Maximising conservation impact by prioritising islands for biosecurity

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Abstract Invasive alien species are one of the primary threats to native biodiversity on islands worldwide, and their expansion continues due to global trade and travel. Preventing the arrival and establishment of highly successful invasive species through rigorous biosecurity is known to be more economic than the removal of these species once they have established. However, many islands around the world lack biosecurity regulations or practical measures and establishing biosecurity will require social and financial investments. Guiding these investments towards islands where native biodiversity is at highest risk from potential invasions is of strategic importance to maximise conservation benefit with limited resources. Here we implement an established prioritisation approach, previously used to identify which islands will have the greatest conservation gains from the eradication of invasive species, to identify which islands would benefit the most from establishing or improving biosecurity. We demonstrate this approach for 318 islands in the Caribbean UK Overseas Territories and Bermuda where we considered all threatened native terrestrial vertebrates that are vulnerable to the most harmful invasive vertebrates (black and brown rats, cats, small Indian mongoose, green iguana). The approach calculates the increase in conservation threat score resulting from anticipated negative effects of potential invaders on native biodiversity, and highlighted Sombrero (Anguilla) and Cayman Brac (Cayman Islands) as important islands where threatened reptile species would likely be eliminated if rats, feral cats or mongoose invaded. Feasibility and cost implications should now be investigated more closely on the highlighted islands. The prioritisation presented here can be expanded to more islands and more invasive/native taxa (herbivores, plants and invertebrates), but requires a classification of the severity of potential impacts between invasive and native species for which currently little information exists. Besides highlighting opportunities for biosecurity, this approach also highlights where knowledge gaps about population sizes of and threats to reptiles with restricted ranges exist.

Keywords: Caribbean, feral cat, iguana, invasive mammals, mongoose, rats, reptiles

INTRODUCTION

The majority of the world's archipelagos have been invaded by non-native species, some of which have detrimental effects on native biodiversity (Atkinson, 1985; McCreless, et al., 2016; Turbelin, et al., 2017). Although some islands can be restored by eradicating certain invasive species, such operations can be expensive (Martins, et al., 2006; Holmes, et al., 2015). The limited amount of funding available for island restoration efforts has motivated managers to prioritise the islands where an eradication would yield the greatest biodiversity benefits at global and regional levels (Brooke, et al., 2007; Dawson, et al., 2015; Stanbury, et al., 2017). However, current technologies limit restoration via eradication to 15% of islands that have been invaded (Keitt, et al., 2019), hence eradication is not a universal solution to preserve global island biodiversity.

Preventing harmful species invading those islands which still have globally significant biodiversity values is an important and efficient avenue to prevent loss of biodiversity (Broome, 2007; Russell, et al., 2008; Spatz, et al., 2017). Biosecurity measures also require financial investments, both initially and in perpetuity, to detect and eliminate any potential invaders to islands (Oppel, et al., 2011; Key & Moore, 2019). Because the costs for biosecurity can be considerable, financial constraints can also limit the number of islands that can be protected with effective biosecurity measures (Moore, et al., 2010; Greenslade, et al., 2013). Here we propose to use established prioritisation approaches (Brooke, et al., 2007; Dawson, et al., 2015; Stanbury, et al., 2017) to guide the investment of resources for biosecurity to minimise the risks of invasion of non-native vertebrates to islands where they would cause the greatest loss of biodiversity. We demonstrate this approach for 318 islands that belong to United Kingdom Overseas Territories (UKOTs) in the Caribbean and Bermuda.

The islands in the Caribbean UKOTs feature globally important biodiversity (Forster, et al., 2011; Dawson, et al., 2015; Churchyard, et al., 2016), with a large number of endemic reptiles, birds, and plants. Due to centuries of human habitation and inter-island trade, most islands have been invaded by some non-native species (Hilton & Cuthbert, 2010), but only a few islands contain the complete suite of invasive vertebrate species present in the Caribbean region. In addition, >100 small and uninhabited islands are still free of invasive vertebrate species and function as refugia for some globally threatened species that cannot coexist with harmful invasive vertebrates (Dawson, et al., 2015). Preventing the invasion of non-native vertebrates that have caused significant declines to native species on other islands could secure globally significant populations of threatened vertebrates. Despite the recognised threat of invasive species to endemic biodiversity, biosecurity regulations and implementations are generally insufficient to reduce the risk of further spread of invasive species between islands in the Caribbean region (RSPB, 2017; Key & Moore, 2019).

