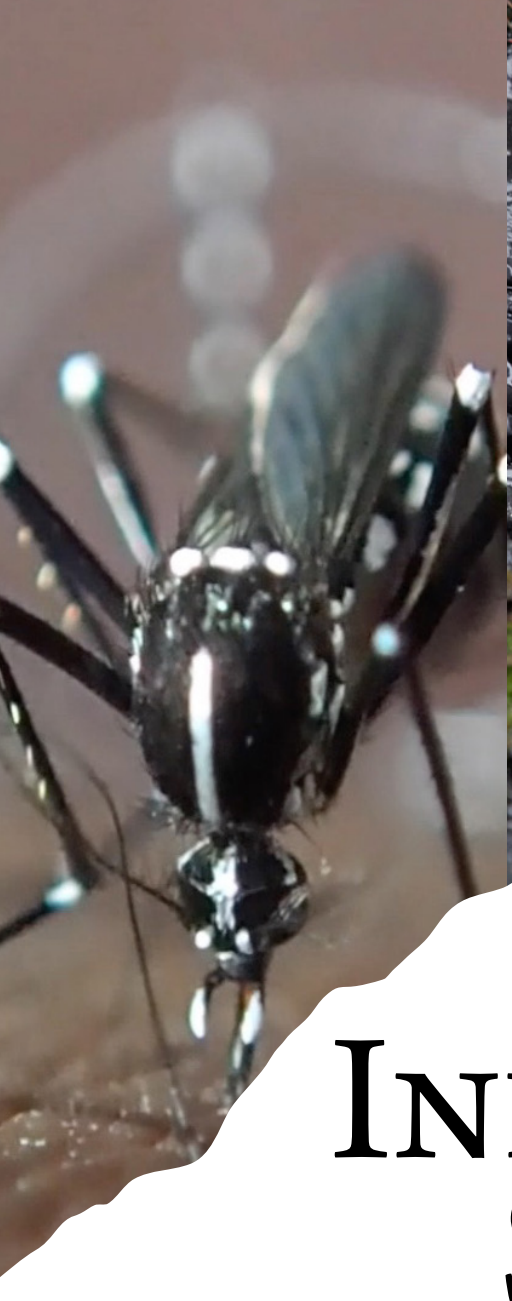

The Innovation Summit

VISION+SCIENCE+TECHNOLOGY=SOLUTIONS

Overcoming the Invasive Species Challenge

REPORT ANNEX · 2016

COVER PHOTO CREDITS
Tiger mosquito (left): Robert Boyd
Sagebrush landscape: Jamie K. Reaser
Brown rat: Steve Ebbert, USFWS

This report fulfills contract obligation #D16PX00293 to the National Invasive Species Council (NISC) Secretariat. April 2017.

The Annex complements a brief report available at: https://on.doi.gov/2pmGXCp

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The Innovation Summit

VISION+SCIENCE+TECHNOLOGY=SOLUTIONS

Overcoming the Invasive Species Challenge

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National Museum of the American Indian
4th Street & Independence Av. sw, Washington DC

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ANNEX II: PROGRAM SUMMARY

The following sections provide a brief synopsis of the major points made by the speakers and panelists during the Summit. The presentations are available at hstebstettps://www.doi.gov/invasivespecies/innovation-summit-2016-presentations.

INTRODUCTORY REMARKS

Scott Miller, Smithsonian Institution

Invasive species are one of the most significant drivers of species extinction and endangerment. They have substantial impacts on ecosystems, public health, the economy, infrastructure, and cultural values. Existing control and eradication efforts rely on a long-established toolbox of practices, but the increasing pressure of invasive species and their impacts demand that we revisit the list of possible approaches. New technologies need to be developed to increase the scale of their application, while being cost-effective and time efficient. This will require better incentives for technological innovation and building support within broader social and regulatory frameworks.

Over 300 participants from all over the world have registered for the Summit and represent a range of federal, state, local and tribal governmental agencies, non-governmental organizations, the private sector, academia, and other stakeholders. The Summit is sponsored by the National Invasive Species Council Secretariat in collaboration with the Smithsonian Institution, Laura and John Arnold Foundation, Island Conservation, Conservation X Labs, and the Aquatic Nuisance Species Task Force. The Summit has been organized to celebrate and inspire new technologies for addressing invasive species, and to start creating a culture of innovation, openness, and boldness within the invasive species management community.

MAKING THE CASE FOR INNOVATION

Jamie K. Reaser, National Invasive Species Council Secretariat

Invasive species are among the most significant yet least addressed challenges of our time. There is a limiting belief that the problems associated with invasive species are too big, too costly, too diffi-

cult. This "mythology of impossibility" undermines the inspiration, capacity, and will to innovate. It undermines our capacity to address the challenge. The consequences of not addressing invasive species challenges are significant, including endangerment to human health, species extinctions, damage to ecosystem services, destruction of agricultural crops, loss of cultural resources, spread of infectious diseases, and destabilization of infrastructure. This has been and will be further exacerbated by globalization, the shifting bio-geographies of flora and fauna due to global change, and land degredation, which makes environments less able to withstand the adverse impacts of biological invasions.

We can change limiting beliefs by looking at a problem from different perspectives. Being open to new possibilities can lead to the identification and exploration of new options or tools, and ultimately a new perspective on what is possible. Innovation provides an opportunity to move from a limiting perspective to the recognition that there are alternative possibilities, to a test of those possibilities, to the accceptance and application of the new possibilities. Innovation allows us to take a problem and to move from "can't" to "can."

A notable example of such vision is the New Zealand government's recent announcement to eliminate invasive predators that impact ecosystems, agriculture and other natural resources by 2050. It's a daring proposition, as the techniques to do this are not currently in hand. It requires trust that the practical will follow the bold. It establishes the enabling belief that a grand challenge can be overcome. The Innovation Summit is intended to create a similar culture of vision and creative solutions within the invasive species community by looking at new possibilities in technology, program management, and communication.

Together, we can do this…

Session 1
Grand Challenges and Technological Innovation

Presenters: Will Pitt, Smithsonian Conservation Biology Institute (moderator); Steve Gittings, National Oceanic and Atmospheric Administration (NOAA); Gintas Zavadzkas, Miccosukee Tribe; Earl Campbell, U.S. Fish and Wildlife Service (USFWS); David Lodge, Atkinson Center for a Sustainable Future, Cornell University; Greg Ruiz, Smithsonian Environmental Research Center

The Summit began with an overview of invasive species challenges for the technology innovation community to address. Speakers conveyed the existing constraints to solving such challenges from both technological and social perspectives. The diversity of the challenges presented by the speakers reinforced the complexity of the issue as well as the need for creating a large, adaptable innovation culture.

SPECIES CHALLENGES: LIONFISH

Steve Gittings, NOAA

The lionfish invasion across the wider Caribbean is among the greatest threats to the region's native ecosystems. Lionfish (*Pterois volitans & P. miles*) are native to the Indo-Pacific Ocean and Red Sea, and were introduced to the Western Atlantic over 30 years ago. Lionfish are highly productive, laying up to 50,000 eggs every three days. The fish has spread and established populations from the mid-Atlantic coast of the U.S., through the Caribbean and Gulf of Mexico, to the coast of South

MEASURE	EXAMPLES
Market options	• Blue Ventures is providing skills training for making lionfish fins, spines, and other body parts into jewelry • Commercial ventures include Edible Invaders' Lionfish Dip and grocery stores are beginning to stock lionfish (e.g., Whole Foods, Publix, and Wegman's) • Without appropriate planning, market options could create a perverse incentive to maintain or even enhance the population stock of the species
Recreational or bounty hunting	• Non-governmental organizations (NGOs) and state governments are providing training on how to capture and handle lionfish • Lionfish are relatively easy to kill • Special stuff sacks have been developed for collecting hunted fish
Traps and kill devices	• Lionfish live at waters beyond the depth of most divers, but are caught as bycatch in lobster traps • Modifications of existing traps are being tested that include passages or detection systems that allow lionfish, but not other fish, to enter • Remotely operated vehicles (ROVs) are being tested to shoot lionfish; others could be modified to inject them with poison • Additional control technologies under development include suction devices that macerate the fish and equipment mounted with electric panels designed to electrify lionfish
Environmental DNA (eDNA)	• Use of eDNA detection techniques could help determine the presence of lionfish and estimate the size of lionfish populations

Figure 1. Examples of control methods for lionfish

America. Lionfish are voracious predators that can consume anything that fits in their mouths, including juveniles of commercially-important fish. As a result, they have reduced native populations by up to 65% in the most extreme cases.

