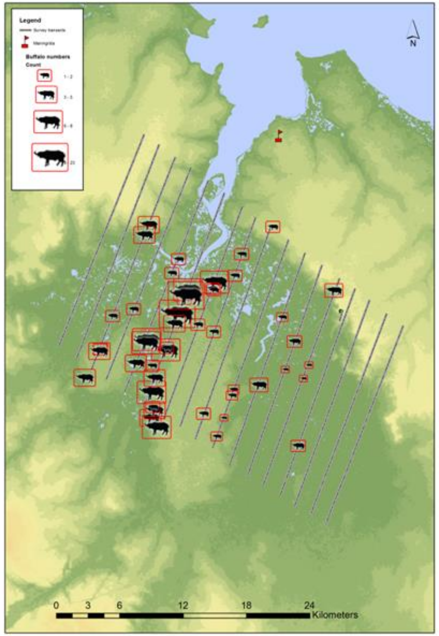
Njanjma Rangers

#SpaceCows

Landscape scale herd management of unmanaged cattle and buffalo in northern Australian indigenous estates

Microsoft





Partners:

APN Cape York

NAILSMA NORTH AUSTRALIAN INDIGENOUS LAND AND SEA MANAGEMENT ALLIANCE

QUEENSLAND PARKS AND WILDLIFE SERVICE

kinéis

NORMANBY LAND MANAGEMENT

CHARLES DARWIN UNIVERSITY AUSTRALIA

CSIRO

Australian Government Department of Agriculture, Fisheries and Forestry

JAMES COOK UNIVERSITY AUSTRALIA

MIMAL LAND MANAGEMENT

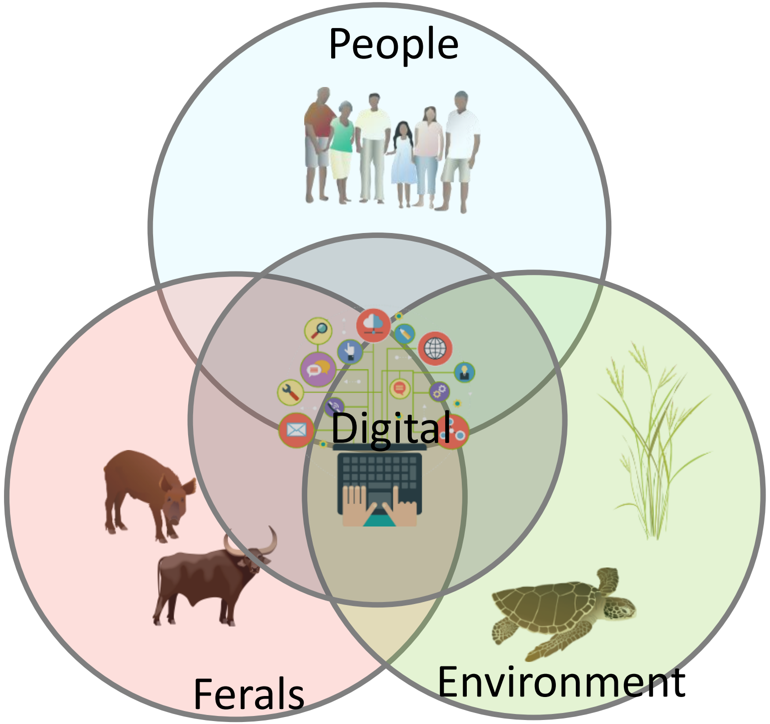
Why do we do it?

Currently buffalo are eating almost all the grass on the Northern flood plains.

#SpaceCows

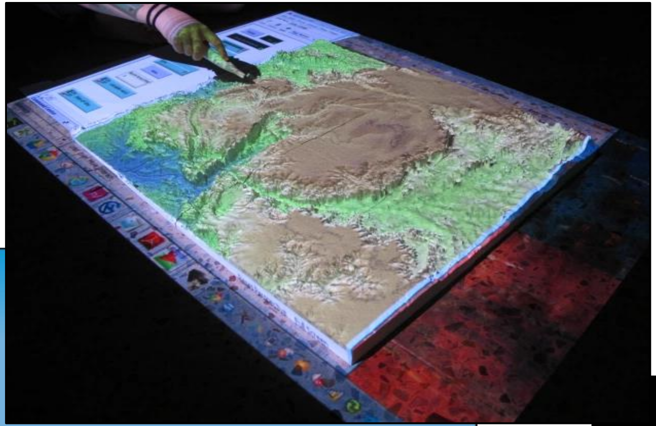
- **Tech-based decision-support platforms for unmanaged and feral herds on Country:**
  - Tech development (tech & data platforms)
  - Indigenous training (tech & ethical mustering)
  - Protection of environmental and cultural values
  - Create/support viable on Country business opportunities

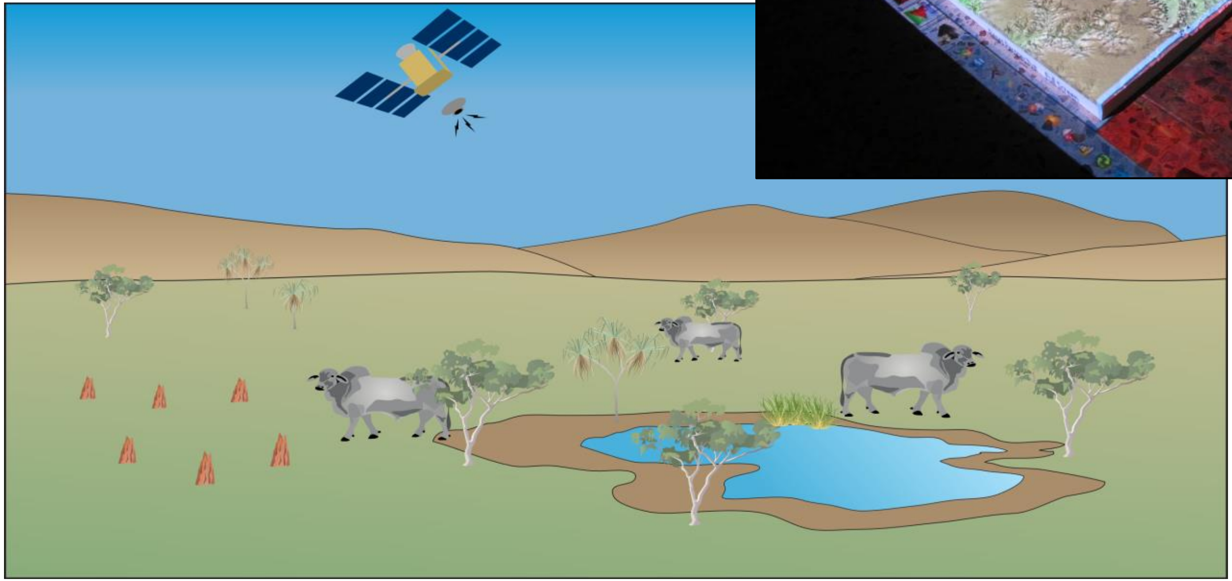
- **Complex context:**
  - Pastoral & Buffalo enterprise
    (pet meat, live trade, safari hunting, crocodile food)
  - Local meat consumption (key social issue)
  - Impact on traditional resources (crocs, turtles, water lilies)
  - Impact on environmental values
  - Impact on cultural sites (paintings, sacred sites)
  - Carbon impacts