We conducted a prioritisation that identifies those islands where the invasion of five potentially harmful invasive vertebrates could cause the greatest loss to biodiversity in the Caribbean UKOTs. We recommend immediate investment in feasibility studies and biosecurity on those islands to avoid the invasion of these five species and the subsequent loss of native biodiversity, and we recommend that similar approaches should be used in other regions, or indeed globally, to identify islands where investment in biosecurity is most urgently needed.

METHODS

Study area

We used all 318 islands in the five Caribbean UKOTs (Anguilla, British Virgin Islands, Cayman Islands, Montserrat, and Turks and Caicos Islands) and in Bermuda, which is situated 1,500 km north of the Caribbean but

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is climatically similar (Fig. 1). These islands are mostly tropical and range from small sandy islets of 0.01 ha to islands with mountain ranges and a variety of habitat types > 20,000 ha. Only 14 islands are permanently inhabited by human communities of up to 65,000 people, while the remaining islands are either completely uninhabited, function only as tourist resorts or destinations, or are visited temporarily by fishermen.

Selection of potential invasive species

To assess biodiversity loss that could result from the invasion of harmful animal species, we selected the five most harmful invasive terrestrial vertebrates (McCreless, et al., 2016) that are widespread in the Caribbean region. Green iguanas (*Iguana iguana*) are known to hybridise and compete with native reptiles (Gibbon, et al., 2000; Vuillaume, et al., 2015), small Indian mongoose (*Urva auropunctata*) are versatile predators considered one of the worst invasive species (Hays & Conant, 2007; Barun, et al., 2008), brown (*Rattus norvegicus*) and black rats (*R. rattus*) and feral cats (*Felis catus*) are efficient predators that can have detrimental effects on island biodiversity (Towns, et al., 2006; Jones, et al., 2008; Medina, et al., 2011; Nogales, et al., 2013). These five species are distributed widely across islands in the Caribbean (Kairo, et al., 2003; Dawson, et al., 2015) and are therefore potential invaders of all islands in the region.

Distribution of native and invasive species

For each island we previously collated information on the presence of native and invasive terrestrial vertebrate species for an eradication prioritisation (Dawson, et al., 2015) and a general inventory of biodiversity (Churchyard, et al., 2016), and updated these previous compilations with recent information and threat assessments (IUCN, 2017). We considered all globally threatened terrestrial vertebrate species (including marine turtles) as listed on the International Union for Conservation of Nature Red List of Threatened Species (IUCN, 2017) and all colonial seabird species and restricted range bird species. We also included reptiles of conservation concern that are endemic to a single territory or inhabit fewer than 15 islands across their range (Dawson, et al., 2015). We updated this information with new records shared by local partner organizations since 2013 (Hedges, 2017). We considered the green iguana that exists on Montserrat as a genetically distinct conservation management unit, because it is genetically closely related to the iguana on Saint Lucia, which is treated as a native species of conservation concern (Powell, 2004; Stephen, et al., 2013; Vuillaume, et al., 2015). Due to the lack of sufficient distribution data and limited existing knowledge of interactions, native and invasive plant or invertebrate species were not considered in this prioritisation.

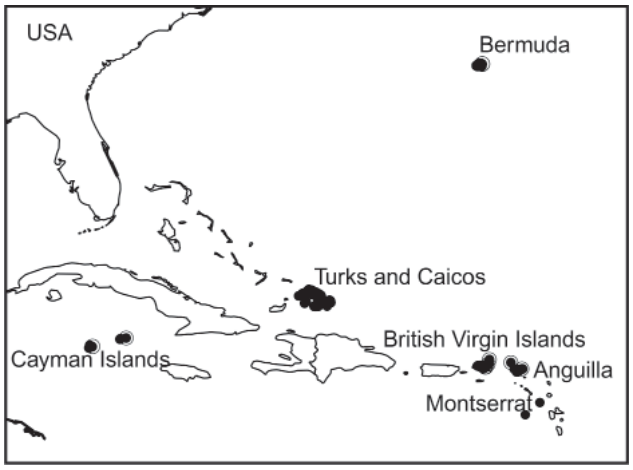

Fig. 1 Location of 318 islands (black dots) in six United Kingdom Overseas Territories where the priority for biosecurity was assessed. Circles around islands indicate the location of the highest priority islands listed in this paper.