Near-term control options for lionfish have largely focused on culling and harvesting by divers, but dense, inaccessible populations exist hundreds of feet below scuba depths.

Research shows that managing lionfish abundance, specifically keeping them below 25% of their potential population density, can slow and minimize the impact on local ecosystems. Many technologies are being tested for capturing or killing lionfish, including mechanical and electronically operated traps, and a variety of lethal devices carried by divers, remotely operated underwater vehicles (ROVs), and autonomous underwater vehicles (AUVs). Remote spearing, vacuums, electrocution, poison injection, and laser cutting have all been either proposed or attempted.

NOAA and two non-profit organizations have supported research on a modified trap that uses a fish-attraction device, allows for deep water control of lionfish, minimizes bycatch, and is easy to transport, deploy, and retrieve. In initial tests, the trap caught over 75% of the lionfish it attracted

during an 18-day "soak time." NOAA is working on the next generation of the device, which will improve the trap, and also continue to test other attraction methods, such as sound, light, and pheromones. Additional methods and approaches to the lionfish invasion are summarized in Figure 1.

SPECIES CHALLENGES: BURMESE PYTHONS

Gintas Zavadzkas, Miccosukee Tribe

Tribes are important land managers in the U.S., second only to the Federal Government in terms of the amount of land managed, and can play a vital role in combatting invasive species. The Miccosukee Tribe is located in central Florida and has been affected by the invasion of Burmese pythons (*Python bivittatus*). Burmese pythons are a threat to the endangered Florida panther (*Puma concolor coryi*) and eat small mammals, such as marsh rabbits and raccoons, who are seed dispersers of the tribe's medicinal plants. Large female pythons can lay between 50 to 100 eggs in a single clutch each year, and 80–90% of the eggs successfully hatch. Researchers estimate that anywhere between 20,000 and 150,000 Burmese pythons are freely roaming in the Everglades.

As with lionfish, eradication in the near term is not feasible due to a lack of highly effective tools. Most efforts are focused on population control. Their camouflage makes the snakes hard to detect in the Florida Everglades habitat via human or machine vision as well as aerial photography taken by

MEASURE	EXAMPLES
Genetic engineering and editing	• Genetic analysis has determined that there are only 2 distinct populations • Genetics techniques may be one of the only viable options for large-scale control, but these options are not currently being investigated • Genetic sterilization of pythons sold in the pet industry may also be a means of reducing potential future risks
Recreational or bounty hunting	• Python challenges are a highly visible means of control, but are likely to have little overall effect on overall populations – http://pythonchallenge.org • Bounties aren't practical given the sizable population of snakes • Dogs can be used for detection, but they are costly
Biologging and traps	• Biologging through the use of tracking devices can provide baseline data on movements and refine detection and removal techniques • "Judas snakes" that are tagged have had some effectiveness in locating snakes during mating events • Pheromone attractants and pattern recognition devices are being developed to enhance traps
eDNA	• Techniques using eDNA can help determining snakes' ranges, but there are limits to its efficacy

Figure 2. Examples of control methods for Burmese pythons

drones. Detector dogs have been explored but are expensive and not feasible in many remote areas of the Everglades. Biologging and the use of "Judas snakes" with imbedded GPS tags have improved detection and removal techniques. Pheromone attractants, pattern recognition traps, and eDNA are being explored in addition to other identification and control options. Genetic techniques may be one of the only options for large-scale control or eradication, but authorities are currently wary over the use of such technologies. Additional methods and approaches to the python invasion are summarized in Figure 2.

ECOSYSTEM CHALLENGES: HAWAIIAN FORESTS

Earl Campbell, USFWS

Certain ecosystems are highly unique and/or vulnerable to invasions from non-native species, especially islands. The Hawaiian Islands are home to at least 9,975 endemic species, of which 1,100 species have already gone extinct. More than 5,000 non-native species have been introduced to Hawaii, and 300 to 500 of these non-native species are considered invasive. Native species such as endemic land birds, honeycreepers, and the o'hia tree are under severe threat from invasive species. For example, there were originally more than 46 endemic species of land birds and honeycreepers, of which 17 species remain. These species are important not just for ecological systems and biological diversity, but they are also an important part of Hawaii's cultural history.

The situation in Hawaii has numerous invasive species threats, including ungulates (deer and feral hogs), brown tree snakes, avian malaria, and rapid o'hia death. Federal and state agencies, along with additional partners, have identified a number of lessons learned from their work on invasive species. To gain public support and remain effective, land managers must focus on champions and tangible examples of success that have a real impact on people's lives, the bio-cultural importance of invasive species management, and winnable targets and avoidance of "mission creep." Implementation and administration strategies need to address sustained resources for specific targets, dedicated coordination and planning, and partnership building.

ECOSYSTEM CHALLENGES: THE GREAT LAKES

David Lodge, Cornell University

Since the opening of the St. Lawrence Seaway, which enabled increased transport and travel, the Great Lakes have experienced an increase in biological invasion. In the last 50 years, more than 150 invasions have occured, including the establishment of dreissenid mussels (zebra and quagga mussels), which clog ship propellers, cause problems for hydropower production, eliminate plankton (the base of the food chain), concentrate pollutants in the food chain, and wash up as sharp sea shells on beaches. Zebra mussels have spread through the U.S. river systems quickly and will, in the absense of management, soon reach the Columbia River. Likewise, the Asian carp (silver carp; *Hypophthalmichthys molitrix*) was intentionally introduced to eat algae but rapidly spread.

Recent innovations are reducing invasions from ships and commerce in living organisms, while simultaneously increasing net economic benefits. New DNA-based technologies provide improved early detection tools, which, if combined with large-scale eradication and control technologies, open the door to a reinforcing cycle of innovation, business opportunity, and environmental protection. These solutions can be facilitated and advanced by public policy that increases the overall net economic benefit of trade. Targeted research and development programs can be extremely useful and good investments (Figure 4).

APPROACH	DESCRIPTION AND COMMENTS
Ungulate management	• Ungulates (deer, pigs), originally introduced for sport in Hawaii, now cause significant ecological damage, including digging troughs where mosquitoes can breed • Control techniques include fencing, hunting, use of Unmanned Aerial Vehicles (UAVs), and flares • 435,000 acres are currently under ungulate management with very results • Public perception and engagement is critical as pigs are culturally important in Hawaii despite their invasiveness
Brown tree snake interdiction program	• The brown tree snake caused the loss of an entire avifauna in Guam • A large-scale interdiction program works to keep the brown tree snake from getting off Guam and into Hawaii and other U.S. territories in the Pacific • Control techniques include traps, visual searching, and dogs to detect the snakes • U.S. Department of Agriculture (USDA) researchers have been developing and deploying an automated aerial bait delivery service with a snake toxicant
Avian malaria	• Native birds of Hawaii have no resistance to avian malaria that arrived in 1826, and as a result a number of species of forest birds have gone extinct and remaining populations are under pressure • Changes in precipitation and temperature will expand the area susceptible avian malaria • Current vector control strategies include investigation of sterile insect techniques (irradiation, Wolbachia) and population replacement (gene drives) • Deployment of such technologies will require balancing community support, the technique's efficacy, and the regulatory approvals and agency authorities
Rapid O'hia Death	• Rapid O'hia Death (ROD) is a chytrid fungus that is spreading rapidly on Hawaii Island with 10% of the o'hia forest already infected • The o'hia tree has an important cultural value based in modern and ancient traditions and is found foundational species in a majority of Hawaii's forest systems • Insects bore into trees infected and weakened by ROD; dust from the boring includes the fungal pathogen and is spread by the wind to infect additional trees • The state recently convened an ROD summit to support a strategic response plan that also emphasizes the bio-cultural importance of the tree

Figure 3. Invasive species challenges in Hawaii and Guam

There are examples of success. Risk-based management is common, effective, and cost effective, and it's important to look at applications in pharmaceutical development, food safety, and infectious disease. The SARS virus is an example of an invasive pathogen that was successfully contained. In less than a year and with global coordination, the spread was stopped, the invasion rolled back, and the virus fully eradicated.

