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GREEN IGUANAS: A THREAT TO MAN AND WILD IN FIJI ISLANDS?

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Abstract

Green iguanas are heavily hunted and traded in their native range, and apprehended as invasives in their introduced range, where their populations have become increasingly challenging to monitor and control. Fiji islands in the Pacific are endowed with unique biodiversity and ecosystems; there are four native iguana species, three of which are endemic to the islands. Green iguanas were introduced accidentally as a pet in the island of Qamea, and have since spread to the islands of Matagi, Taveuni, Vanua Levu, Laucala, Koro and Wakaya, possibly by natural and anthropogenic means of dispersal. Reports of adverse impacts on biodiversity, communities and livelihoods have surfaced but local communities encounter difficulties in distinguishing between the native and introduced iguanids. Invasive species management has been prioritised for localising the invasion, however, there is a strong need to incorporate research as an indispensable tool for evidence based decision making. This is particularly important for accidently introduced species whose impacts are unconfirmed but suspected to be serious. Recognising inter- and transdisciplinary approaches in invasion science can facilitate participatory decision making and generate long term benefits. Research on the foraging behaviour and nutritional physiology, impacts on seed germination and dispersal of native and invasive plant species, ecological processes, and interactions between the green and native iguanid population, would improve our understanding of actual and potential impacts on species, ecosystems and habitats. At the same time exploring the environmental, social and economic impacts, benefits and costs, and people's perception can generate strong support for management actions, secure long term funding and foster closer coordination between scientists, local communities, and policymakers.

Keywords: *Invasive species research; Green iguana; Biodiversity; Livelihoods; Fiji Islands*

Introduction

Green iguanas (*Iguana iguana* L.) have a strong environmental tolerance which enables them to occupy a diversity of habitats ranging from coastal areas and mangroves to inland mountains, forests, and urban areas [1, 2]; typically inhabiting arboreal environments near water bodies, and descending to the ground for nesting and foraging [3]. Among iguanids, they represent an interesting case of a species widely hunted and traded in their native range, and apprehended as pests in the introduced range [1, 2, 4]. Although their native range of distribution is in Central and South America, yet they have been introduced to several parts of

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the world [5]. Extensive export is primarily due to the pet trade [1], with more than 4.6 million green iguanas legally traded in the global market over the period 2001-2008 [6]. Consequently in their native range, green iguanas are over-exploited and have been listed under CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Appendix II which includes species not necessarily threatened but in which trade must be regulated [7]. Moreover, overhunting and habitat destruction have put excessive pressure on their population [1, 4, 7]. Humans are among major predators of green iguanas in the native range [1] where they have traditionally been a source of animal protein in the form of both meat and eggs for more than 7000 years and are even farmed for human consumptions [8-11]. The eggs are believed to possess aphrodisiacal properties. This poses a grave threat to gravid females when they converge in communal nesting sites [7, 10-12]. In Colombia the fat of green iguanas is used to treat cough and asthma in humans [7], and in Brazil it is used to treat pits, furuncles and pointed stakes in animals [13]. Green iguanas are also valued by the leather industry; in the native range, countries such as Mexico export skin and skin products to markets in USA [14]. This overexploitation has given rise to headstarting conservation projects, Fundación Pro Iguana Verde (FPIV) in Panama and later Costa Rica, Iguana Verde Foundation (IVF) in Costa Rica and the Green Iguana Conservation Project in Belize which aim at rearing green iguanas in captivity for subsequent reintroduction in the wild [10, 15, 16].

On the other hand, unintentional and deliberate release from captivity has resulted in naturalised populations of the species in the introduced range: United States (Florida, Texas), Pacific Islands (Fiji and Hawaii), and the Caribbean (Puerto Rico, Anguilla, Cayman Islands, Saint Martin, Barbuda, Antigua, Virgin Islands and Lesser Antilles) [1, 2, 10, 17]. Green iguanas have also been listed in the Global Invasive Species Database [12]. Adverse socio-economic and ecological impacts of green iguanas on man and wild have been raised as major concerns in the introduced range wherein their populations have become increasingly challenging to monitor and control [18, 19]. Extensive damage to residential and recreational landscape vegetation including ornamental and fruit bearing plants has been reported in Puerto Rico and Florida [1, 2, 5]. *A.L. Lo´pez-Torres et al,* [20] observed damage to root crops such as yautia (*Xanthosoma* spp.) and yams (*Dioscorea* spp.) in Puerto Rico. Although green iguanas are typically herbivorous [21], potential impacts on other species include predation of the native tree snail *Drymaeus multilineatus* [22], and using burrows of the Florida Burrowing Owl (*Athene cunicularia floridana*), a species of Special State Concern [5]. In Florida green iguanas also feed on nickerbean (*Caesalpinia* spp.), the principal larval host plant of the endangered Miami Blue Butterfly (*Cyclargus thomasi bethunebakeri*) [23, 24].