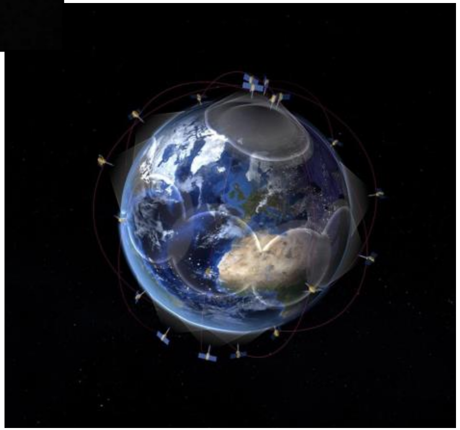


Tracking technology platform

Create the world's largest remote herd monitoring program

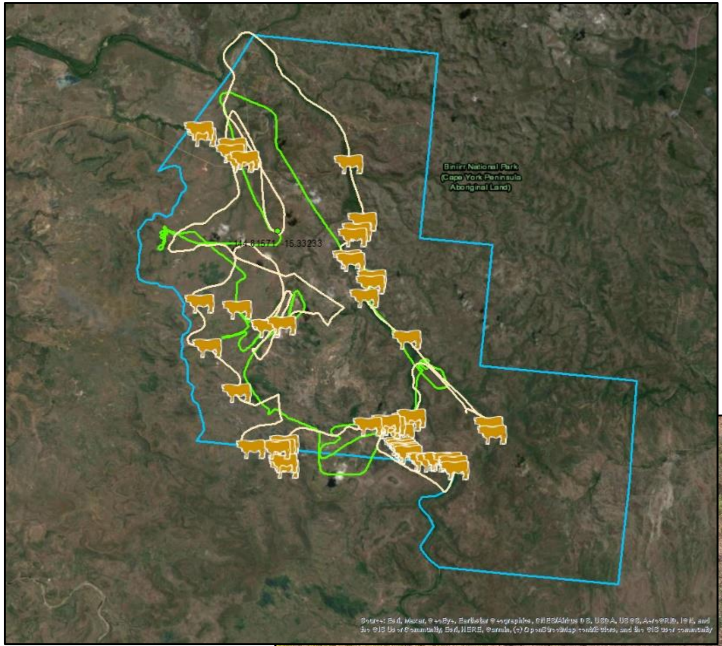






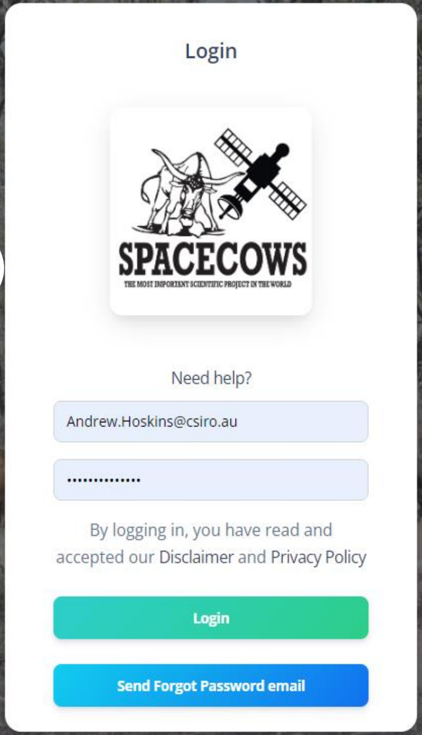
Movement field data collection

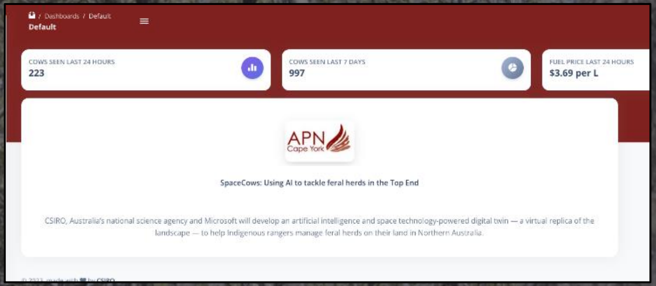
- **Animal density**:
  helicopter surveys
- **Animal Movements**:
  GPS/Satellite tracking ear tags
- **Management activity**:
  GPS/Accelerometer tracking of vehicles
- **Forecast herd movements**
  data analytic platform

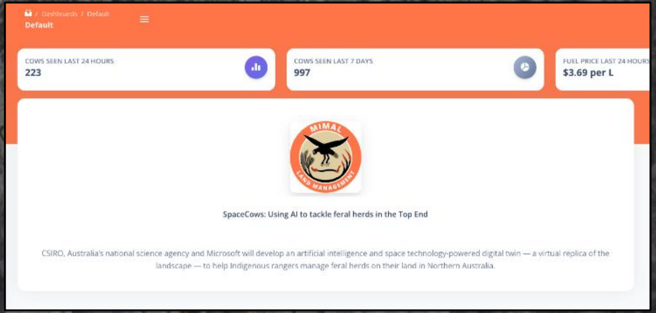


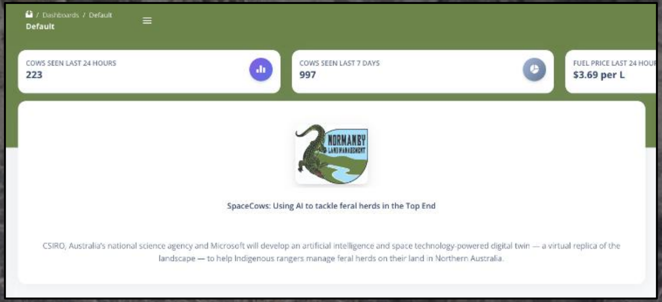
SpaceCows Dashboard (business specific):

- Herd forecasts (density/location)
- Meat prices
- Fuel prices
- Mustering efficiency (remoteness)
- Viability of harvesting
- Carbon benefits
- Environmental cultural benefits