PATHWAY CHALLENGES: BALLAST WATER

Greg Ruiz, Smithsonian Environmental Research Center

The rate of new detections of aquatic invasive species has increased exponentially over time, with 42% of non-native species arriving in the last 20 to 30 years. Hull fouling and ballast water are the two primary pathways for new aquatic invasions. There are approximately 100,000 arrivals to U.S. ports annually (overseas and domestic); cumulative ballast water discharge is approximately 100 million metric tons and hull surface is approximately 336 km2. Ships are a critical vector at multiple

PREVENTION	• Species profiling, statistical modeling, and machine learning can be used in risk assessment processes to identify non-native species that present a higher risk
SURVEILLANCE	• eDNA can be used to create a baseline for species occurrences, monitor imperiled species, and provide surveillance for new and ongoing invasions • eDNA enables the collection of more information, over a greater geographic range, in less time and increasingly at less expense
ERADICATION	• Eradication is not just for islands; while work is ongoing to slow the spread of zebra mussels (e.g., through inspections, boat washing stations, ballast water treatment system) additional control mechanisms and strategies need to be developed

Figure 4. Tools in the toolbox

scales: initial introduction and colonization frequently happens via commercial ships and small boat traffic then causes secondary spread.

There has been a stepwise approach over time for reducing the propagule supply in ships' ballast. In 1990, voluntary guidelines were established for ballast water management. In 2004, ballast water exchanges were required in the open ocean. In the U.S., federal discharge standards are replacing ballast water exchanges with phased implementation on established dates. This stepwise approach has increased the efficacy of efforts to address the ballast water pathway.

There has also been a rapid increase in treatment technology for hull fouling over the last 10 years. Anti-fouling and foul-release coatings are two main approaches currently used for combating biofilm formation. Anti-fouling coatings prevent or deter the settling of biofouling organisms on a surface by the use of leached biocides, typically cuprous oxide or tributyltin, into the water. The

biocides are either tethered to the coated surface or are released from the surface into the surrounding environment. Foul release coatings present a hydrophobic, low surface energy that minimizes the adhesion of the biofouling organisms. Additional work is needed for processes to treat submerged niche areas of ships (e.g., rudders, sea chests.) where organisms can find shelter.

In sum, vector management for priority aquatic pathways of introduction has progressed rapidly over the last quarter century, but additional measures for smaller vessels are needed to stop coastal spread. This progress stems from a better understanding of the invasion process and its consequences. Additionally, interventions have improved based on a combination of technological fixes, social engagement, and motivated managers and researchers.

Session 2
Encouraging Technology Investment and Incentivizing Innovation

Panelists: Alex Dehgan, Conservation X Labs (moderator); Lydia McClure, National Science Foundation (NSF); Nagesh Rao, U.S. Small Business Administration (SBA); Wendy Taylor, U.S. Agency for International Development (USAID); Chris Nelson, White House Office of Science and Technology Policy (OSTP)

Large, challenging problems like invasive species require patience, time, and in-depth understanding. Federal agencies can play important roles to incentivize technological development, and there is a significant opportunity to learn and model innovative approaches from other federal agencies (e.g., prizes and challenges, mass collaboration, high-risk/high-reward research, citizen science, technology acceleration and scaling). Those struggling with invasive species, including federal agencies, need to adopt and advance a cultural and managerial vision that embraces innovation.

This panel sought to answer the following set of key questions:

- What are the barriers to technology investment and incentives?
- How do we overcome these barriers?
- What innovative ideas can advance technology investment and incentives in the context of invasive species?
- How could the incoming Administration make substantial progress on this topic?

TRANSFORMING INNOVATORS INTO ENTREPRENEURS: NATIONAL SCIENCE FOUNDATION INNOVATION CORPS

While basic NSF-funded research generally advances a specific field of science or engineering, there is also evidence of its immediate potential for broader applicability and commercial impact. Innovation Corps (I-Corps) programs help researchers translate discoveries into technologies and products with near-term benefits for the economy and society, and in the long term, into commercial enterprises. It teaches NSF grantees to identify valuable product opportunities that can emerge from academic research and offers entrepreneurship training to participants.

The I-Corps program essentially applies the scientific method to entrepreneurship by encouraging researchers to test their hypotheses about demand. In this process, it is critical for researchers, such as the creators of artificial coral reefs, to get out of their technical area of practice to determine whether there is broader market demand for a product, and if not, how a "product" should be redesigned in the face of that evidence.

UNLOCKING RESEARCH: SMALL BUSINESS INNOVATION RESEARCH PROGRAM

Small businesses can be nimble catalysts for change and can commercialize solutions, and entrepreneurs need financing to capitalize on high-risk/high-reward approaches. The government has a role to play to incentivize innovation, which can help draw experts from other disciplines. Different types of supporting resources (e.g., mentorship networks) and forms of capital (e.g., intellectual, social, financial) can be offered to entrepreneurs, but strong motivators, such as love, pride, and fear are also important drivers.

The Small Business Innovation Research (SBIR) program is a highly competitive program that encourages domestic small businesses to engage in research and development that has the potential for commercialization. Through a competitive awards-based program, SBIR enables small businesses to explore their technological potential and provides incentives to profit from commercialization. By including qualified small businesses in the nation's research and development arena, high-tech innovation is stimulated and the U.S. reinforces an entrepreneurial spirit as it meets specific research and development needs. Such programs are useful for taking research out of the lab, and turning it into tangible products and services that are the basis for scalable enterprises.

A key lesson learned from experiences with the SBA is the importance of connecting the problem space (e.g., an invasive species grand challenge) to economic opportunity in order to create a demand for new innovation. In this regard, government agencies need to consider how they use these tools and levers to build private sector opportunities.

OPEN INNOVATION: TRANSFORMING RESEARCH AND DEVELOPMENT THROUGH PRIZES AND CHALLENGES

Greater degrees of global connectivity have created a new paradigm of open source science, which is transforming how scientific discoveries are made. Open source approaches can help develop and/or source new ideas or products, distribute the burden for collecting and analyzing data, co-design new solutions, and share in the burdens of research, publication, and funding, while simultaneously engaging the public. Such innovation is useful for soliciting expertise and applications from other fields.

Prizes and challenges can "crowdsource" new solutions with the recognition that breakthroughs may not come from expected disciplines or institutions. A prize focuses on a single breakthrough, while a challenge helps create new communities of solutions and practice. When problems at the core of a prize or a challenge are well defined, they focus research and development efforts and can capture the imagination of the world's best researchers and innovators. Moreover, prizes and challenges lower the costs for new entrants outside the core discipline of the prize to participate. This is their most important power: the ability to engage new solvers and new solutions, including those from adjacent fields that haven't been adapted to the problem at hand.

USAID through the Global Development Lab started Grand Challenges in an effort to be more catalytic. That experience showed that how you ask for solutions is very important. The ask must be broad but sufficiently outline the barriers and problem space so as to solicit useful solutions. It can't be so narrow as to close the door on new thinking or go as far as defining the desired solution itself. USAID has successfully used open innovation for responses to Ebola and Zika outbreaks. Another approach is the use of "hack-a-thons" for curating new solutions via co-creation by bringing together experts and solvers.

Finally, considering a strategy for scaling up the application of a technology is just as important as the innovation itself. USAID, and many other fields of social enterprise such as food security or global health, have a scale problem where good ideas have not been promoted at a sufficient scale

to address the problem. Considering scale and sustainability as part of the core innovation design process is critical to achieving the greatest impact.

INNOVATION FOR GOVERNMENT

Chris Nelson of the Office of Science and Technology Policy (OSTP) in the White House highlighted that federal agencies need a portfolio approach to innovation that varies potential tools as appropriate to the problem, available resources, and solution class. Citizen science is one such tool, which, when coupled with increases in connectivity, provides new ways of engaging the distributed capacity of the public. This provides a unique means to address laborious tasks, serve as "citizen sensors," and even participate in data analysis or the proposal of new research questions. Additionally, it's important to promote opportunities for public-private partnerships and therein to recognize the role of profit as a core driver. Entrepreneurs will seek to monetize their solutions, and federal agencies need factor this into their incentivizing efforts when seeking solutions.

Session 3
Potential Game Changers: A Spotlight on Selected Emerging Technologies

Presenters: Stas Burgiel, National Invasive Species Council Secretariat (moderator); James Leary, University of Hawaii; Vince Bryan III, Whooshh Innovation; Jon Morton, U.S. Army Corps of Engineers; Derric Nimmo, Oxitec; Karl Campbell, Island Conservation

Innovation to address invasive species problems is occurring on a wide range of fronts. Opportunities include application of dual-use technologies, automation, and genetic tools. While many of these are currently specific to a particular geography or invasive species, there are possibilities for broader application that will require identification of and overcoming barriers to scaling up.