Calculating the conservation threat score of islands

We followed the approach of Dawson, et al. (2015) to calculate the conservation threat score (termed 'conservation value' in Dawson, et al., 2015) of each island based on the sum of each native species' vulnerability. The vulnerability was calculated as the product of the global threat status, the irreplaceability, which indicates the global significance of an island's population, and the severity of impact of the most harmful invasive vertebrate species already present on an island (i.e. the species with the greatest severity of impact score; Dawson, et al., 2015; Stanbury, et al., 2017). We scored threat and impact categories on both a linear and logarithmic scale to address the arbitrariness of assigning quantitative values to normative categories (Game, et al., 2013; Helmstedt, et al., 2016). The severity of impact was classified in three categories, depending on whether an invasive species had no impact on a native species (0), small to moderate impact that would reduce population size but allow the native species to persist (1), or a severe impact that would eventually lead to the local extinction of the native species (2). We classified unassessed reptiles as 'At Risk', which received a numerical value equivalent to 'Vulnerable' (Dawson, et al., 2015).

Simulating the invasion of islands to calculate increase in conservation threat score

To quantify the magnitude of biodiversity loss that could result from invasion, we first assessed which of the five selected invasive species were already present on an island in 2016, and then simulated the arrival and invasion of those species that were not yet present in 2016. We then re-calculated the conservation threat score of each island as described above, where the vulnerability of each native species was adjusted to reflect the most harmful invasive species on the island, which may be one of the simulated invaders. We assumed that all invasive species not yet present on an island would invade, because biosecurity measurements should, in our opinion, not be tailored for a single species but guard against the arrival of a broad suite of species. However, we emphasise that our prioritisation could also be performed for single species invasions, but assessing the merits of guarding against one or another invasive species would require information about the relative invasion risk of various species.

The calculation of the conservation threat score depends on a classification of the threat posed by each invasive species to each native species, but these threats can be hypothetical for interactions between certain island endemic species and invasive species that have so far not invaded the respective island. Consequently, we drew on taxonomically related or otherwise very similar species to specify the potential threat that would result from invasion. For example, if black rats adversely affect a small *Sphaerodactylus* gecko on one island, we assumed that a similarly sized *Sphaerodactylus* species that is endemic to an island without any rats would suffer similar effects if the island were invaded by rats (Case & Bolger, 1991).

Prioritising islands for biosecurity

Islands that should receive the most immediate investment into biosecurity are those where the native fauna would face the greatest increase in conservation threat score if the five selected vertebrate species invaded. We therefore calculated the difference in conservation

value at present and after the simulated invasion of the five vertebrate species, and ranked islands based on the magnitude of this difference. We present the results as a ranking table and include information on island size and human population size for each island. These aspects will affect the complexity and cost of biosecurity measures, as well as the probability of invasive species arrival and establishment, but they did not factor into our prioritisation of islands for biosecurity, which was entirely based on the potential threat to native biodiversity. All calculations were performed in R 3.2.5 (R Development Core Team 2015) based on the code provided by Dawson, et al. (2015).

RESULTS

Of the 318 islands in our assessment, 125 did not have any invasive species on them, and 150 (47%) did not have any of the five focal invasive species. Of the islands with any of the five focal invasive species, 31 (10%) had one invasive, 117 (37%) had two, 12 (4%) had three, 6 (2%) had four, and only two islands (Tortola and Virgin Gorda, British Virgin Islands) had all five of the focal invasive species. On 183 islands (57.5%) the invasion of any of the five focal invasive species would not lead to an increase in the conservation threat score, because the native vertebrates on these islands were not at greater risk of predation from those invasive species that have not yet invaded. Thus, biosecurity measures to prevent the invasion of at least one of the five focal species would be useful on 133 islands in our assessment.