In the Pacific Island region, green iguanas have been reported from Fiji (Figure 1), where they are known as American iguanas to avoid confusion with the green coloured native iguana species [1]. Green iguanas were brought illegally as a pet by expatriates in the year 2000 in Qamea Island, east of Taveuni. Within a decade, the species was recorded in neighbouring islands such as Matagi and Taveuni. More recently the species has been sighted in the islands of Vanua Levu, Laucala, Koro and Wakaya (Fig. 2) [1, 25]. This inter-island dispersal may be attributed to accidental transport of eggs or young juveniles in cargos or probably the adults swam to nearby islands [1]. A man-animal conflict has ensued wherein the invaded islands under the Biosecurity Act 2008, have been declared as Biosecurity Emergency Areas [26]. Several management measures have been adopted to localise the invasion and prevent dispersal of green iguanas to surrounding islands and islets. Although invasive species management has been prioritised as evident in other parts of the Pacific, there is a strong need to incorporate research as an indispensable tool for evidence based decision making. This paper is an attempt to assess the potential socio-economic and ecological threats of green iguanas in Fiji based on observed impacts in their introduced range of distribution elsewhere. We further discuss the response measures for green iguana incursion in Fiji, some of the challenges of managing

biological invasions on islands, and argue the cause of scientific research in invasive species management.

Fig. 1. Green iguana in Fiji (Source: www.fijivillage.com)

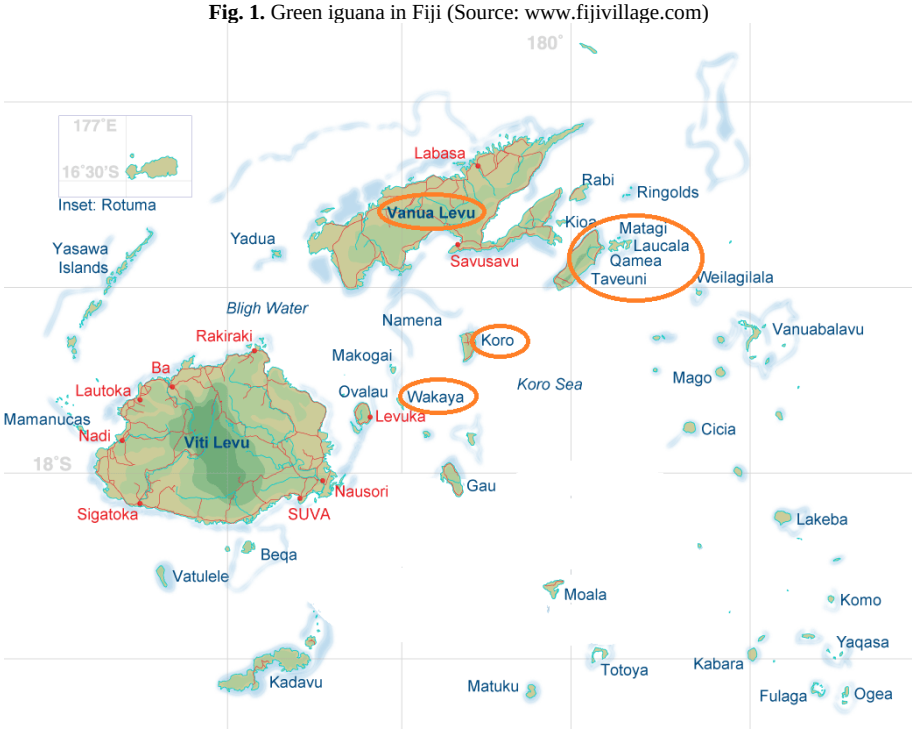

Fig. 2. Map of Fiji Islands showing areas of reported sightings (Source: yachtpartnersfiji.com)

Invasive capacity in the Pacific Islands

The climatic suitability of the Pacific islands enhances their risk of invasion by the green iguanas, which have a preference for and easy adaptability to tropical conditions [1, 17]. They are also restricted to low elevations upto 1000 meters above sea level [27, 28]. In the Pacific region, inter-island spread is likely to be facilitated through anthropogenic or natural dispersal mechanisms [1].