HERBICIDE BALLISTIC TECHNOLOGY

James Leary, University of Hawaii

Herbicide ballistic technology (HBT) has been a game changer for protecting Hawaii's watershed, where weed management is much more challenging than in temperate climates. Native to Central and South America, the genus *Miconia* has many biological attributes that make it a highly successful invader of Hawaii, particularly with regard to its high fecundity and ability to germinate in shade and on steep slopes. The *Miconia* invasion started with a single plant in 1970 and went unchecked for 22 years. On the island of Maui, incipient populations of *Miconia spp.* are colonizing remote sections of priority watersheds on slopes that are inaccessible to ground management.

The University of Hawaii has been working to apply innovative practices in weapons ballistics to local weed management needs – basically identifying a second, or dual use for those technologies. HBT uses an encapsulated 0.68 caliber herbicide-filled projectile for treating plants up to 20–30 meters away with a highly surgical and targeted application. The operations team has conducted more than 100 HBT operations, eliminated more than 20,000 *Miconia* targets, protected 18,000 ha of native vegetation, and avoided $384.2 million in future management costs.

There will be opportunities to continue to improve the technology. The HBT platform encourages greater investment in Intelligence, Surveillance, and Reconnaissance, tactics used by the military, for improved decision making and containment of spread. Big data analytics could be used to monitor tactical performance and strategic projections. Using a telemetry system in conjunction with an

HBT system may allow for better strategic data collection and will eventually be complemented with higher resolution images of the management terrain and better cell network access for high quality data processing in real-time. In the future, heavy-payload UAVs with adequate sustained flight could displace manned operations, allowing access to more terrain for longer periods of time.

FISH PASSAGE AND EXTRACTION TECHNOLOGY

Vince Bryan III, Whooshh Innovations

Stream-dwelling fish need connected habitats. Waters fragmented by large dams or small, poorly placed or maintained road culverts keep fish from accessing habitat. To solve this problem, innovators have developed fish passage technology, including the developers of Whooshh Innovations. Whooshh Innovations developed a flexible tube that uses moist air to safely transport fish over any barrier, a cheaper, faster, and more adaptable alternative to heavier infrastructures, such as fish ladders and fish lifts. Such fish passage technology can also be "dual use," when integrated with real time electronic scanning to identify and extract the invasive species when they try to pass the barrier.

The Whooshh system allows for intervention during the fish passage process to visually identify and manually extract fish by shunting them to a separate Whooshh transport tube. Advances in machine vision from the fruit processing industry and artificial intelligence could allow full automation of such a system with the benefit of fewer impacts on native fish and real-time feedback to invasive species managers. Given the current high costs of current fish passage technologies only five percent of dams and barriers have any structures in place for native fish passage, and invasive species have inhibited recovery of higher value native and commercial food source species. Technology solutions such as the Whooshh system would offer dam and water management operators a more cost-effective alternative for selective fish passage, that would help address invasive species propagation issues at the same time.

UNMANNED AERIAL VEHICLES (UAV) APPLICATIONS TO INVASIVE SPECIES MANAGEMENT

Jon Morton, U.S. Army Corps of Engineers

Unmanned Aerial Vehicles (UAVs) can be a valuable tool for invasive species management, because they provide high-resolution imagery, serve as a reliable data collection source to support aerial mapping and environmental reporting, and can operate in a wide range of settings. In Florida, the Army Corps of Engineers (USACE) is currently using a NOVA/NOVA Block II UAV system, which can carry 15 pounds, cover 750 acres, and take images at a 3.5 cm resolution.

There are many applications for these UAVs including: environmental restoration, invasive species monitoring, and community vegetation mapping. Efforts in Florida have also engaged geomatics experts to help with auto-classification of the aerial imagery collected from UAVs to automatically identify specific objects of interest. For instance, USACE uses auto-classification algorithms for wetlands restoration projects that identify invasive grasses and classify other vegetation types.

DNA-BASED DIAGNOSTICS FOR INVASIVE SPECIES MANAGEMENT

David Baisch, Conservation X Labs

Numerous molecular diagnostic tools have been developed in recent years for use in clinical settings, and there is has been a push to apply similar tools to conservation and invasive species research and management. One particular class of these tools builds on techniques to identify species in the field from trace remnants of their DNA known as environmental DNA (eDNA).

eDNA is DNA found in organic material shed from an individual specimen, which can be collected

from a variety of environmental sources (water, soil, snow). Thus the specimen itself doesn't need to be captured or observed, as researchers can test for its trail of DNA. eDNA employs DNA barcoding, a taxonomic method which has identified short genes that correspond one-to-one with individual species. This precludes the need to sequence entire genomes to ascertain the identity of species.

eDNA can be used to track the presence, absence, or spread of an invasive species as well as estimate biomass and the abundance of each species. eDNA can be very useful for early detection and rapid response, because only small quantities of DNA in the absence of specimens themselves are sufficient to detect the presence or absence of a small or elusive population. A limiting factor of eDNA is that it can't determine the age of a specimen, and there is always the small possibility that the DNA was introduced through another method.

Currently, there are a number of portable DNA devices in production or being tested, including miniature sequencers (MinION), portable PCR machines (Puro Molecular), isothermic and cyclic reactions (Conservation X Labs DNA barcode scanner), and lateral flow analysis (Swiss DeCode).

GENETIC ENGINEERING TO CONTROL MOSQUITOES: THE OXITEC SOLUTION

Derric Nimmo, Oxitec

The dangerous *Aedes aegypti* mosquito is responsible for transmitting several of the world's most debilitating mosquito-borne viruses including dengue, chikungunya, yellow fever, and Zika. Native to Northeast Africa, *Aedes aegypti* is now an invasive species in over 100 countries throughout the world, and it is estimated that up to half of the world's population lives alongside this mosquito. Control of this anthropophilic species which breeds in and around homes, office buildings, and schools, poses numerous challenges, and domestication of these "container breeders" has made them an extremely difficult target for conventional approaches. In addition, the repeated use of chemical insecticides, an intervention that may also have damaging effects on human health and the environment, is leading to rising resistance in *Aedes aegypti* worldwide creating operational problems for mosquito control programs.

Oxitec has pioneered a new Friendly™ mosquito control approach by placing two genes into the *Aedes aegypti* mosquito: a self-limiting gene that causes the offspring to die, and a marker gene for monitoring. Males, which do not bite or transmit disease, are sorted and released. When a male mates a wild female it passes the self-limiting gene on to all its offspring, which die before reaching adulthood. Unlike other approaches, Friendly™ *Aedes* mosquitoes die along with their offspring, and therefore do not persist in the environment or leave any ecological footprint.

Five efficacy trials showed greater than 90% suppression of *Aedes aegypti* in the Cayman Islands, Brazil and Panama. These unparalleled results compare favorably to conventional mosquito control methods that at best are only able to suppress *Aedes aegypti* populations by an estimated 30-50%. In Brazil and the Cayman Islands, the Oxitec approach is now in programmatic use, and currently being deployed in areas that cover over 65,000 people. This solution has proven scale-up capabilities for area-wide control of this disease-carrying mosquito.

The self-limiting method is supported by years of independent research, and has been proven safe and effective in other countries. In 2016, Oxitec received a final finding of no significant impact and final environmental assessment from the U.S. Food and Drug Administration (FDA) for an investigational trial in the Florida Keys. The FDA team, which consisted of experts from the Center for Veterinary Medicine (CVM), the Centers for Disease Control and Prevention (CDC), and the Environmental Protection Agency (EPA), concluded that the reared mosquitoes will have no significant impact on human health, animal health, or the environment.

The speaker noted that public support has been exceptional for a genetically engineered technology. Over 92% of people in Piracicaba, Brazil where the Oxitec's solution has been deployed since 2015, support the ongoing control program. Additionally, surveys indicate that 69% of Grand Cayman residents support the approach, and in a non-binding referendum in Monroe County, Florida, 31 of the 33 precincts voted in favor of using the technology to control *Aedes aegypti*.

CRISPR GENE DRIVE AND RNAI APPLICATIONS FOR RODENT ERADICATION

Karl Campbell, Island Conservation

Islands are less than 5% of the world's landmass, yet are home to 40% of the world's endangered species. Eighty percent of extinctions on islands are caused by invasive species. Four species of invasive rodents impact 88% of the critically endangered vertebrate species on islands. Rodents are a critical impact point for reducing extinctions on islands. The current rodent eradication tool – broad-spectrum toxicants – lacks species specificity, which limits broad application of this strategy.