We identified several important islands across the Caribbean UKOTs and Bermuda where biosecurity could help prevent the loss of globally important biodiversity (Table 1). Two islands emerged where an invasion of non-native vertebrates could lead to an increase in the conservation threat score more than five times greater than on any other island included in our study, mostly due to the potential loss of Critically Endangered endemic reptiles (Table 1): Sombrero (Anguilla), and Cayman Brac (Cayman Islands).

Among the most important islands we identified for biosecurity, three were inhabited by >1000 people and have existing populations of rats, feral cats, and green iguanas (Cayman Brac, Grand Cayman, and Montserrat, Table 1). However, the small Indian mongoose is so far absent from those islands and reducing the risk of invasion of this efficient predator on islands that already have other harmful invasive species could help secure globally important biodiversity. Together with Montserrat, Anegada in the British Virgin Islands was among the top priorities for biosecurity to reduce the risk of invasion of black rats and small Indian mongoose, despite both islands also being a high priority for the eradication of already existing invasive species (Dawson, et al., 2015).

DISCUSSION

We show that effective biosecurity on islands in the Caribbean UK Overseas Territories could reduce the risk of further spread of harmful invasive vertebrates to islands where globally threatened reptiles and birds would be at risk. Investing in effective biosecurity procedures and educating the public and policy makers about the risks to their national heritage when no biosecurity is in place should be the immediate next steps of UK and local governments, private island owners, and international funding bodies. Our approach offers the guidance to focus on a limited number of vulnerable islands, as more than half of the islands we evaluated are not at immediate risk of further biodiversity loss from the invasion of the five invasive vertebrate species that we selected.

Similar to other prioritisations identifying islands for eradication of invasive species (e.g., Harris, et al., 2012; Dawson, et al., 2015; Stanbury, et al., 2017), our list is subject to incomplete information about the distribution of both native and invasive species. The distribution of several reptile species is poorly documented across many islands of the Caribbean, and their threat status is also poorly assessed on the IUCN Red List, both of which may affect our assessment of their local importance and therefore introduce bias to our projections of loss in conservation value (Russell, et al., 2017). Further surveys to increase the knowledge of native and invasive species on islands would be beneficial but should not be used as an argument to delay the immediate adoption of effective biosecurity protocols to safeguard the most important islands that we identified.

Besides thorough knowledge about the native and invasive species occurring on an island, our approach also requires a classification of the interactions between native and invasive species. Because these interactions can be hypothetical for single-island endemic native species that have not been exposed to invasive species, due caution is necessary when interpreting the output of our prioritisation. We used the response of taxonomically similar species to the same invasive species to predict biologically plausible consequences of an invasion, but interactions between native and invasive species are often complex and unpredictable (Simberloff & Von Holle, 1999; Simberloff, 2006). We encourage researchers to provide robust and reliable predictions about the potential consequences of invasions to assist with strategic investment decisions for reducing the risk of invasive species becoming established on islands harbouring globally important biodiversity (Moore, et al., 2010).

In summary, we demonstrated that biosecurity is not only important on small uninhabited islands or privately owned tourist resorts where natural habitats remain and endemic and globally threatened species persist. Even on large and populated islands such as Grand Cayman, Cayman Brac, and Montserrat, the invasion of small Indian mongoose could result in a significant deterioration of the conservation status of several globally threatened vertebrates (Hays & Conant, 2007). We therefore urge local governments, private island owners (e.g. Mosquito Island) and communities to carefully inspect all incoming cargo and people and establish ongoing measures to detect and remove any new invasive species. Training of border officials and conservation staff, public education and awareness campaigns targeting the accidental introduction of invasive species onto uninhabited islands by visiting people (e.g. fishermen, tourists) should also be implemented, because international and domestic biosecurity measures are currently weak across all Caribbean UK Overseas Territories (Key, 2017; RSPB, 2017). Laws governing biosecurity measures in the Caribbean UK Overseas Territories and Bermuda are disjointed, not comprehensive and scattered through various environmental, agricultural and customs regulations. Collaboration under existing national legislative mechanisms may improve the situation quickly prior to enacting any new legislation (RSPB, 2017). We would also encourage regional collaboration in developing biosecurity measures, information sharing and learning from any existing biosecurity initiatives.