Biological traits of green iguanas also favour successful colonisation in the introduced range [18]. A relatively high fecundity with around 50-80 eggs per breeding season [29-32], abundance of food resources during the hatching season which coincides with the wet season, relatively rapid rate of growth of hatchlings, and storage of sperms by females for years after mating [17], are all factors contributing to the rapid proliferation of the species. The ability to

camouflage and blend with the surroundings [1, 29], remain submerged in water for hours [17], and flee fast from humans upon sensing threat, impedes efforts for their eradication and control.

I. iguana expands rapidly in terms of both numbers and range over a short time period [1]; with remarkably much higher densities recorded in invasive as compared to native populations [20, 27]. Since predation pressure is a powerful impediment to successful colonisation, the factor of predator free space creates conditions favourable for population expansion. This is particularly applicable to Fiji and the Pacific where there are no reported natural predators of green iguanas. *W.E. Meshaka* [18] and *H.T. Smith* [33] reported rapid population growth and changes in age-class structure of green iguanas following sudden release from intense predation due to raccoon removal in State Parks of Florida. Although multiple factors determine successful establishment and spread of an Invasive Alien Species (IAS) and seemingly the threat to the Pacific islands is latent, however under favourable conditions green iguana populations may rapidly proliferate [1].

Potential threats in Fiji

Socio-economic threats to man

In Fiji green iguanas are considered a threat to village subsistence gardens with local communities raising concerns regarding damage to vegetable farms [34, 35]. Among agricultural crops, people have reported sweet potato (*Ipomoea batatas*) and bele (*Abelmoschus manihot*) as food plants of the green iguanas. One of the few studies on the status of green iguanas in Fiji by *R. Van Veen* [29] asserted that although taro leaves (*Colocasia spp.*) are also commonly cited by villagers as a preferred food plant, yet there were no actual incidences where iguanas were seen feeding on the plant. Concerns have however been raised regarding adverse impacts of green iguanas on Fiji's taro export industry largely based in the island of Taveuni. The same study also reported that the preferred food plants of the green iguanas were primarily trees and invasive weeds distributed in and around mangrove habitats such as *Pongamia glabra* (vesivesi), *Erythrina varigata* (drala), *Morinda citrifolia* (noni) and *Merremia peltata* (wabula). This discrepancy in reported food plants of the green iguanas emphasises the need to conduct empirical studies on their foraging behaviour in the invaded sites. Such information could improve our understanding of actual and potential threats on food production systems. Until then, it would be naive to consider green iguanas a severe threat to the agricultural sustainability and food security of the region.

Since the tourism sector is a major source of foreign exchange earnings in Fiji, concerns have been raised that green iguanas may threaten the industry, wherein dispersal by natural or anthropogenic agencies to the main islands could adversely affect visitor inflow. However, outside their native range, tourist responses and attitudes towards green iguanas are both positive and negative. In Florida and Puerto Rico, green iguanas have become a tourist attraction, and regularly feature in souvenirs [1, 2]. Iguana feeding stations and iguana-watching kayak and boat tours in Puerto Rico are also gaining popularity among tourists [36]. Conversely reports of giant invasive iguanas disturbing tourism activities have emerged from countries such as the Bahamas [37].

Furthermore, in recent times, reptile associated health hazards have increased with increasing popularity of exotic pets [38]. Green iguanas are a source of *Salmonella* infection, a zoonosis with the greatest threat to children and immunosuppressed patients [38-40]. Similarly a recent study reported that green iguanas carry diarrheagenic *Escherichia coli* (DEC) in their intestines which can cause gastrointestinal infections in humans and is also resistant to first-line antibiotics such as penicillin [41]. Nevertheless, *W. Falcon et al*, [1] observes that although pet

green iguanas can transmit infection to humans it is unlikely for free-ranging iguanas to pose a threat to human health.