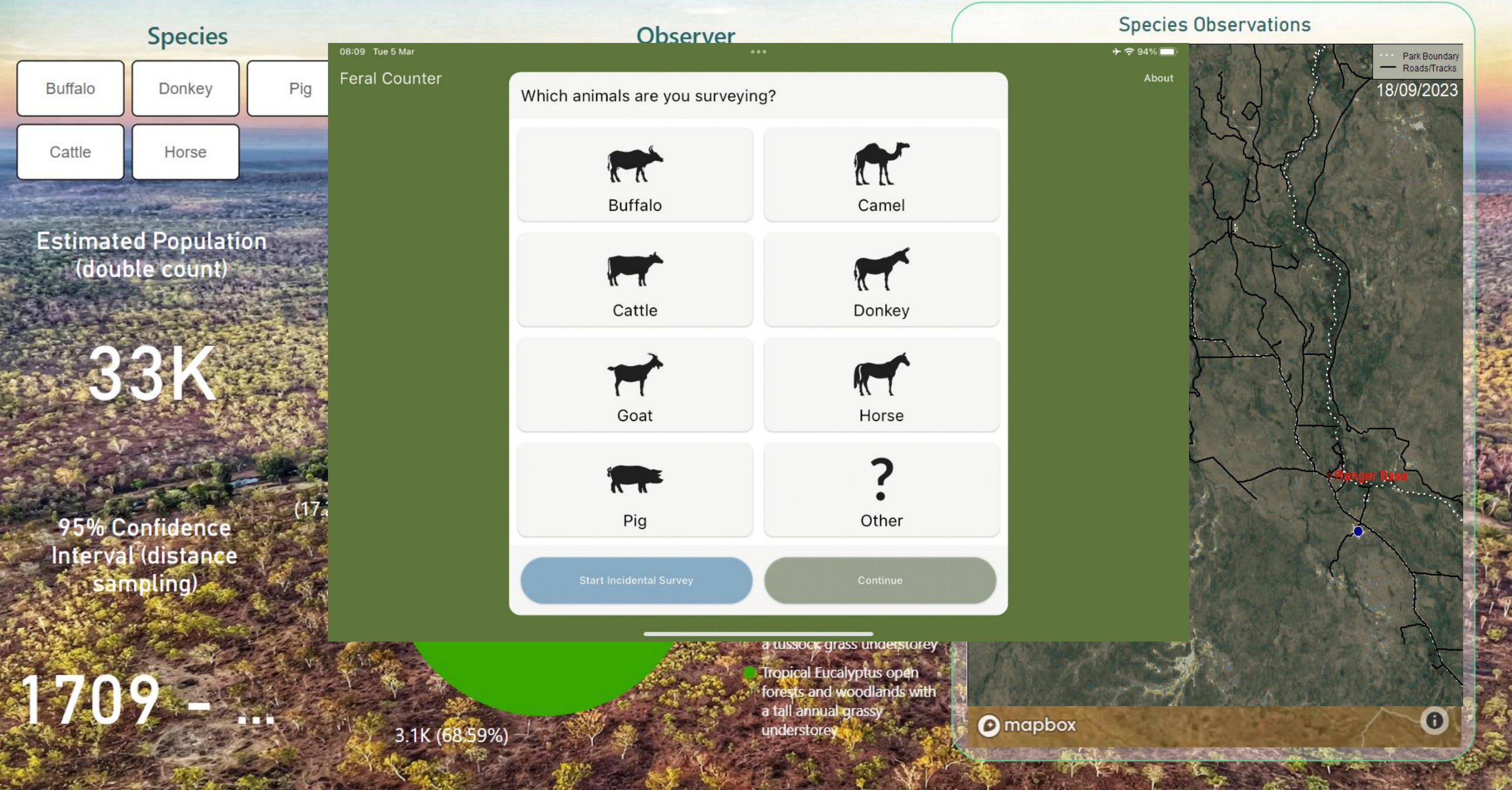




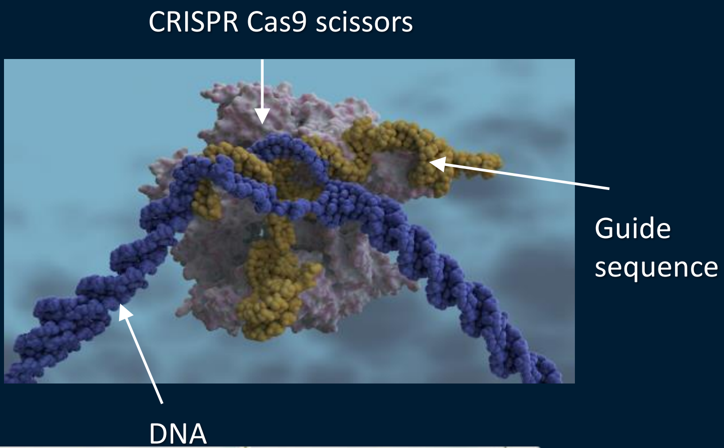


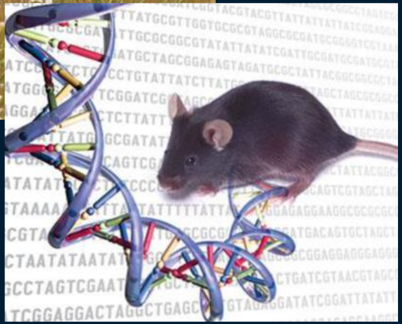


Mimal SpaceCows Feral Animal Survey



Genetic control approaches



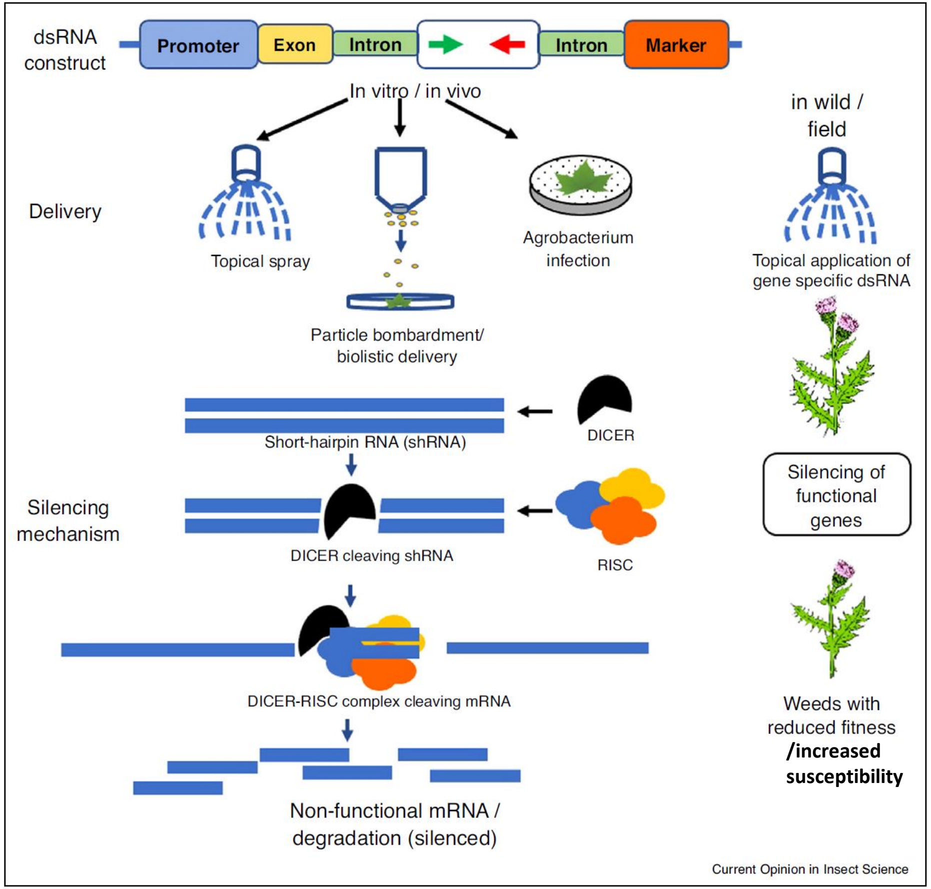


2 x Gene-tech weed management interventions

- **RNAinterference** - Switching-off genes mediating growth and reproduction

- **Gene modification & editing approaches -** Spread modified traits to engineer/edit wild populations with reduced fitness

Gene Technologies – spray on RNAi



Exogenous gene silencing

Topical application of double-stranded RNA to ***silence genes*** mediating functional traits (e.g. growth and development pathways, herbicide/insecticide resistance)

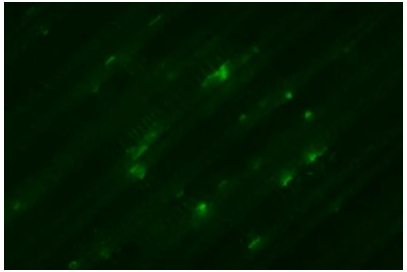
Guo et al. (2016). *Curr Genomics, 17: 476-89*

Joga et al. (2016). *Front Physiol, 7: 553*

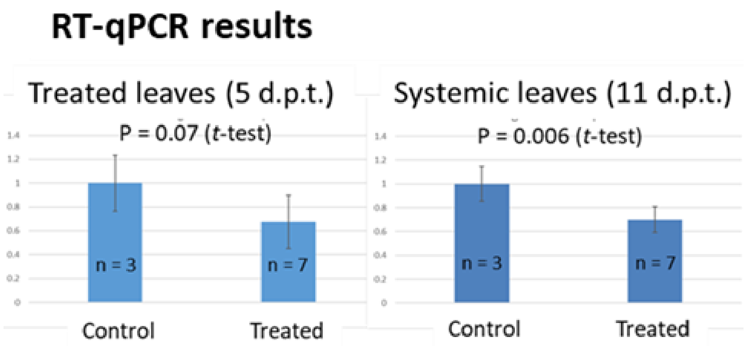
Phragmites – RNAi results so far

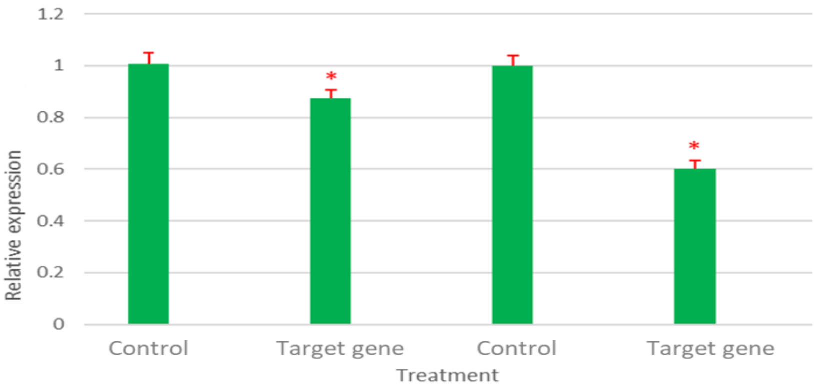
Kurt Kowalski USGS,
Ping Gong USACE

Expression of GFP in *Phragmites* leaves using a carrier (top) vs. carrier-only control (bottom).