Gene drives may emerge as a potential species-specific tool that holds promise for invasive rodent eradication on unprecedented scales. Gene drives cause certain genes to be inherited more frequently than normal, sometimes up to 100% of the time. The gene drives are passed on through inheritance and thus require sexual reproduction. CRISPR Cas9, as a gene-editing tool, gives resource managers the capability to modify wild populations by designing and inserting new genes, and/or modifying or deleting existing genes. Given that gene drives can be transferred to all offspring, even those where a species may be native, there is a need to develop, test, and deploy the technology with extreme precaution. This could include contained testing conditions in geographically or climatically isolated areas.

Ribonucleic Acid interference (RNAi) is a biological process in which RNA molecules inhibit gene expression or translation by neutralizing targeted messenger RNA molecules through an increase or decrease in their activity. In the wild, this approach may protect species against viruses that insert parasitic nucleotide sequences. This approach has been used as a potential cure for cancer and in agriculture. It may also be applicable for invasive species as a highly precise (taxa specific), efficient, and stable biopesticide, using prey species as vectors for transmission. Vertebrates may also digest RNA nanoparticles, which may serve as a delivery vehicle.

Session 4

Addressing "Social License" and Advancing Regulatory Framework to Support Innovation

Panelists: Michael Stebbins, the Laura and John Arnold Foundation (moderator); Robbie Barbero, White House Office of Science and Technology Policy (OSTP); Larry Clark, Animal and Plant Health Inspection Service; Ritu Nalubola, U.S. Food & Drug Administration; Mike Mendelsohn, U.S. Environmental Protection Agency; Earl Campbell, U.S. Fish and Wildlife Service

The process of technology development does not occur in a vacuum and needs to consider social and policy considerations. This includes both the social acceptance of new technologies and the regulatory frameworks necessary to support innovation. Federal agencies need to be flexible to work with new products and tools, whether that be reviewing their efficacy and safety or integrating them into conservation planning and field implementation. Public engagement is clearly necessary

for controversial technologies or where there may be a clash of value systems. This requires not just outreach but also a process for authentic dialogue.

Given the highly interactive nature of this panel discussion, comments have been grouped into the broader categories of social license and regulatory frameworks. Social license (sometimes referred to as "social license to operate") is essentially public approval or broader acceptance of a particular activity or set of activities, in this case the development and application of advanced biotechnologies for invasive species control and eradication. Such license extends beyond the narrow conduit of formal public comment on regulatory reviews of biotechnology applications to include larger scale understanding of the technologies themselves, the problems they are meant to address, possible alternatives along with their costs and benefits, as well as more specific site-based considerations for where they may be applied.

This panel sought to answer the following set of key questions:

- What role do the "social license" and regulatory frameworks play in our ability to apply technologies to pressing invasive species challenges?
- What are the potential barriers to achieving "social license" and how can they be overcome?
- How can we evolve regulatory frameworks in the context of rapidly emerging technologies?
- How could the incoming Administration make substantial progress on this topic?

SOCIAL LICENSE AND PUBLIC ENGAGEMENT FOR THE APPLICATION OF NEW TECHNOLOGIES

One of the principal approaches to obtaining social license for the use of a particular advance technology is to appeal to the benefits of effective invasive species management for avoiding impacts or saving particular species or habitats. It is critical to define the audience and understand its opinions, attitudes, background, and preferred language in order to better hone the message to motivations and values that may have traction in gaining their support and buy-in. Community forums and surveys are two examples of how to engage the public, understand their concerns, and gain public trust and spread that trust in a solution anecdotally. Public resistance to a technology can easily hamstring its application, regardless of its effectiveness or other positive attributes.

ADVANCING REGULATORY FRAMEWORKS

Federal rulemaking can have a profound influence on technology development; the nature of that influence can be either negative or positive. Although many view federal regulations as suppressing commercialization or undermining innovation, the government's goal is to increase predictability for technology development and ensure public safety. Contrary to popular belief, the Federal Government does not regulate technologies or processes (i.e. gene editing), rather it regulates products. The challenge comes with new technologies that do not fall clearly into existing areas of an agency's responsibility, or that cut across multiple agencies, such as biotechnology. In the case of advanced biotechnology applications for invasive species, the most appropriate legal framework would be the Coordinated Framework for the Products of Biotechnology, which is currently being updated by APHIS, EPA, FDA and OSTP.

Under the Coordinated Framework, it can sometimes be difficult to determine which agency's regulations apply to a particular innovation or technology, and the lack of clear or effective regulatory frameworks can encourage inconsistent application of regulations or unnecessary bureaucratic burdens on innovators. The Zika mosquito eradication programs provide one example – is this

within the purview of the EPA to regulate as a novel pesticide, or does this constitute a pharmaceutical under the auspices of FDA? While having one agency regulate biotechnology might be more convenient for innovators, under the U.S. system, authorities and expertise span multiple Departments. Programmatic flexibility and interagency cooperation will be critical within the update of the Coordinated Framework to allow the development of new technological innovations to address the grand challenges posed by invasive species.

Session 5
Attracting Technology Innovators and Applications to Invasive Species Challenges

Panelists: Karl Campbell, Island Conservation (moderator); Alex Dehgan, Conservation X Labs; Kent Redford, Archipelago Consulting; Johanna Wolfson, U.S. Department of Energy

Moving beyond the species challenges that invasive species present and existing technological applications, there is a clear need to engage a broader community of innovators. Given the highly interactive nature of this panel discussion, comments have been grouped into the broader categories of messaging and attracting new communities of innovators.

This panel sought to answer the following set of key questions:

- How do we inspire technology innovators to solve invasive species challenges?
- How do we explore the "invasive species application" of existing technologies developed for other purposes?
- How can we harness the technologies that are becoming increasingly "public-friendly" in their acquisition and application? What risk and benefits do these pose?
- How could the incoming Administration make substantial progress on this topic?

CHANGING THE MESSAGE

The conservation community needs to move away from documenting environmental doom and gloom toward the inclusion of optimism as a critical part of the message. Historically, conservation has tended to be technophobic and pessimistic (including perspectives on the prospects of invasive species management). This reality has precluded engagement with other professional fields and academic disciplines that may have powerful new tools, such as biotechnology and synthetic biology. There are opportunities to change the core message for conservation to make it more engaging through improved storytelling, understanding behavior change and why people engage and respond, and positive deviance – highlighting those that have developed better solutions than their peers using the same set of resources. Better science communication will help create an inspired community and incentivize them to act.

Openness to novel ideas will be a critical part of such dialogue. Catalytic change requires new problem solvers and the application of solutions from other fields. New entrants also present a challenge – they may not know the limitations and assumptions that are standard to the field. However, this also grants them an advantage in being able to experiment with new approaches and question long-held assumptions – that may or may not hold true.

ATTRACTING NEW SOLVERS AND SOLUTIONS

We now recognize that conservation professionals may be the best suited to define the challenges of invasive species, but they are not in possession of all the solutions. Attracting new solvers and potential paths forward is a critical element for stimulating the innovation pipeline. Prizes and challenges can bring in new solvers from new disciplines, and are pay-for-performance mechanisms that do not prejudge the solution or influence the potential solution range. Mass collaboration, co-creation, and open source approaches also serve to encourage collaboration across non-traditional disciplines. This may include crowdsourcing data to increase the leverage of public sector actions. Public-private partnerships provide another opportunity to bring in new solvers and engage them.

The panel closed the session by posing a set of questions for managers seeking to attract, engage, and maintain a novel community of solvers: What are the incentives for participation? How do you lower the barriers for participation? And, how do you facilitate and reward collaboration across disciplines?

Session 6
Where Do We Go from Here

REPORTING AND RECOMMENDATIONS

Alex Dehgan, Conservation X Labs

The presentations and panel discussions have been inspiring, and confirmed that technology innovation can make the impossible possible. They have also raised a wide range of questions for us to consider as we build and mobilize a new culture of innovation for the invasive species community. The act of delving into these questions will, in and of itself, be transformative. These questions will better enable us to dare mighty things.

- How do we use both the power and limitations of government to fuel and unlock innovation?
- How do we create social legitimacy, credibility, and trust (i.e., social license)? This is difficult to do when you have technology that is increasing exponentially, because it is almost impossible to imagine what things will be like even a short period of time into the future.
- The ways that we have begun to share knowledge have contributed to the dilution of what constitutes evidence. How do we find and communicate the signal in the noise in a way that enables the changes that we need to make on the ground?
- How do we unlock the private sector through innovative partnerships? The solutions will be both inside and outside of government. We can harness and bring in new people through prizes and challenges.
- We need to think about the scale of products being developed and whether what we are producing is really "revolutionary over evolutionary" (i.e., transformative vs. incremental change). How can we go big when increasingly told to work with less?
- How do we fundamentally rethink risk? Is the precautionary approach costing us species due to our unwillingness to take the risks necessary to develop and apply innovative solutions?