Damage to infrastructure has also been associated with green iguanas. They are capable of burrowing weak seawalls and foundations leading to the collapse of structures, and possible soil and beach erosion contributing to landslides [17, 42]. *A. Sementelli et al*, [43] estimated a burrow density of 1740 to 2825 burrows/ha along drainage canals used for flood control and water management in Southern Florida, with an estimated repair cost of approximately US$400/burrow. In Puerto Rico green iguanas entering runways are considered an air-strike hazard that can disrupt air traffic by delaying or aborting flights. The country is spending close to US$80,000 to 98,000 annually in removing iguanas from airport premises [1, 2, 43, 44].

Ecological threats to flora and fauna

Fiji has four native iguana species: Lau banded iguana (*Brachylophus fasciatus*) occurring in dry forests of eastern Fiji, Fiji banded iguana (*B. bulabula*) occupying mesic forests of central Fiji, crested iguana (*B. vitienses*) found in dry forests of western Fiji and the recently discovered *B. gau* in the island of Gau [45-47]. Both the Lau banded and Fiji banded iguana, have been listed as endangered in the IUCN Red List of Threatened Species. The critically endangered crested iguana is protected under Fiji's Endangered and Protected Species Act 2002 and is the only reptile in Fiji listed as endangered in the National Biodiversity Strategy and Action Plan (NBSAP), 1998. Although distributed in Yadua Taba, Macuata, Mamanuca and Yasawa islands, extreme density has only been recorded in the tropical dry forests of Yadua Taba which is a crested iguana sanctuary [46-48]. However, tropical dry forests are among the world's most endangered tropical ecosystems, and crested iguana faces pressures of habitat destruction and to a lesser extent predation [47]. Fiji recently launched a 'Conservation and protection of Fiji's endangered iguana species policy' to strengthen efforts for conserving the country's native iguanid population [49]. Although actual impacts of green iguanas on native iguana species are unknown in Fiji, yet it is anticipated that conservation efforts may be hampered due to the aggressive behaviour and large size of green iguanas [50]. Compared to the reproductive vigour of green iguanas, the Fijian native iguanas lay around 3-5 eggs per clutch and have long incubation periods, taking around 8-9 months to hatch with the onset of the wet season [47].

The introduction and subsequent transmission of disease from the invasive to the native species has been raised as another serious cause of concern [29]. *T. Hellebuyk et al*, [51] suggested the possibility that green iguanas may transmit *Devriesea agamarum*, the causal agent of a severe skin disease in the critically endangered Lesser Antillean iguanas (*Iguana delicatissima*) on the French Caribbean island of Saint Barthélemy. On the other hand, a study in Grand Cayman by *I. Popescu* [52] reported the likelihood of endangered blue iguanas (*Cyclura lewisi*) transmitting an infectious disease with high mortality caused by novel *Helicobacter* sp. to green iguanas. Another possible threat is the risk of interbreeding and hybridisation which may result in novel genetic combinations and alter the native gene pool. In the Lesser Antilles the introduced *I. iguana* has been known to hybridise with *I. delicatissima* [53, 54]. Such events can result in the net displacment of the native species, however, the ecological and evolutionary effects of this phenomenon are insufficiently explored. Therefore in the introduced range of distribution, interactions of green iguanas with native iguanid populations to objectively assess possibilities of disease transmission, competition, interbreeding and hybridisation, warrants further investigation.

It is also anticipated that there may be a risk of direct competition between the native and introduced iguanas for food, space, nesting sites and other resources, particularly in shared environments. Potential risk to native Fijian flora due to herbivory is a possibility since green