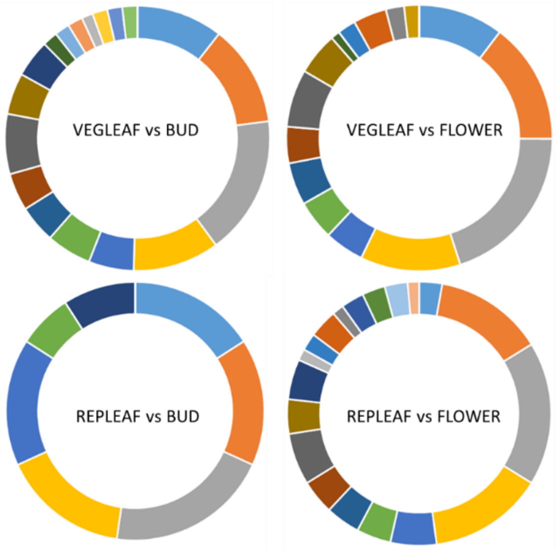
Gene silencing induced by sprayed dsRNA

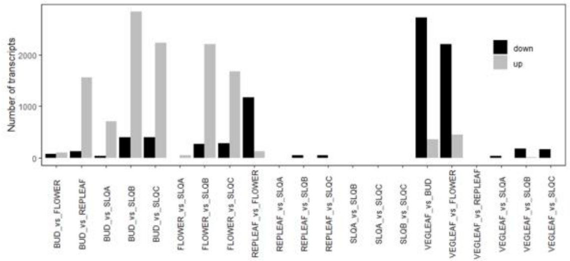




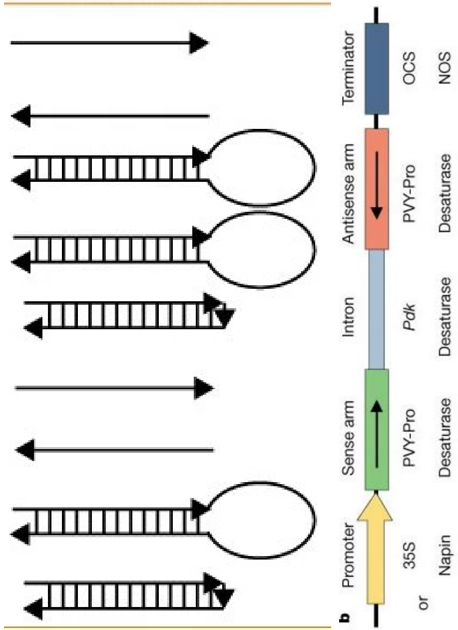
UNPUBLISHED RESULTS

Current research at CSIRO - Wild radish RNAi





Annotated transcriptome

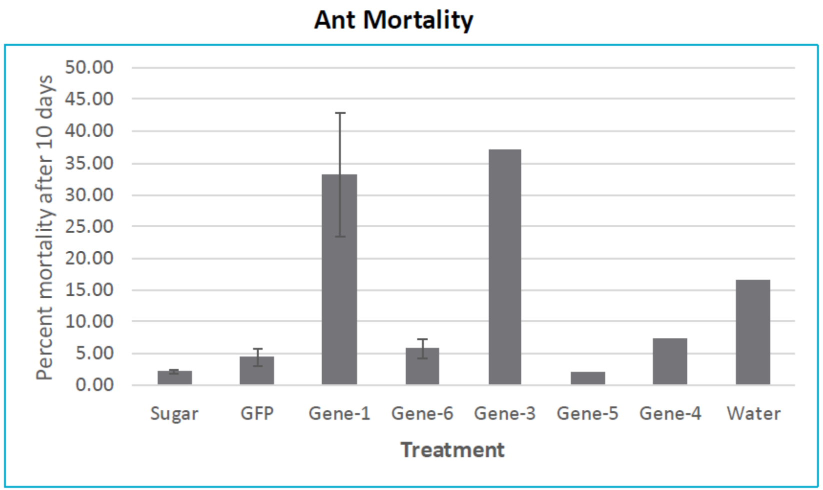


dsRNA constructs

Kumaran Nagalingam & Amol Ghodke CSIRO

UNPUBLISHED RESULTS

Double Stranded RNAi trials in Red Imported Fire Ants – targeting conserved genes in a range of invasive ants



Kumaran Nagalingam & Amol Ghodke CSIRO

2 x Gene-tech weed management interventions

- **RNAinterference** - Switching-off genes mediating growth and reproduction

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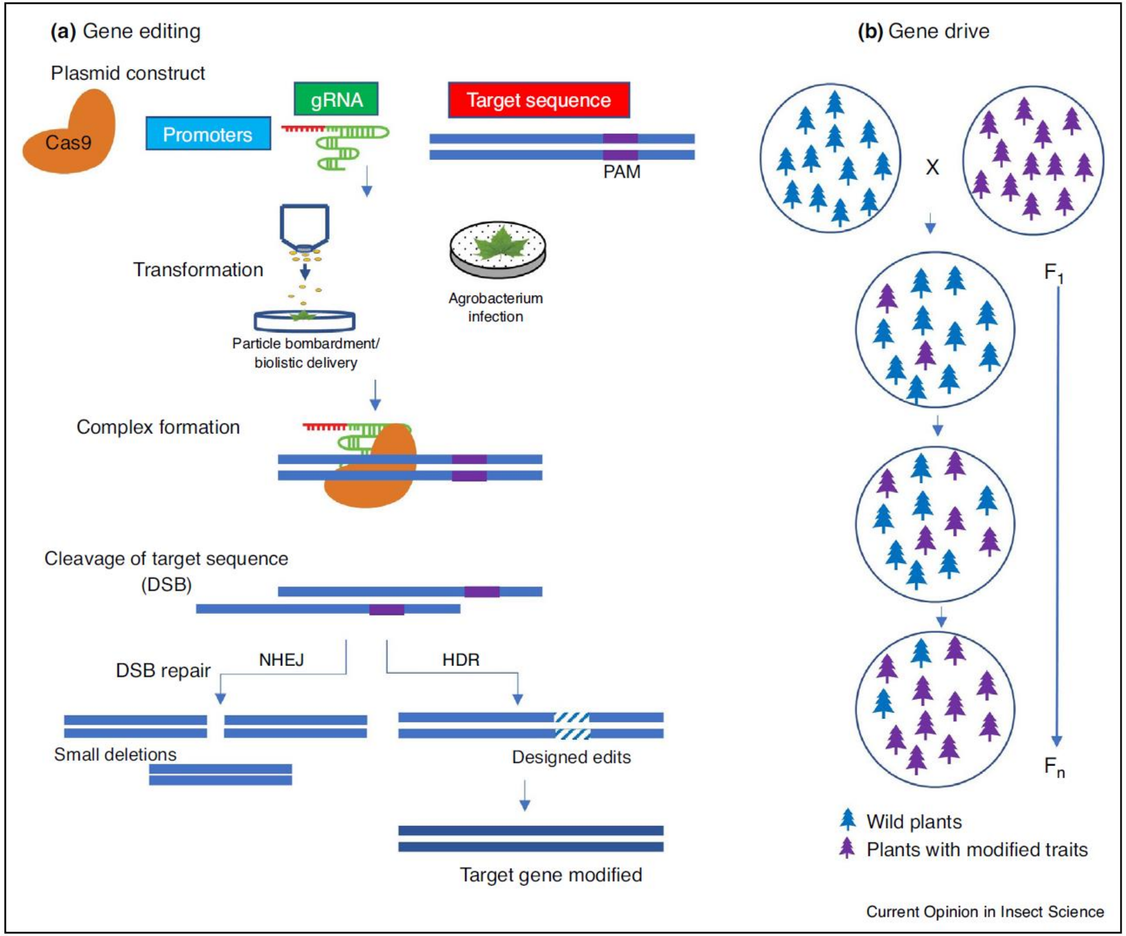
  - Spread modified traits to engineer/edit wild populations with reduced fitness

Gene Technologies – GM workflow



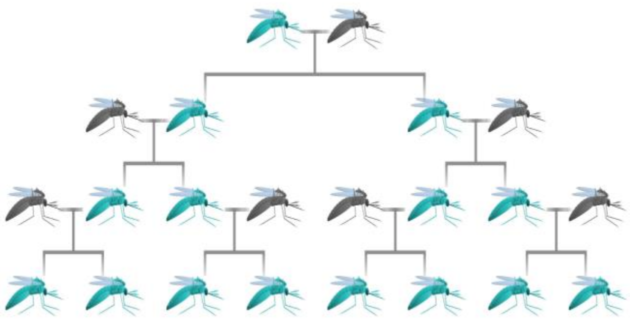
Genetic modification/editing approaches

Genomic editing or modifying Invasive Alien Species to spread deleterious genes that alter sex ratios and otherwise suppress populations

Burt (2003). *Proc R Soc B Biol Sci, 270: 921-28*
Barrett *et al.* (2019). *Proc R Soc B Biol Sci, 38:6-14*
Kumaran *et al.* (2020). *Curr Opin Insect Sci, 38:6–14*
Webber et al. (2015). *PNAS, 112: 10565-67*

CSIRO

1st successful target malaria mosquito



LETTERS

TARGET MALARIA

nature biotechnology

A CRISPR-Cas9 gene drive system targeting female reproduction in the malaria mosquito vector *Anopheles gambiae*

Andrew Hammond[1], Roberto Galizi[1], Kyros Kyrou[1], Alekos Simoni[1], Carla Siniscalchi[2], Dimitris Katsanos[1], Matthew Gribble[1], Dean Baker[3], Eric Marois[4], Steven Russell[3], Austin Burt[1], Nikolai Windbichler[1], Andrea Crisanti[1] & Tony Nolan[1]

Gene drive systems that enable super-Mendelian

homozygote in a process known as 'homing'. Through this mechanism,

PNAS

Highly efficient Cas9-mediated gene drive for population modification of the malaria vector mosquito *Anopheles stephensi*

Valentino M. Gantz[a,1], Nijole Jasinskiene[b,1], Olga Tatarenkova[b], Aniko Fazekas[b], Vanessa M. Macias[b], Ethan Bier[a,2], and Anthony A. James[b,c,2]

[a]Section of Cell and Developmental Biology, University of California, San Diego, La Jolla, CA 92093-0349; [b]Department of Molecular Biology and Biochemistry, University of California, Irvine, CA 92697-3900; and [c]Department of Microbiology and Molecular Genetics, School of Medicine, University of California, Irvine, CA 92697-4500