A CALL TO ACTION

Michael Stebbins, the Laura and John Arnold Foundation

In order to address the invasive species challenge we need everyone on the same page and working together. To this end, one of the products the Innovation Summit team will begin to develop is a paper summarizing the event and the recommendations that emerged from it. This report will help us to communicate with the larger scientific and technical community. It will help us help others to see themselves as part of the problem and part of the solution.

WE CAN DO THIS

Jamie K. Reaser, National Invasive Species Council

The Innovation Summit was an initial step in creating a conversation space around the role of technology in overcoming the invasive species challenge. While this meeting was an opportunity to celebrate technology and technology advances, and to inspire people to get together and generate solutions, it is about more than that. It is about creating a culture of innovation within the invasive species community. "We can do this…" needs to become our sustaining belief and our mantra. We invite you to spread this message through the materials that you produce (footers of PowerPoint slides, business cards, email signatures, hashtags on social media, etc.) in order to help change the conversation from "we can't" to "we can."

CLOSING REMARKS

Jamie K. Reaser, National Invasive Species Council

Thanks were given to the many people who helped make the Innovation Summit happen.

ANNEX III: ABSTRACTS

MAKING THE CASE FOR INNOVATION

Jamie K. Reaser

Invasive species are among the most significant yet least addressed challenges of our time. Even though they threaten livelihoods and lives, the invasive species problem is often considered too big, too complex, and too costly to address. This limiting belief has undermined the will and innovative spirit necessary to safeguard the environment and other national assets. The Innovation Summit will foster new technological breakthroughs and new beliefs about what is possible. We need to make the bold decision to take on the invasive species challenge and trust that the practical solutions will follow.

RETHINKING THE TRAP (AND OTHER DEVELOPMENTS IN LIONFISH CONTROL)

Steve Gittings

The lionfish invasion across the wider Caribbean is among the greatest threats to the region's native ecosystems. To date, population control has been primarily by spearfishing at scuba depths, but high populations exist hundreds of feet deep. Stemming the invasion will require culling in priority conservation areas and commercial harvesting over the entire range of the invasion. Many technologies are being tested for capturing or killing lionfish, including mechanical and electronically operated traps, and a variety lethal devices carried by divers, ROVs, and AUVs. Remote spearing, vacuums, electrocution, poison injection, and laser cutting have all been either proposed or attempted.

BURMESE PYTHONS AND OTHER LARGE CONSTRICTORS

Gintas Zavadskas

Abstract Unavailable

HAWAIIAN ISLANDS AND GUAM: INVASIVE SPECIES CHALLENGES FOR AVIAN CONSERVATION

Earl Campbell (presenter), Mary Abrams, Craig Clark, Larry Clark, Domingo Cravalho, John Eisemann, Joshua Fisher, Robert "Goose" Gosnell, Steve Hess, Stephen Miller, Brand Phillips, Will Pitt, Robert Reed, Shane Siers, David Tessler

The conservation of endemic Pacific Island avifauna and their ecosystems has been a long-term goal of resource managers. In the Hawaiian Islands and Guam, innovative approaches have been developed and implemented for multi-scale ungulate, small mammal, and brown tree snake control. Cutting edge tools and mechanisms are presently being developed to control introduced snakes on Guam at a landscape scale. In addition, significant initiatives are underway to find pioneering solutions for broad, landscape-scale control of introduced mosquitoes. These on-going efforts shine a bright light on the future protection and recovery of Pacific Island avifauna.

INVASION IMPACTS AND INNOVATION IN THE NORTH AMERICAN GREAT LAKES

David M. Lodge

The invasive subset of almost 200 nonindigenous species in the North American Great Lakes cause at least $200 million in annual damages. Those damages have mostly been accepted as a necessary by-product of global trade. Such fatalism is unnecessary and financially foolish. Recent innovations are reducing invasions from ships and commerce in living organisms, while simultaneously increasing net economic benefits. New DNA-based technologies provide improved early detection tools, which, if combined with large-scale eradication and control technologies, open the door to a virtuous cycle of innovation, business opportunity, and environmental protection.

PATHWAY SPOTLIGHT: SHIP'S BALLAST WATER AND HULL BIOFOULING

Greg Ruiz

Abstract not available.

HERBICIDE BALLISTIC TECHNOLOGY (HBT) DEPLOYED TO ELIMINATE INCIPIENT MICONIA IN THE EAST MAUI WATERSHED

James Leary

Miconia was introduced to East Maui, Hawaii as a single horticultural specimen circa 1970. The management of *Miconia* commenced two decades later and continues on today. Native to Central and South America, this species has many biological attributes that make it a highly successful invader of Hawaii including high adult fecundity and frugivorous dispersal of progeny. In less than 40 years, incipient *Miconia* populations have invaded remote sections of the East Maui Watershed. Herbicide Ballistic Technology (HBT) is a concept for pneumatically delivering 0.68 caliber herbicide-filled projectiles with long range, surgical accuracy (i.e., 30 m distance) with wide vertical and horizontal attitudes allowing us to uniquely treat targets on cliff faces or deep gullies that would otherwise be inaccessible to conventional management options. The best utility of HBT has been demonstrated as a novel treatment platform on manned helicopter surveillance/reconnaissance operations searching for incipient populations in these remote, inaccessible areas; virtually doubling the efficiency of flight time by combining intelligence gathering with target elimination in real time. Starting in 2012, we have conducted over 100 missions, approaching 500 hours of operational flight

time (OFT), treating over 20,000 high-value, incipient targets covering 8,800 ha of the watershed. This robust set of institutionalized operations data allows us to explore novel performance analytics in a real management setting, i.e., search efficiency, herbicide use rate, etc., largely driven by target densities encountered. A further advancement of HBT was the development of a telemetry system providing a higher degree of spatial resolution and an accurate account of herbicide dose, with every projectile discharged, time-stamped and georeferenced with more exacting off-set locations. All of these variables can be monetized for determining variable costs of an operation. On average, operations search ~50 hectares (ha) hr-1 treating ~47 targets ha-1 at an estimated cost of less than $30 ha-1. With basic geographic information systems, we have determined the dispersal kernel of *Miconia* in the EMW, with 99% of progeny within 600 m of the maternal source and stochastic events occurring up to 1644 m away. Thus, further assisting with determination of area impacted. Our goal is to use these new model parameters for optimizing containment strategies with effective impact reduction and highest return on future cost avoidance. The aerial deployment of HBT is proving to be an efficient management system reducing further impact to these fragile ecosystems.

POTENTIAL GAME CHANGERS: SPOTLIGHT ON EMERGING TECHNOLOGIES

Vince Bryan III

As invasive fish species threaten ecosystems and native fish populations, federal, state, and tribal fisheries managers try to control and contain these "invasives"—while also complying with mandates to assure volitional fish passage for all fish species in all waterways. Because these policies appear to be at odds with one another, we will address solutions to both problems and examine how the Whooshh system could be used at migratory intersections to effectively pass native fish species while also permanently removing invasive fish species from the waterway.

UTILIZATION OF UNMMANED AERIAL SYSTEMS (UAS) FOR VEGETATION MAPPING AND RESTORATION

Jon Morton

The Jacksonville District of the U.S. Army Corps of Engineers (Corps) has been exploring the use of Unmanned Air Systems (UAS) since 2005 to gain spatially accurate, very high-resolution imagery (~3cm) for the detection and monitoring of select invasive species and to support ecosystem restoration efforts. Now that the imagery acquisition part of the UAS program is fully operational, the focus is on assessing and quantifying the data within the images for a variety of different invasive species and vegetative community mapping projects. This presentation will give a background of the Corps' use of UAS and some of the current technologies and challenges associated with image acquisition, processing, and analysis.

DNA-BASED DIAGNOSTICS FOR INVASIVE SPECIES MANAGEMENT

David Baisch

Molecular diagnostic tools have been developed in leaps and bounds in recent years for use in clinical settings, and a call for the application of similar molecular methods has been made for conservation applications and in the research and management of invasive species. This presentation will consider

the advancements made in eDNA applications in monitoring and detection of invasive species, and consider where these methods are headed as these technologies improve over time. Several technologies will be discussed, including point-of-care systems and next-generation sequencing, along with the future of sequence data management for use in not only invasive population identification and elimination, but also in early detection and rapid response of biological invasions.