iguanas in their invasive range have a preference for the family Malvaceae and mangrove plants. In Fiji the beach hibiscus, *Hibiscus tiliaceus*, heavily foraged by the native iguanid population may face additional pressure from the introduced species [1]. In Puerto Rico green iguanas are known to feed on red (*Rhizophora mangle*) and black mangrove (*Avicennia germinans*) [1, 55]; it is likely that the native mangrove cover of Fiji is also a food source. Although predominantly herbivorous, green iguanas in their non-native range may be opportunistically carnivorous. An analysis of *I. iguana* gut content in Puerto Rico revealed crab, snail shell and insect components [55]. In Florida predation on the arboreal tree snail *D. multilineatus*, commonly found in open native and disturbed forests, and anthropogenic habitats has been reported [22]. Green iguanas are occasionally also known to consume bird eggs, nestlings and carrion [5, 20, 56]. The feeding behaviour of green iguanas can however play a critical role in determining plant community structure by affecting seed dispersal and germination. Green iguanas can enhance germination rates of seeds in xeric habitats such as tropical dry forests in their native range through endozoochory [57] because of the long gut passage times and microbial activity in intestines, and can even facilitate seed dispersal through epizoochory which involves external transport of seeds stuck to the iguana's snout while eating fruits [58]. Outside the native range in Puerto Rico, a study by *J.A. Burgos-Rodrı´guez* [59] reported that the impact of *I. iguana* on seed germination and dispersal for native and non-native plants was species specific. This study further emphasised that green iguanas can facilitate seed dispersal in mesic tropical habitats because of their fruit consuming habits, long retention time, defecation of relatively intact seeds and their ability to move across habitats which are relatively less accessible or have limited potential for dispersal by air. *A.C.A. Moura et al*, [60], argue that the fragment-tolerant *I. iguana* may assist seed dispersal and maintain plant communities, when local extinction of seed dispersers takes place due to deforestation and subsequent forest fragmentation as observed in the Atlantic forest of Brazil. Conversely, some authors have also reported enhanced dispersal of seeds of invasive plants [18, 55].

Such discrepancies in terms of ecological impacts highlight the need to exercise caution and gather enough empirical evidence to determine the actual threats of *I. iguana* on native Fijian flora and fauna. The foraging behaviour of green iguanas including studies on frugivory, dietary diversity and seed deposition patterns should also be further investigated to determine potential long term impacts on community structure and species composition in indigenous forests. Likewise research on actual and potential socio-economic impacts of green iguanas in the country can provide key insights into enhancing the resilience of sectors including agriculture, tourism, health and infrastructure.

Response to green iguana incursion in Fiji

In February 2010 the then Department of Agriculture under the Ministry of Primary Industries (MPI) established the American Iguana Eradication Campaign (AIEC) taskforce consisting of several government and non-government stakeholders. This taskforce had a heavy reliance on good communication with local communities to prevent and control the spread of *I. iguana* in Fiji. The following month a Biosecurity Promulgation was released by the taskforce declaring the islands of Qamea, Matagi, Taveuni and Laucala Biosecurity Emergency Areas, making the transport of green iguanas into and out of such areas an illegal activity. An amnesty period of 30 days was stipulated for surrender of any green iguanas in possession, with separate fines for individuals and corporate bodies in case of non-compliance.

The Critical Ecosystem Partnership Fund (CEPF) and the Fijian Government through a local non-government organisation NatureFiji-MareqetiViti supported a project to contain the spread of green iguanas, raise awareness campaigns for local communities and develop a

feasible eradication plan [25]. This involved trapping and killing the green iguanas, and destroying eggs and nesting sites; though at times this activity was effortless due to the excellent climbing and swimming abilities of the iguanas, untimely reporting of community sightings, and also because these tasks require a lot of team effort, tools and capturing skills. Further, awareness and training of villagers was undertaken to monitor, scrutinize and destroy green iguanas and their breeding sites, educate communities and prevent inter-island dispersal. Along with the eradication plan, herpetologists desexed the captured males and used telemetry for future identification before releasing them into the wild. Although, this provided valuable ecological data, the short duration of the study did not provide information on the actual home range size or annual spatial and habitat use [25].

In 2013 a bounty program was launched by the Biosecurity Authority of Fiji (BAF) and Nature Fiji -Mareqeti Viti which rewarded people for capturing green iguanas at a rate of $10 and $5 dollars for adults and juveniles, and 50 cents for eggs [61]. The Global Environment Facility (GEF) approved a grant of USD 3.5 million for building capacities to address invasive alien species to support the long-term survival of terrestrial endemic and threatened species on Taveuni and surrounding islets over the period 2018-2023. This project has four components: a National IAS management framework for preventing terrestrial invasive species from entering Fiji, a system for inter-island IAS prevention, surveillance and control, eradication and control of green iguanas on Taveuni and surrounding islets, and awareness, knowledge management and outreach to address IAS.