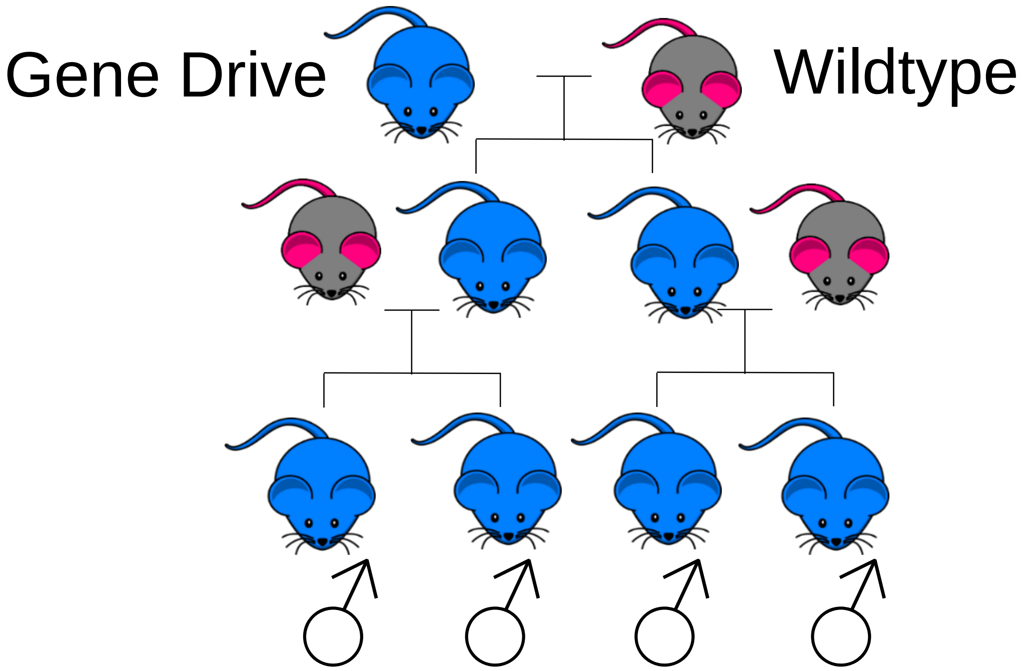
Contributed by Anthony A. James, October 26, 2015 (sent for review October 11, 2015; reviewed by Malcolm Fraser and Marcelo Jacobs-Lorena)

Genetic engineering technologies can be used both to create transgenic mosquitoes carrying antipathogen effector genes targeting human malaria parasites and to generate gene-drive systems capable of introgressing the genes throughout wild vector populations. We developed a highly effective autonomous Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)-associated protein 9 (Cas9)-mediated gene-drive system in the Asian malaria vector *Anopheles stephensi*, adapted from the mutagenic chain re-

directed to new sites while providing confidence that treated areas will remain malaria-free (5, 7).

We and others are pursuing a population-modification approach that involves the introduction of genes that confer a parasite-resistance phenotype to mosquitoes that otherwise would be fully capable of transmitting the pathogens (8–13). The expectation is that the introgression of such an effector gene at a high enough frequency in a vector population would decrease or

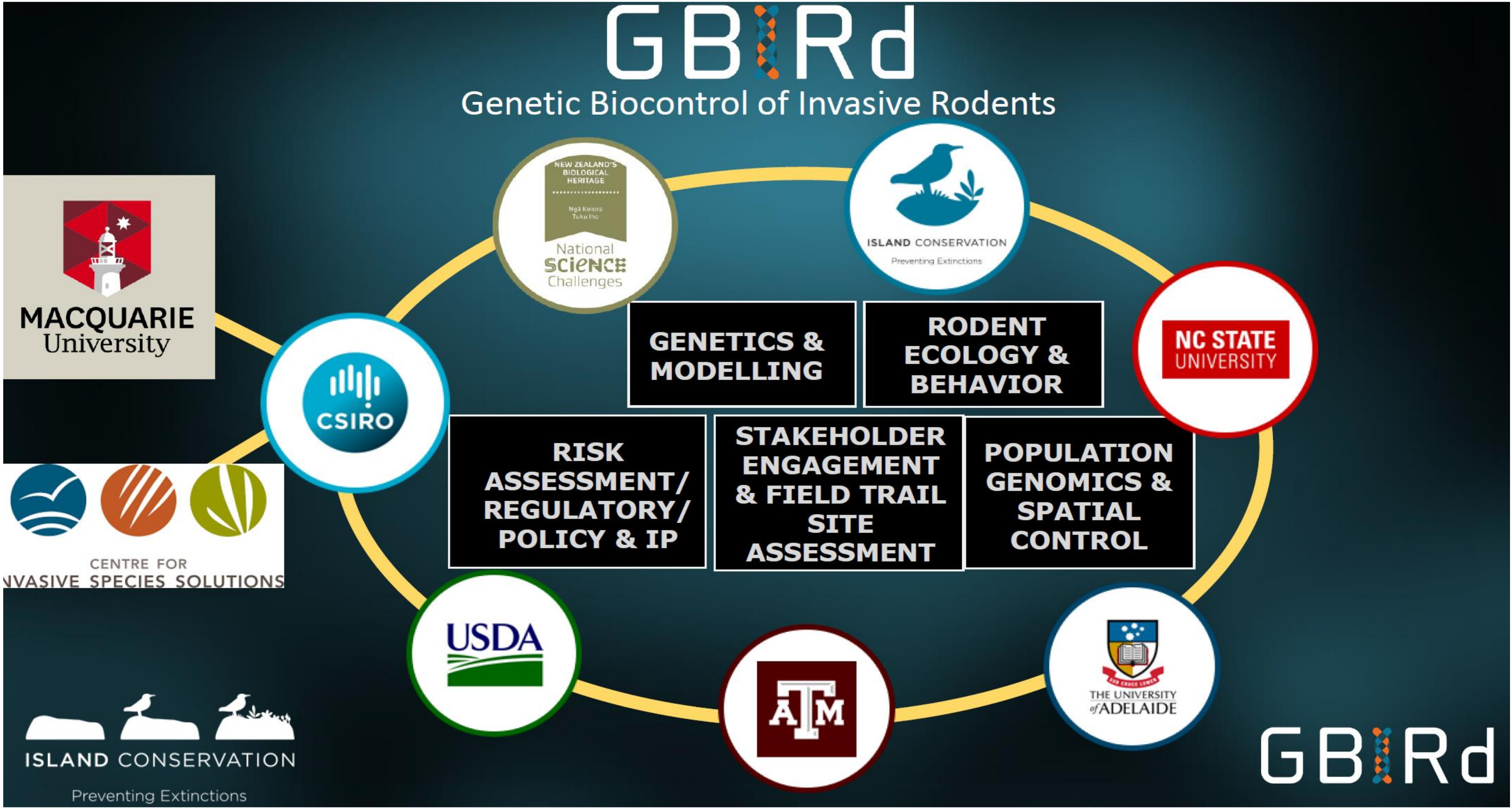
Meiotic Gene-drive



Natural selfish gene
T-Sry

← Genetic Approaches →

CRISPR/Cas9 GMO



GBIRd
Genetic Biocontrol of Invasive Rodents
NEW ZEALAND'S BIOLOGICAL HERITAGE
Ngā Koiora Tuku Iho
National Science Challenges
ISLAND CONSERVATION
Preventing Extinctions
MACQUARIE University
CSIRO
NC STATE UNIVERSITY
GENETICS & MODELLING
RODENT ECOLOGY & BEHAVIOR
RISK ASSESSMENT/ REGULATORY/ POLICY & IP
STAKEHOLDER ENGAGEMENT & FIELD TRAIL SITE ASSESSMENT
POPULATION GENOMICS & SPATIAL CONTROL
CENTRE FOR
NVASIVE SPECIES SOLUTIONS
USDA
ATM
THE UNIVERSITY of ADELAIDE
ISLAND CONSERVATION
Preventing Extinctions
GBIRd

2nd target mice

Paul Thomas

THE UNIVERSITY of ADELAIDE

NATURE July 2018

NEWS IN FOCUS

GENE EDITING

Gene drives tested in mammals for first time

Technology worked inconsistently in mice.

BY EWEN CALLAWAY

A controversial technology that can alter the genomes of entire species has been applied to mammals for the first time. In a preprint published on 4 July, researchers and researchers have suggested that the technology could help to kill off rodent pests. The technique has attracted controversy — and even a failed attempt to ban its global use — because, if released in the wild, organisms carrying gene drives might be hard to contain.

Science

1K

28

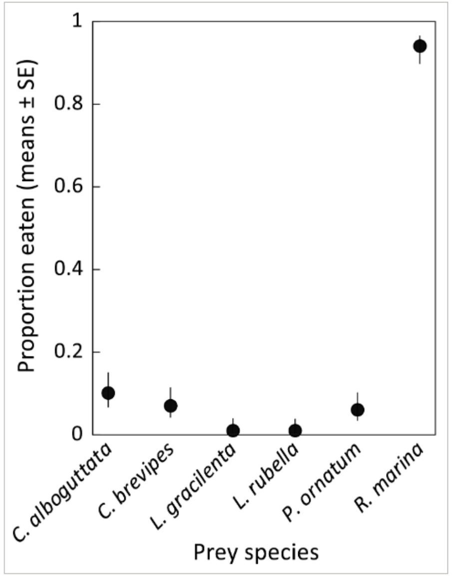
The genome editor CRISPR can be used to engineer female lab mice that have increased odds of passing down a specific gene to offspring. ISTOCK.COM/GORKEMDEMIR