GENETIC ENGINEERING TO CONTROL MOSQUITOES: THE OXITEC SOLUTION

Derric Nimmo

The *Aedes aegypti* mosquito is responsible for transmitting several of the most debilitating mosquito-borne viruses, including dengue, Zika, chikungunya, and yellow fever. Native to Africa, *Aedes aegypti* has now spread across the world, and it is estimated that up to half of the world's population lives alongside this invasive species. The lack of available treatments for many of the diseases transmitted by the mosquito means that controlling the *Aedes aegypti* population is the best way to combat disease. However, control of this species poses numerous challenges. The mosquitoes live in and around human habitation so can be very difficult to reach. They have also developed resistance to many existing chemical insecticides, interventions which may also have damaging effects on health and the environment. With the best methods currently available, mosquito control organizations are generally only able to suppress *Aedes aegypti* populations by 30–50% at best, which is not sufficient to prevent disease transmission.

GENE DRIVE AND RNAI APPLICATIONS FOR RODENT ERADICATION

Karl Campbell

Invasive vertebrates are implicated in 58% of all extinctions; most have occurred on islands with invasive rodents responsible for more than half of the losses. Broad-spectrum toxicants, the current rodent eradication tool, lack species specificity, limiting feasibility and broad application of this strategy. Gene drives may emerge as a potential species-specific tool that holds promise for invasive rodent eradication on hitherto unconsidered scales. Teams are assessing the technical feasibility of this technology in mice while simultaneously assessing ecological risks, public/stakeholder tolerance, regulatory gaps and ethical questions to evaluate suitability of this tool. Ribonucleic acid interference also holds promise for future developments in rodent-specific toxins.

ANNEX IV: SPEAKER BIOGRAPHIES

David Baisch is the Molecular Innovations Director for Conservation X Labs and is leading a partnership with the Smithsonian Institution and the University of Washington to develop a portable, handheld DNA barcode scanner to combat the trade and sale of illegally sourced wildlife and timber. His expertise is in DNA sequencing technologies, DNA barcoding, marine population genetics, biological oceanography, and field sampling design. Before coming to the Conservation X Labs team, David had spent ten years analyzing mitochondrial DNA sequences in phylogenetic analyses on Atlantic salmonids, collecting catch composition information and DNA samples while working on commercial fishing vessels in the Bering Sea and Northern Pacific Ocean, working in regulatory biology in the Detroit District of the United States Army Corps of Engineers, leading field studies in marine systems in Canadian near-shore ecosystems, and teaching as a professor on conservation biology in the Pacific Northwest. David received his MS in Biology-Population Genetics and his BS in Biology-Aquatic Sciences with a minor in Chemistry and from Grand Valley State University.

Robbie Barbero is a biological engineer trained at MIT and Dartmouth College. Between undergraduate and graduate school he spent five years working for three biotechnology startups. During graduate school, he worked in the biomolecular materials research group at MIT on a variety of nanotechnology and biological engineering projects with applications in energy and medicine. Robbie is currently Assistant Director for Biological Innovation in the White House Office of Science and Technology Policy working on a broad range of policy matters related to the life sciences, technology, and innovation, including modernizing the federal biotech regulatory system, reducing the organ waitlist, cancer diagnostics for the developing world, the Administration's response to Zika, synthetic biology, genome editing, and supporting the President's BRAIN Initiative.

Vincent Bryan III is CEO of Whooshh Innovations, a company he co-founded in 2007. Since then, the company has worked with federal, state, and local agencies, tribes, conservation groups, and regulators to consider the innovative Whooshh™ fish passage technology in the recovery of native

fish species. Bryan, also known as V3, comes from a family of entrepreneurs and inventors (medical device and cervical cancer vaccine), developers (Gorge Amphitheater, Cave B Resort and Spa), and vintners (Familigia and Cave B Winery) with a reputation for solving big challenges. Formerly Associate General Counsel at Adobe Systems, Bryan holds B.A. degrees in Economics and Political Science (USC), a JD degree (Seattle University Law School) and Master's degree in Transnational Business Transactions (McGeorge School of Law).

Stanley W. Burgiel ("Stas") serves as the Assistant Director for Policy and Program Coordination with the U.S. National Invasive Species Council (NISC) Secretariat, where he manages a portfolio of invasive species activities identified in the NISC Management Plan and relevant Executive Orders related to early detection and rapid response, applications of modern biotechnology, free trade agreements, international trade and environmental policy, and the National Environmental Policy Act. Stas has a long history of work on international environmental issues and has worked and consulted for a range of nongovernmental, governmental and intergovernmental organizations. He received his PhD in international service from the American University and a BA in political science from Swarthmore College.

Earl Campbell has worked on invasive species issues in the Pacific and Caribbean for over twenty-five years. Early in his career, he conducted original research on invasive snake, rodent, and frog control for the U.S. Fish and Wildlife Service (USFWS) – National Biological Survey – U.S. Geological Survey and U.S. Department of Agriculture – Wildlife Services – National Wildlife Research Center. Since 2001, he built and managed an Invasive Species Program for the USFWS working with a dedicated staff on a wide range of issues. Additionally, he has served in a range of regulatory, managerial, scientific, and policy roles relative to Pacific Islands conservation.

Karl Campbell is the Program Director for Island Conservation in the Galapagos. Karl has worked for 19 years on some of the world's largest and most complex eradication campaigns of invasive mammals. His role typically involves identifying sites and partners, detailing a strategy, plan and budget, fundraising, managing field operations and refining strategies as required. In projects he's been involved with, new techniques or refinements to existing techniques have been made in aerial hunting, dog training, toxic baiting, trapping, Judas animals, detection probability tools, and the use of GPS, GIS, and digital data collection and management technologies. Karl initiated Island Conservation's Innovation Program, has worked on restoration projects in over a dozen countries and has published over 50 scientific and popular articles.

Larry Clark is the Director of the National Wildlife Research Center (NWRC) and serves as the Scientific Integrity Officer for the USDA's Animal and Plant Health Inspection Service. Larry has degrees from the University of Maryland (BS), Northern Arizona University (MS), and the University of Pennsylvania (PhD). Over the years, Larry's research has included the physiology and physics of temperature regulation in animals, the use of plant-derived biopharmaceuticals by wild animals, sensory biology, quantitative structure activity relationships of chemical irritants, the study of animal pain perception, and transferring scientific findings into management and policy. Besides extensive publications and professional recognitions, Larry is the recipient of the prestigious Kerry-Manheimer Award for career achievements in the chemosensory sciences.

Alex Dehgan is the CEO of Conservation X Labs, a company focused on harnessing exponential technologies, open innovation, and entrepreneurship for conservation. He is also the Chanler Innovator at Duke University, where he researches and lectures on technology innovation for conservation and development, including through a Massive Open Online Course (MOOC) with Coursera. Alex Dehgan recently served as the Chief Scientist at USAID, with rank of Assistant Administrator, and founded the Global Development Lab. Prior to USAID, Alex worked in multiple positions within the Office of the Secretary and the Bureau of Near Eastern Affairs at the Department of State, including overseas service in Iraq. As the founding director of the Wildlife Conservation Society Afghanistan Program, Alex helped create Afghanistan's national park system. Alex holds a PhD from the Committee on Evolutionary Biology at The University of Chicago.

Steve Gittings is Chief Scientist for NOAA's National Marine Sanctuary Program, and is former manager of the Flower Garden Banks National Marine Sanctuary. He is broadly experienced in conservation science, specializing in coral reef ecology, monitoring, and characterization. He has extensive field experience in scientific diving, ROV operations, and submersible use. Recently, Dr. Gittings has been developing a trap designed to catch lionfish in waters beyond scuba depth. The trap minimizes by-catch, eliminates the possibility of ghost-fishing, and could create new opportunities for fishermen to help create a steady supply of lionfish to seafood and other developing markets.
James Leary is an Associate Specialist with a split research and extension appointment at the University of Hawaii at Manoa, land grant institution. His mission is to extend knowledge and technology contributing to efficient and effective invasive plant species management. To that end, he enjoys collaborations with a wide range of academic disciplines in biology, engineering, economics, and GIS. His claim to fame, so far, has been the development of Herbicide Ballistic Technology (HBT) for treating individual weed targets. With this novelty now being deployed operationally, he is becoming more interested in the applied sciences of large data acquisition, performance analytics, quantitative ecology, operations research, and management science; all contributing to higher-level tactical and strategic decisions.