Challenges of invasive species management on islands

As per the island biogeography theory, native species richness decreases with isolation due to lower natural dispersal and colonisation on remote islands. However with globalisation and increased connectivity through trade and transport, islands are becoming increasingly vulnerable to biological invasions [62]. It has also been observed that alien invasive species richness increases on islands due to low resistance of native biota which have remained isolated from pressures such as competition or predation [63]. Prehistoric human activities have been responsible for the loss of more than 2000 bird species in the tropical Pacific islands, primarily due to predation by man and non-native mammals [64]. Around three-fourths of globally threatened bird species on oceanic islands are affected by invasive species [65]. On the other hand, the small geographical area of islands and limited entry points such as air and sea ports increases the probability of successful biosecurity operations. Globally over 1200 eradications of invasive mammals have been attempted on 800 islands, with a success rate of 85%; 60% of these attempts were made in the Pacific (particularly New Zealand) [66].

Fisher [67] emphasises three challenges in island invasive species eradication programmes. The first challenge is that since tropical Pacific herpetofauna is still being discovered, understood and described, there is great uncertainty regarding the impact and potential risk of eradication programmes on critical populations. This also gives rise to the possibility of serious short term impacts on vulnerable small populations on small islands despite long term benefits of IAS management. The second challenge pertains to monitoring responses of reptile species to management actions, and difficulties in species identification. In Fiji, communities often fail to differentiate between juvenile green iguanas and adult Fiji banded iguanas, which appear similar. Awareness programmes are therefore being conducted to facilitate species identification and protect native iguanas from extermination [25]. The third challenge emphasises the need to exercise caution, since management actions may trigger accidental spread of IAS particularly invasive reptiles to pristine, remote, uninvaded islands in the tropical Pacific [67]. A fourth challenge is enhancing the scope of invasive species research

to include perspectives of marginalised groups including indigenous people for participatory decision making. Early research on biological invasions had a strong focus on ecological aspects including impacts of invasive species on ecosystems. Recent studies have explored the economic costs of such incursions; however, the social and cultural dimensions have been largely marginalised. *A.S. Vaz et al*, [68] argue the cause of interdisciplinarity by reframing invasion science as a social-ecological phenomenon to understand multiple social and ecological drivers of invasions, develop novel approaches for management, and ensure greater coordination between science, governance and society. The influence of socio-economic and cultural processes on biological invasions emphasises the need to recognise the human dimension through transdisciplinary research [69, 70]. *K. Kapitza et al*, [71] emphasised the role of perception in the management of invasive species through the examination of both social and cultural perspectives of local communities; key to aligning the dynamics of invasions' processes and stakeholders' interests. To this end, they categorised factors influencing the social perception of IAS into five: ecological conditions, social conditions, values and beliefs, impacts, and benefits. Sustainable IAS management is possible by recognising inter- and transdisciplinary approaches in invasion science research which can facilitate participatory decision making and generate long term benefits. In the case of islands it is important that IAS research and management extend beyond the conventional assessment of impacts on biodiversity and ecosystems, by adopting a more inclusive and holistic approach that extends to agriculture, health, culture and livelihoods of local communities. Stronger coordination among island countries dealing with similar IAS in similar socio-ecological environments may further strengthen efforts on IAS management [66]. However, in the Pacific islands the ecological, economic and socio-cultural impacts of IAS are poorly understood. Similarly cost-benefit analysis and post control monitoring are often missing in IAS management initiatives in the region [72].

The need for scientific research

The invasion curve includes four stages of biological invasions management: prevention (invasive species absent), eradication (small number of localised populations), containment (rapid increase in distribution and abundance), and asset protection (widespread and abundant throughout the potential range). The invasion curve indicates that while chances of eradicating an invasive species decrease, the cost of its management increase, as time progresses. Early detection of an invasive species has lower economic cost and environmental impact with increased probability of eradication [73, 74]. Although tackling biological invasions in the early stages of the invasion curve is more cost effective, yet due to difficulties encountered in early detection and eradication, land managers are often left with the option of protecting resources from already established invasive species [75].