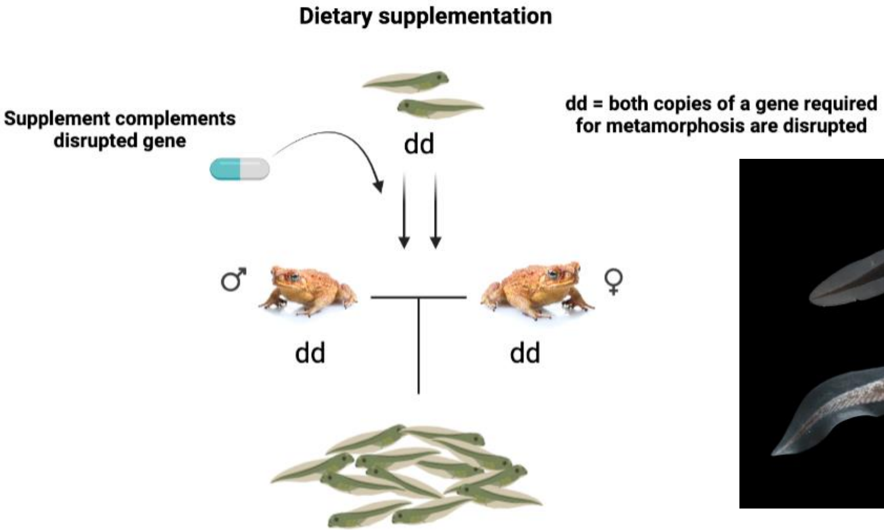
'Gene drive' passes first test in mammals, speeding up inheritance in mice

By Jon Cohen | Jul. 10, 2018 , 1:50 PM

Researchers have used CRISPR, the genome editing tool, to speed the inheritance of specific genes in mammals for the first time. Demonstrated in lab-reared insects several years ago, this controversial "gene-drive" strategy promises the ability to quickly spread a gene throughout an entire species. It has sparked dreams of deploying lethal genes to eradicate pests such as malaria-carrying mosquitoes—and now, perhaps, crop-damaging, disease-causing mammals such as rabbits, mice, and rats.

Gene-drive alternatives 1 - Cannibalistic Cane Toad metamorphosis-disrupted tadpoles





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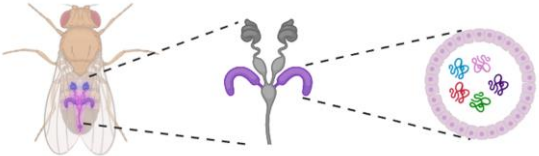
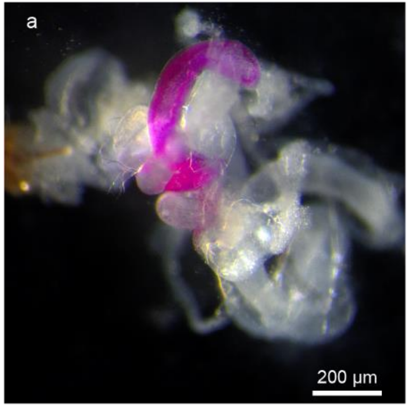
NSW 2109, Australia

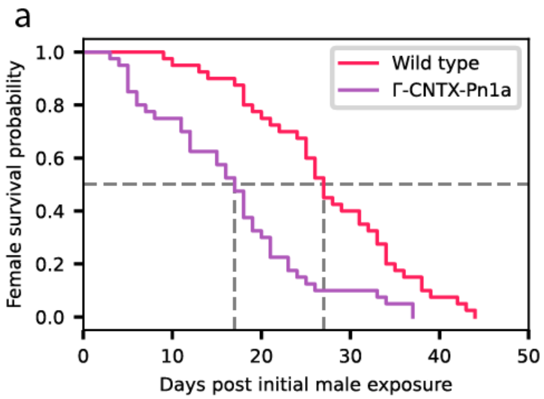
.. dependent only on CRISPR knockouts, so classified as SDN-1, so **not** considered GMO in Australia

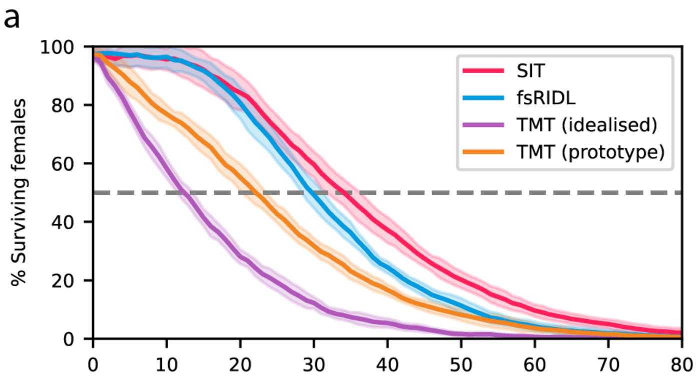
Gene-drive alternatives 2 – "*Sterile Insect Technique*" - Toxic Male constructs

OR









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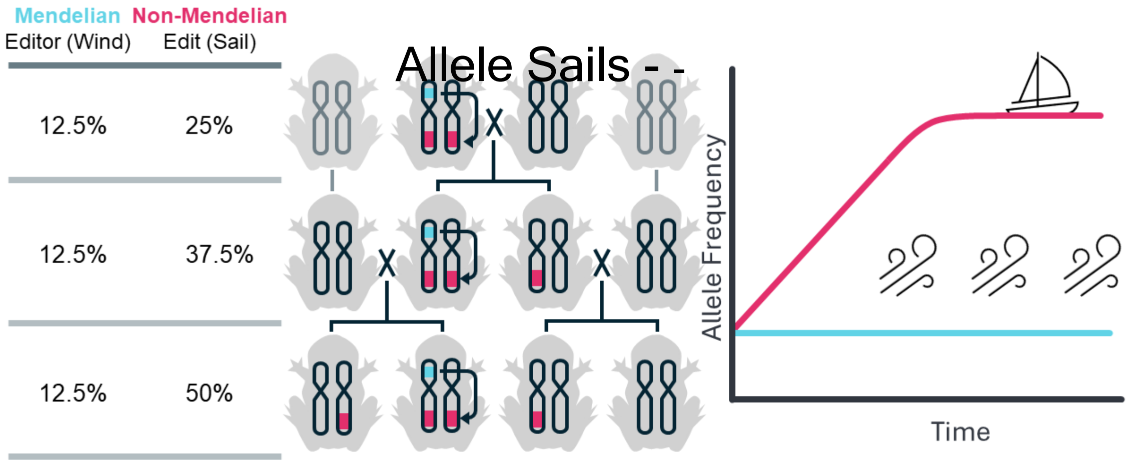
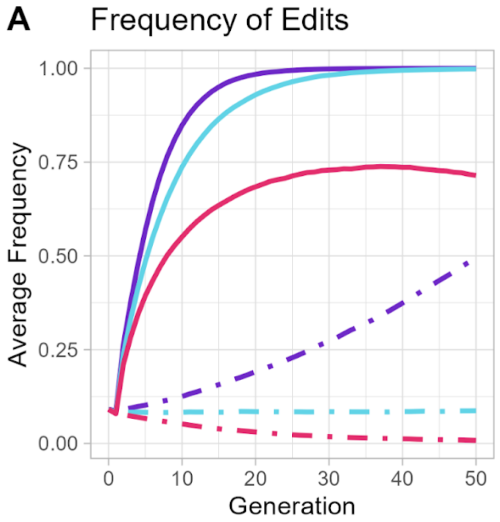
NSW 2109, Australia

Gene drive alternative 3 - Allele Sails

Animal with transgenic genome editor (e.g. Cas9) creating homozygous viable and fertile mutations. The frequency of the mutation increases to fixation while the transgene construct population frequency is constant