David Lodge is one of the world's leading experts on invasive species. His research focuses on ecological forecasting and environmental risk assessment, natural resource management, and policy. Lodge served as the first chair of the U.S. government's national Invasive Species Advisory Committee (2000–01), on advisory committees for EPA, International Joint Commission, and NOAA, and as a Jefferson Science Fellow in the Department of State. As a Rhodes Scholar, Lodge received a PhD from the University of Oxford. Lodge has published more than 200 scientific papers, edited two books, and is the director of Cornell University's Atkinson Center for a Sustainable Future.

Lydia McClure is the Program Director for the Innovation-Corps (I-Corps) program at the National Science Foundation (NSF). Prior to joining the NSF, Lydia was a national instructor for the I-Corps program based out of the Southwest I-Corps node. In addition to her work with I-Corps, Lydia was the Director of the university-focused, pre-seed portfolio at The Austin Technology Incubator (ATI). The capstone program of her portfolio was Student Entrepreneur Acceleration and Launch (S.E.A.L.) held in partnership with the Kauffman Foundation. Lydia spent 10 years with The University of Texas at Austin studying human disease, identifying ways to monetize university

research, and as a Venture Partner with Texas Venture Labs. She earned a BA with a concentration in Biochemistry from Carleton College and PhD in Molecular Biology from the University of Texas at Austin.

Mike Mendelsohn graduated with a BS in Microbiology from the University of Maryland. He has been working at the EPA in the Office of Pesticide Programs on biotechnology issues since 1987. He currently is a senior advisor in the Biopesticides and Pollution Prevention Division.

Scott Miller has managed research and collections programs in major institutions for over 20 years. At the Smithsonian's National Museum of Natural History, he has served as Chairman of the Department of Entomology and Chairman of the Department of Systematic Biology, with oversight of a combined staff over 300 federal employees with an annual budget of over $20 million. His previous experience includes 12 years at the Bishop Museum (Hawaii) managing its programs in biology and geology, with heavy involvement in public programs and development. He spent two years in Kenya initiating a biodiversity and conservation program at an international agriculture research institute (the International Centre of Insect Ecology and Physiology).

Ritu Nalubola is a Senior Policy Advisor in FDA's Office of Policy, Office of the Commissioner. She advises senior leadership at FDA on complex and cross-cutting policy issues, including those related to genetic engineering, nanotechnology, food safety, nutrition, and international consensus-based standards. She also has a leadership role in FDA's implementation of the Food Safety and Modernization Act. She routinely represents FDA at various domestic and international policy forums. She started her career at FDA's Center for Food Safety and Applied Nutrition in 2001.

Christofer Nelson is the Assistant Director for Open Innovation at the Office of Science and Technology Policy (OSTP). Christofer has been involved in prizes, challenges, citizen science, crowdsourcing, and public science education for nearly a decade. Previously, he was Program Director of the Georgetown University Program on Science in the Public Interest, which teaches actionable innovation and equips students to apply scientific problem solving skills to complex global challenges. Christofer lead the launch and administration of the Georgetown University Energy Prize, a national competition challenging 50 small-to-medium size cities and counties to rethink their energy use.

Will Pitt is the deputy director for the Smithsonian Conservation Biology Institute (SCBI), where he administers and manages SCBI's science centers and research programs. He is responsible for the financial and facility programs, the operations of the Smithsonian-Mason School of Conservation, and SCBI's 3,200-acre conservation and research facility in Front Royal, Virginia. He oversees more than 220 scientists, postdoctoral fellows, and students from universities around the world. He works passionately to improve the conservation of endangered species through collaboration, education, and research.

G. Nagesh Rao is a 2016 USA Eisenhower Fellow whom also serves as Chief Technologist and Entrepreneur in Residence with the U.S. Small Business Administration's Office of Investment and Innovation. His portfolio of work includes advising senior leadership around the Small Business

Innovation Research/Small Business Technology Transfer programs, co-leading the SBA Growth Accelerator program and co-leading coordination of the Fueling Small Business Innovation Interagency Policy Committee for the White House's Lab to Market Commercialization Agenda, as well as handling all things "techie" and "nerd-related."

Jamie K. Reaser serves as the Executive Director of the National Invasive Species Council (NISC). In addition to guiding all aspects of NISC Secretariat operations, Jamie has been providing the leadership necessary to develop an Arctic Invasive Alien Species (ARIAS) Strategy and Action Plan under the auspices of the Arctic Council; producing a documentary on invasive species entitled, Protecting What Matters; establishing the Innovation Summit; and raising the capacity of other governments to more effectively institutionalize invasive species programs. She received a PhD in Biology from Stanford University and BS in Field Biology from the College of William and Mary.

Kent H. Redford is Principal at Archipelago Consulting (archipelagoconsulting.com) based in Portland, Maine, USA. Archipelago Consulting is designed to help individuals and organizations improve their practice of conservation and has worked with the Global Environment Facility, U.S. National Park Service, and the Moore Foundation. Prior to Archipelago Consulting Kent spent 14 years at the Wildlife Conservation Society in New York and five years in The Nature Conservancy. He started his career with a decade on the faculty at University of Florida. He received his PhD in Biology from Harvard University. Kent has co-convened several meetings bringing together conservation biologists and synthetic biologists.

Greg Ruiz is a marine ecologist with diverse interests in invasion biology, biogeography, and ecology in coastal marine ecosystems. Based at the Smithsonian Environmental Research Center (SERC), Greg heads a team of 40 full-time biologists, conducting research to assess status, trends, and drivers of marine invasions throughout North and Central America. This work includes extensive analysis of trade dynamics and management strategies to limit species introductions associated with commercial ships and other transfer mechanisms (vectors). Greg received his PhD from University of California, Berkeley and has published over 150 scientific articles, focusing primarily on marine invasion ecology and management.

Michael Stebbins is Vice President of Science and Technology at the Laura and John Arnold Foundation. He joined the foundation after serving as the assistant director for biotechnology at the White House Office of Science and Technology Policy. At the White House, Michael was responsible for developing and driving initiatives in life sciences research, including the Administration's efforts focused on improving veterans' mental health, combating antibiotic resistance, increasing access to federally funded scientific research results, restoring pollinator health, and reforming the regulatory system for biotechnology products. Michael previously served as a science advisor to the Obama Campaign and on the Obama Presidential Transition Team. He is the former director of biology policy for the Federation of American Scientists, co-founded and served on the board of directors for Scientists and Engineers for America and taught bioethics at the University of Pennsylvania. In addition, Michael worked as a legislative fellow for U.S. Senator Harry Reid and a public policy fellow for the National Human Genome Research Institute. Before coming to Washington, he was a senior editor at Nature Genetics. He received his BS in biology at SUNY Stony Brook and his PhD in genetics while working at Cold Spring Harbor Laboratory.

Wendy Taylor is Founder and Director of the Center for Accelerating Innovation and Impact at the USAID, a center of excellence applying innovative, business-minded approaches to accelerate the development, introduction and scale-up of priority global health innovations. Joining the Administration in 2010, she created and built the Center; spearheaded Grand Challenges to globally crowd source groundbreaking solutions to tough health challenges, including the successful Saving Lives at Birth, Fighting Ebola, and Combating Zika and Future Threats Grand Challenges; and created multiple public-private partnerships.

Johanna Wolfson is the Director of Technology-to-Market in DOE's Office of Energy Efficiency and Renewable Energy (EERE). In this position, she leads efforts to reduce barriers and inefficiencies in the U.S. innovation system in service of getting promising clean energy technologies to market. Existing efforts under Tech-to-Market help launch entrepreneurs and new businesses out of universities and National Labs, help support early-stage clean energy businesses with funding and incubator services, provide small businesses with technical support at National Labs, and position startup companies for scale-up. She is also responsible for developing new EERE programs in service of the Tech-to-Market mission, and for coordinating Tech-to-Market efforts across EERE's technology offices.

Gintas Zavadskas has always worked at the fringe between management and scientific research, always favoring science-based decision-making processes. He is passionate about biotechnology application, assessment, and management. His current research interests concentrate on the study of invasive species from different angles, ranging from technical aspects of control, new technology evaluation and application, modeling, design of effective control coordination, institutional aspects of decision-making and invasive species jurisdictional responsibilities. He studied biotechnology engineering at the Autonomous University of Guadalajara. After moving to work in the Fish and Wildlife Department for the Miccosukee Tribe in Florida in 2006, his work has been science-based conservation that is centered with indigenous rights and peoples in mind.

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