Scientific research is an invaluable tool for evidence based decision making. Designing research frameworks for invasive species may be influenced by immediate information requirements to support management actions and strategies including the testing and identification of practical control tools [76]. Research is critical to defining the issue, building the capacity of communities and stakeholders, and identifying effective technologies for restoration of ecological processes in affected ecosystems [74]. Research on IAS management should include environmental, social, and economic analyses of the benefits and costs for efficient decision making, assessing temporary versus long-term benefits, convincing decision-makers and funders, and reducing conflicts of interests between stakeholders [78, 79]. Counterfactual analysis can determine the cost-effectiveness of controlling biological invasions by facilitating comparison between what actually happened and what would have happened in

the absence of management interventions [80]. *D. Pimental et al,* [81] estimated that invasive species cost the world USD1.4 trillion annually including losses due to pathogens and diseases, and management costs. The high costs involved in invasive species management and the often insufficient availability of funds are major impediments for resource managers. Long term funding is critical to ensuring sustainable IAS management by investing in post invasion restoration, monitoring, and prevention of reinvasion [82]. Developing tools for ecological restoration of critical habitats and ecosystems, strategies for managing novel ecosystems to continue to deliver goods and services, and guidelines to prevent, detect, monitor, and manage IAS after major disturbances such as extreme climatic events, changes in fire regimes and land use, are other important aspects for exploration [83]. *F. Courchamp et al,* [84] also urge researchers to investigate 'surprise effects', wherein some eradication programmes are accompanied by unanticipated population explosions of seemingly harmless or undetected introduced species which were previously suppressed by the eradicated invasive species. Hence, examination of the response of invaded ecosystems to eradications is also an interesting aspect that merits consideration.

Research frameworks can also be designed keeping in mind the different stages of the invasion curve. The phase of preventing incursions can focus on identifying potential problem taxa and entry pathways, and improving methods for detection, monitoring and surveillance. In the eradication phase a cost/benefit analysis is an indispensable tool to prioritise species for eradication, which incorporates an evaluation of the threats to values. During the containment phase, research should target risk assessment for modelling different invasion scenarios including total occupation if the invasive species becomes uncontrollable. Similarly in the asset protection phase, deciphering impacts on productive and natural values, and devising strategies for the mitigation of adverse impacts can be emphasised. Each of these phases should be supplemented with lesson learning and adaptive management to guide future activities and fill knowledge gaps. Broader cross cutting questions pertain to identifying strategies for enhanced community engagement and stakeholder participation, addressing barriers to coordination, and testing novel technologies including biological control options [76].

Coupling research and management strategies

The IUCN [85] 'Guidelines for invasive species planning and management on islands' identifies 10 thematic areas which need to be covered when planning an invasive species programme for an island or islands. These thematic areas include management, generating support, building capacity, research, policy, biosecurity, prioritisation, monitoring, planning and restoration. Among these, management of established invasives, generating support and building capacity are generally considered in most of the invasive species programmes. However, the other thematic areas including research are either omitted or poorly covered in most islands countries.

Considering the invasive capacity of green iguanas in their accidental introduced range, it is important to adopt management measures in Fiji to prevent dispersal to surrounding islands and islets. Among management measures, the identification of nesting and breeding grounds, and capturing the dominant males in the population are important to curtail any further growth in population. Concurrently, it is important to localise the invasion and prevent further spread of the green iguanas to other surrounding islands and islets through biosecurity surveillance, and enhanced community awareness and participation. The enforcement of stringent biosecurity measures on jetties amongst inter-islands and systematic checking of cargos leaving the shore would be beneficial. The inability of local communities in Fiji to at times differentiate between the green iguanas and the native iguanas also impedes efforts of biodiversity conservation [25].

Awareness programs that facilitate invasive species identification have been conducted in the past and should be an ongoing process to sensitise local communities and ensure greater community participation. Vigilance of local communities and immediate reporting of sightings to concerned authorities can further assist resource managers in controlling and localising the invasion [86].