Gene-drive alternatives –

Sex Reversal Sail

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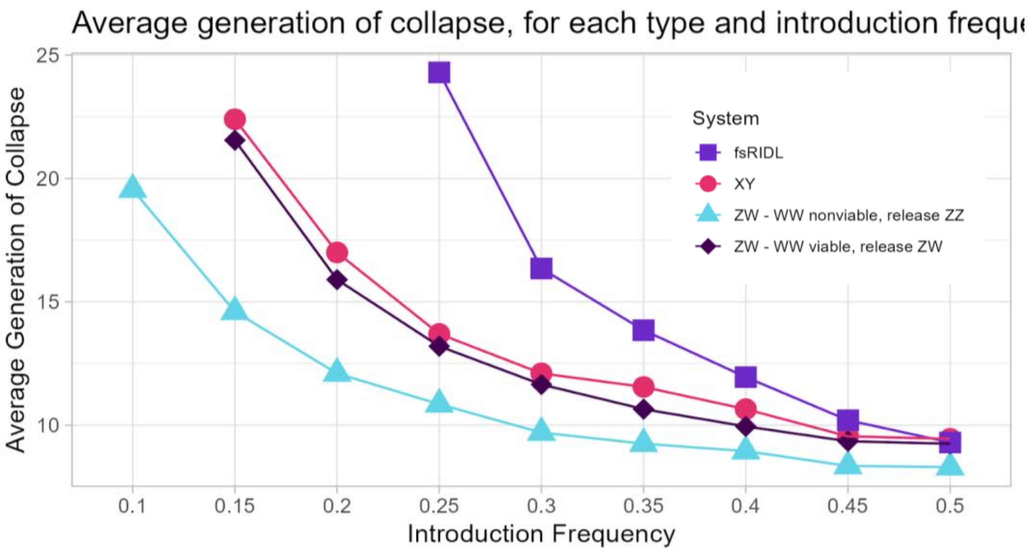
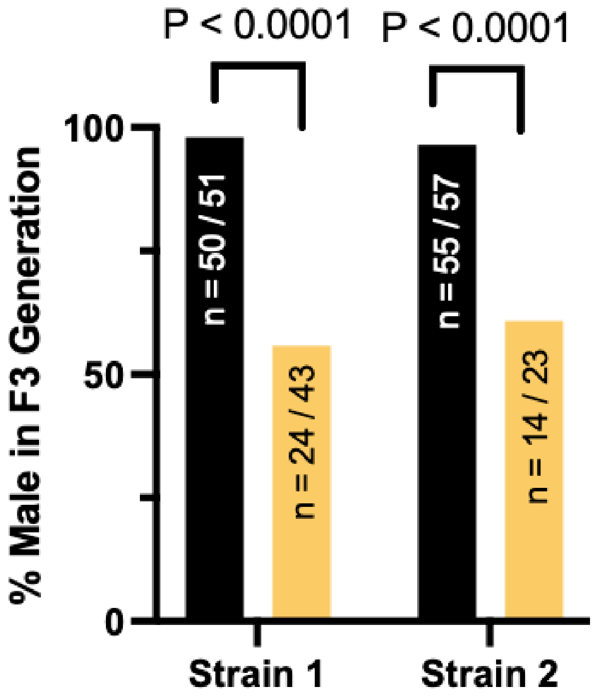




Depending on the introduction density of the transgenic animals

Summary

Technology has IAS management potential we can't ignore.

Scientist's role is to understand the possibilities - Society will decide if they want to use it!

The way to get there is "Responsible Innovation"

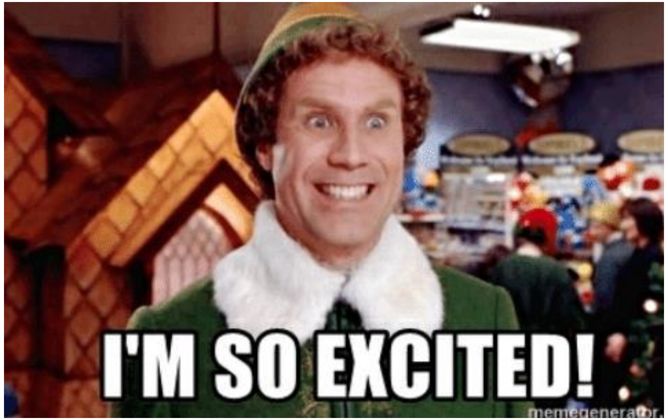
Thank you

Science

Risk assessment

Social License, Liaison

Frameworks, underpinning science



Everything an ideal control tool should be:

- Humane
- Species specific
- Self-disseminating
- NOT CONTAGIOUS (spreads by sexual reproduction)
- Not repeated release of many animals
- Hope ?

Should be banned

- Uncontrollable
- Irresponsible
- GM
- Won't work anyway
- Regulatory nightmare
- International implications
- Ecological and trade risk?
- Humans playing god

BIOETHICS

Science

Principles for gene drive research

Sponsors and supporters of gene drive research respond to a National Academies report

By **Claudia Emerson,[1] Stephanie James,[2] Katherine Littler,[3] Filippo (Fil) Randazzo[4]**

The recent outbreak of Zika virus in the Americas renewed attention on the importance of vector-control strategies to fight the many vector-borne diseases that continue to inflict suffering around the world. In 2015, there were ~212 million infections and a death every minute from malaria alone (*1*). Gene drive technology is being explored as a potentially durable and cost-effective strategy for controlling the transmission of deadly and debilitating vector-borne diseases that affect millions of people worldwide, such as Zika virus and malaria. Additionally, its suitability is being evaluated for various potential applications in conservation biology, including a highly specific and humane method for eliminating invasive species from sensitive ecosystems (*2*, *3*).

The use of gene drives is an emerging technology that promotes the preferential inheritance of a gene of interest, thereby increasing its prevalence in a population. A gene drive is dis-

for the NIH requested that the U.S. National Academies of Sciences, Engineering, and Medicine (NASEM) conduct a study that would "summarize current understanding of the scientific discoveries related to gene drives and their accompanying ethical, legal, and social implications," which was published in 2016 [(*2*), p. vii)]. The authors noted that the promise of gene drives is tempered by uncertainties regarding potential for harm from unintended consequences or misuse of the technology. The potential persistence of genetic change in the target population caused by a gene drive is both the source of optimism for a durable and affordable tool to combat a variety of

RESPONDING TO THE NASEM REPORT

Sponsors of scientific research have a responsibility to support innovation that promotes and sustains the public good (*11*). They share the common goal of advancing knowledge and human well-being, while protecting and promoting societal values that underpin the responsible conduct of science. The 2010 report from The Presidential Commission for the Study of Bioethical Issues, "New Directions: The Ethics of Synthetic Biology and Emerging Technologies," highlights the important point that the responsibility for ensuring the conduct of quality science is not the exclusive domain of scientists, but is a shared responsibility among research sponsors and policy-makers alike (*11*). In this Policy Forum, we use the term "science" in its broadest sense, referring inclusively to the life and physical sciences as well as social science, and the humanities, i.e. ethics. Moreover, researchers, sponsors, and policy-makers also share the responsibility of monitoring the progress of science and communicating it effectively to the public

Guiding principles for the sponsors and supporters of gene drive research

Advance quality science to promote the public good

The purs… note, the public gc… quality science and ethic… et by the research community and relevant decision-making bodies [(*2*), p. 106)].

Public good/Societal value

Promote stewardship, safety, and good governance

Researchers and sponsors are stewards of science and the public trust. It is imperative that gc… especi… liance with ap… standa… ystem in whic… erm effects through appropriate ecological risk assessment, is a hallmark of both good stewardship and good governance [(*2*), pp. 128; 170–172)].

Good governance to maintain public trust

Demonstrate transparency and accountability

Knowledge sharing is not only essential for the advancement of science, but for transp… of result… ent with the tra… …omic science. Measures of transparency and accountability that contribute to building public trust and a cohesive community of practice will be supported [(*2*), pp. 171; 177–178)].

Transparency & accountability

Engag…

Mean… for ensur… in the re… ust, inclus… s of those most affected are taken into account [(*2*), pp. 142–143)].

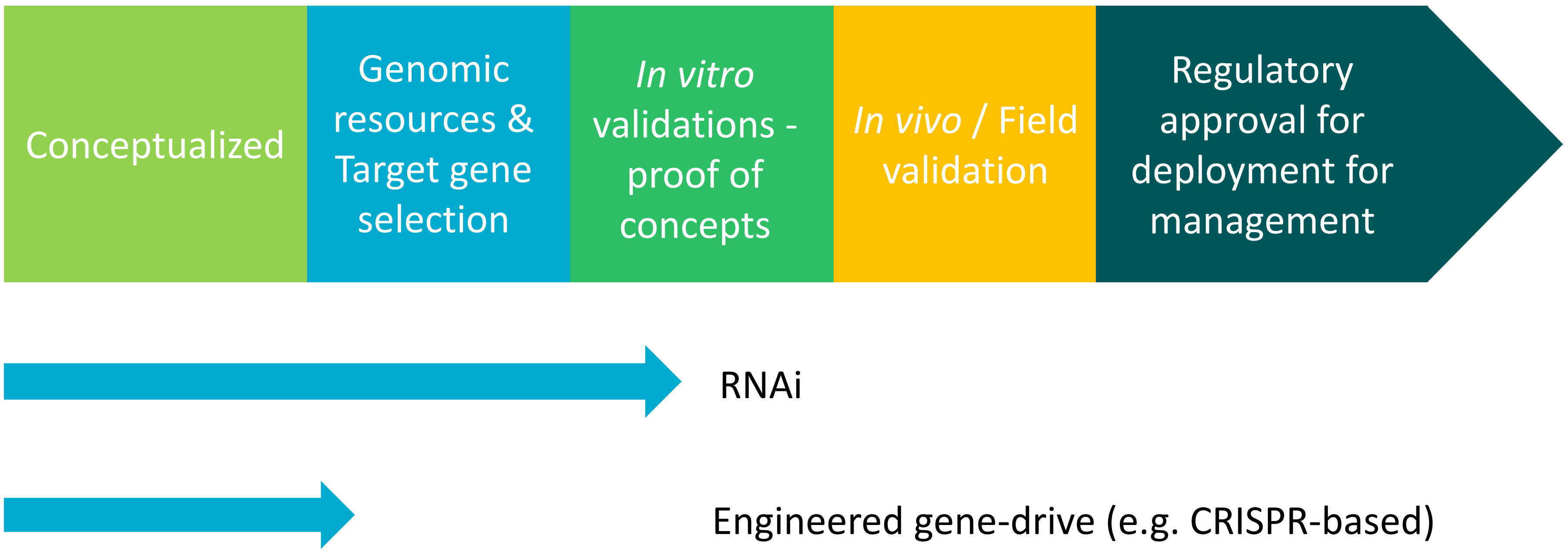
Stakeholder communities engagement

Foster opportunities to strengthen capacity and education

Streng… for enabli… to partne… rch, from t… for testing… [(*2*), pp. 128; 170–172)].

Foster global best practice through education

Pathway to deployment



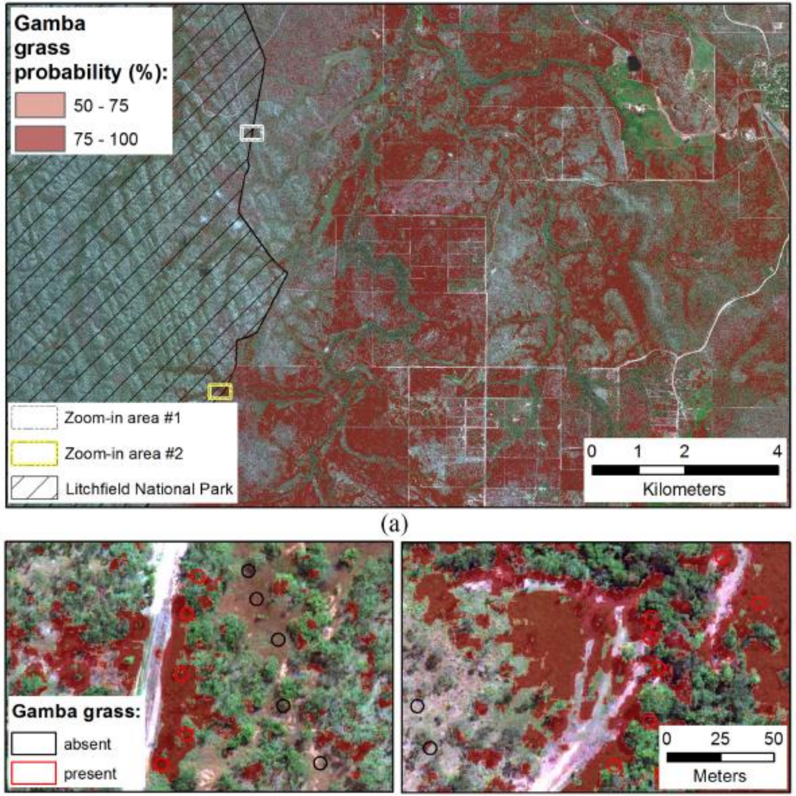
Comparison of hyperspectral imaging platforms

	Satellites	Airplanes	Helicopters	Fixed-Wing UAVs	Multi-Rotor UAVs	Close-Range Platforms
Example Photos	 (Photo: Swales Aerospace)					 (Photo: ASPRS)
Operational Altitudes	400–700 km	1–20 km	100 m–2 km	<150 m		<10 m
Spatial Resolution	20–60 m	1–20 m	0.1–1 m	0.01–0.5 m		0.0001–0.01 m
Applicable Scales	Regional—global	Landscape—regional		Canopy—landscape		Leaf—canopy
Major Limiting Factors	Weather (e.g., rain and clouds)	Unfavorable flight height/speed, unstable illumination conditions		Short battery endurance (e.g., 10–30 min), flight regulations		Platform design and operation

Lu, Bing, et al. "Recent advances of hyperspectral imaging technology and applications in agriculture." *Remote Sensing* 12.16 (2020): 2659.

Satellite imagery - Gamba grass mapping

Shendryk Y., et al.., 2020. Leveraging high-resolution satellite imagery and gradient boosting for invasive weed mapping. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, ***13***, **pp.4443-4450**

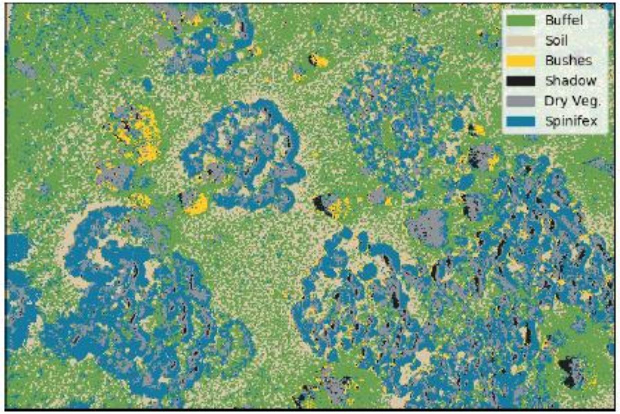


(a)
(b) (c)

- WorldView-3 satellite imagery and tuned the hyperparameter classifier
- Tested the utility of predictors from
  - spectral bands;
  - textural features;
  - spectral indices;
  - combined predictors
- 91 % accuracy

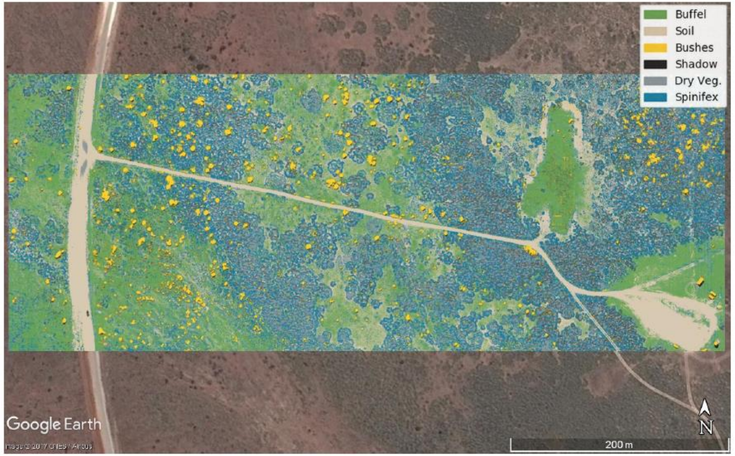
Low orbital satellites coming with 5G

High-resolution red, green, blue (RGB) & Machine learning



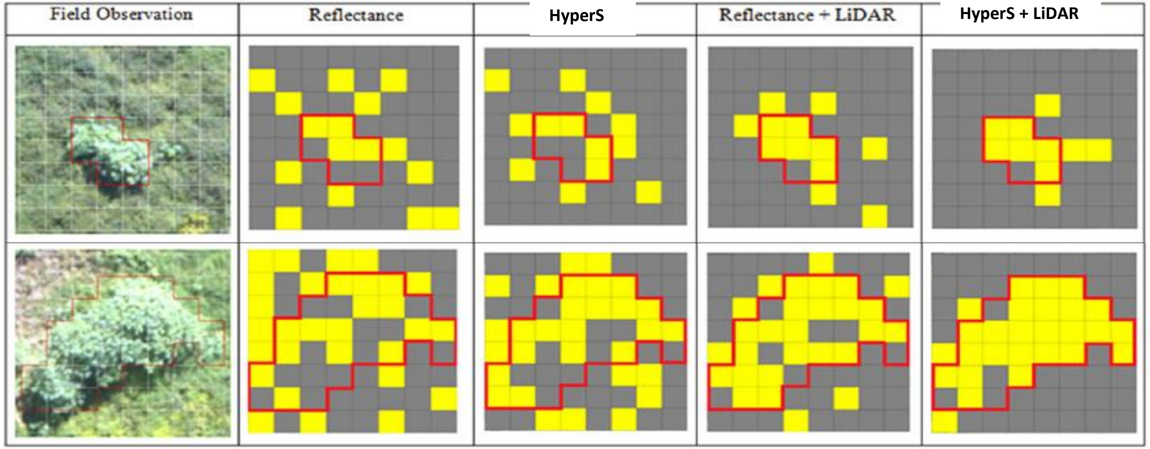
Buffel grass Cape Range National Park, WA

- Individual detection rate of 97%
- Reliable despite light levels, object rotation, occlusion, background cluttering, and floral density variation
- segmented images can be loaded and displayed in any GIS software e.g. Google Earth
- *Single Shot* - startup for EvokeAg



Sandino, Juan, et al. "UAVs and machine learning revolutionising invasive grass and vegetation surveys in remote arid lands." *Sensors* 18.2 (2018): 605.

Hyperspectral + LiDAR for bugweed detection in South Africa



- LiDAR - *Light Detection And Ranging*
- Comparing hyperspectral with LiDAR for detection rate (DR) and false +ve rate (F/+)
- Hyperspectral alone – DR 79% & F/+ 68%
- Hyperspectral + LiDAR – DR 88% & F/+ 7%

Peerbhay, Kabir, et al. "Improving the unsupervised mapping of riparian bugweed in commercial forest plantations using hyperspectral data and LiDAR." *Geocarto International* 36.4 (2021): 465-480.