While it is important to control, contain and prevent the dispersal of green iguanas to surrounding uninvaded island ecosystems, it would also be prudent to invest in scientific research to devise sound management strategies and policies for managing invasions on small island ecosystems. The importance of research on invasive species should not be undermined in the face of management interventions, primarily because incomplete information or lack thereof generates elusive objectives and ineffective outcomes. In the absence of empirical evidence it may be ambiguous to stir heated debates on the adverse impacts of green iguanas on native Fijian flora and fauna. Similar concerns have been voiced by *J.A. Arce-Nazario and T.A. Carlo* [21] on green iguana invasion in Puerto Rico. Another seemingly important observation is that within a biogeographical context, an invasive species may be invasive in one region but not in another. Lake trout (*Salvelinus namaycush*) is highly desirable in the Great Lakes region but invasive in Yellowstone lake where it outcompetes the native cutthroat trout [87]. The Himalayan tahr (*Hemitragus jemlahicus*) 'near threatened' in its native range due to hunting and habitat loss, is invasive in New Zealand due to adverse impacts on native montane grasslands [88], and in South Africa where they cause erosion and damage vegetation [89]. Green iguanas also conform to a similar dichotomy of statuses in their native and introduced range. *B.C. Bock et al,* [4] argue that given this dichotomy, it is surprising that very few publications have a demographic focus. They further suggest that altering hatchling and juvenile survival and growth rates can assist in either augmenting over-exploited populations in the native range or reducing invasive populations in the introduced range. However, there are two noteworthy caveats for an alien species introduced in a new area. First, not all introductions are successful and even some populations which are deemed established may yet fail [90]. Low levels of niche opportunity which refers to conditions that promote invasions including resources, physical environment and natural enemies, their interactions and variation in time and space, can actually inhibit invasion success [91]. The rate of successful establishment of alien reptile and amphibian species therefore varies geographically and with type of landform. While unfavourable environmental conditions may impede successful establishment; on small islands (<6000km^2) the rate of successful establishment is more than two times that on large islands (>8000km^2) and four times that on continents [92]. Using data from *F. Kraus* [92], *R. Tingley et al,* [93] estimated 193 successfully established reptile species versus 164 unsuccessfully established species. Since invasion process comprises sequential stages (transport, introduction, establishment and spread) with barriers to be overcome for a species or population to pass on to the next stage, species establishment may not necessarily progress to invasiveness. Spreading populations face multiple, sequential, and increasingly difficult 'environmental' barriers, and invasions may fail even after spread due to boom and bust cycles. Some classic examples of this cycle are invasive budgerigars (*Melopsittacus undulatus*) imported as pets in Florida from Australia and giant African snails (*Achatina fulica*) introduced to several Pacific islands; initial population explosion was followed by a crash [94, 95]. In restricted sites such as small islands the crash may be more severe with very little chances of recovery due to the absence of metapopulation dynamics [95]. Second, not all alien species have negative impacts; some may have negligible impacts while some may even benefit native species or underpin ecosystem services such as seed dispersal and food resource for other taxa [28, 96]. As per *I.M. Parker et al,* [97] the prioritisation of management efforts should be based on an ability to distinguish between invaders with minor and major effects. The total impact of

an invader depends on the area occupied by the non-native species in its invaded range, abundance in the invaded range, and the per-capita or per-biomass effect of the invader. This is where invasive species research can provide scientific evidence, fill knowledge gaps, and facilitate efficient decision making. Coupling management strategies with scientific data can also facilitate the identification of short term and long term targets which are rigorous, methodical, cost effective and time saving. In addition, increased communication and collaboration among researchers and decision makers can translate existing research findings into policy-relevant guidelines and conversely identify specific policy needs to drive future research directions.

Keeping in mind the indisputable role of research in invasive species management, assessments on the ecological and socio-economic impacts, and social perception of green iguana incursion should be prioritised. In addition, systematic assessment of environmental, social, and economic costs and benefits, can generate greater social support for management actions, secure long term funding, and foster closer coordination between scientists, local communities, and policymakers. Similarly, information on the target species' ecology, population dynamics, and dispersal mechanisms can enhance the efficiency of management strategies, including practical control tools. Investigating the foraging behaviour and nutritional physiology, impacts on seed germination and dispersal of native and invasive plant species, ecological processes and interactions between the green and native iguanid population, can also improve our understanding of actual and potential impacts on species, ecosystems and habitats. This is particularly important for accidently introduced species whose impacts are unconfirmed but suspected to be serious.

Conclusions

Within the Pacific region, the accidental introduction of green iguanas to Fiji has spurred serious concerns due in part to their notoriety as invasive pests in the introduced range of distribution. Most of these concerns are related to adverse impacts on biodiversity, communities and livelihoods. Several management measures have been prioritised to localise the invasion and prevent irreversible damage to man and wild. However, most invasive species programmes on islands overlook the importance of research in invasive species management. There is a strong need for coupling research and management strategies to fill knowledge gaps, identify novel tools and technologies, convince decision-makers and funders, and reduce any conflict of interest between stakeholders. Greater synergies between the two approaches can also inform policies to be more effective, and to efficiently respond to on-the-ground realities.

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