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Table 1 The top 25 islands in Caribbean UK Overseas Territories and Bermuda where the invasion of five common vertebrate species could potentially cause the greatest increase in threats to native biodiversity. Note that some invasive species are already present on some islands (i.e. those with current threat score > 0), and only the potential new invaders are listed; islands with a current threat score >0 would also benefit from the removal of already existing invasive species. Human population size and island area are provided for information, as they will affect invasion risk and effort required for biosecurity. The current and post-invasion threat scores are calculated as the sum of all impact scores of invasive species on all threatened native species present on an island before and after potential invasion.

Island	UKOT	Human popul'n	Island area (ha)	Current threat	Post-invasion threat	Potential increase in conservation threat score	Potential invaders	Globally threatened species at risk from invasion
Sombrero	Anguilla	0	29.2	0.0	5,729.2	5,729.2	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Sphaerodactylus* sp., *Ameiva corvina*
Cayman Brac	Cayman Islands	2,098	3,889.4	1,364.7	6,879.3	5,514.5	Small Indian mongoose	*Dendrocygna arborea, Crocodylus acutus, Anolis luteosignifer, Typhlops epactius, Tropidophis schwartzi, Anolis maynardii, Celestus maculatus, Cyclura nubila caymanensis*
Mosquito Island	British Virgin Islands	0	49.2	50.6	978.1	927.5	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Spondylurus semitaeniatus, Sphaerodactylus parthenopion, Cyclura pinguis, Amphisbaena fenestrata*
Little Scrub Island	Anguilla	0	4.1	0.0	737.6	737.6	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Ameiva corax*
Grand Cayman	Cayman Islands	53,160	20,159.4	1,249.5	1,986.5	737.0	Small Indian mongoose	*Eretmochelys imbricata, Chelonia mydas, Caretta caretta, Dendrocygna arborea, Crocodylus acutus, Cyclura lewisi, Anolis conspersus, Crocodylus rhombifer, Typhlops caymanensis, Tropidophis caymanensis*
Salt Island	British Virgin Islands	0	78.2	161.7	406.6	244.9	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Eretmochelys imbricata, Spondylurus semitaeniatus, Spondylurus sloanii, Amphisbaena fenestrata*
Carval Rock	British Virgin Islands	0	1.0	0.0	242.7	242.7	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Amphisbaena fenestrata, Sphaerodactylus* sp.
Anegada	British Virgin Islands	200	3,844.4	11,103.9	11,313.9	210.0	Black rat, small Indian mongoose	*Chelonia mydas, Eretmochelys imbricata, Dermochelys coriacea, Cyclura pinguis, Spondylurus anegadae*
Nonsuch Island	Bermuda	0	8.2	106.0	310.0	204.0	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Plestiodon longirostris, Pterodroma cahow*

Table 1 (continued) The top 25 islands in Caribbean UK Overseas Territories and Bermuda where the invasion of five common vertebrate species could potentially cause the greatest increase in threats to native biodiversity. Note that some invasive species are already present on some islands (i.e. those with current threat score > 0), and only the potential new invaders are listed; islands with a current threat score >0 would also benefit from the removal of already existing invasive species. Human population size and island area are provided for information, as they will affect invasion risk and effort required for biosecurity. The current and post-invasion threat scores are calculated as the sum of all impact scores of invasive species on all threatened native species present on an island before and after potential invasion.

Island	UKOT	Human populn	Island area (ha)	Current threat	Post-invasion threat	Potential increase in conservation threat score	Potential invaders	Globally threatened species at risk from invasion
Horn Rock	Bermuda	0	0.3	106.0	310.0	204.0	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Plestiodon longirostris, Pterodroma cahow*
Inner Pear Rock	Bermuda	0	0.9	105.3	308.5	203.3	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Plestiodon longirostris, Pterodroma cahow*
Ginger Island	British Virgin Islands	0	102.2	0.0	201.3	201.3	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Eretmochelys imbricata, Spondylurus semitaeniatus, Amphisbaena fenestrata*
Fallen Jerusalem	British Virgin Islands	0	19.5	0.0	194.4	194.4	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Eretmochelys imbricata, Spondylurus semitaeniatus, Amphisbaena fenestrata*
Fish Cay	Turks and Caicos	0	8.5	0.0	170.4	170.4	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Eretmochelys imbricata, Cyclura carinata*
Bush Cay	Turks and Caicos	0	7.8	0.0	168.4	168.4	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Eretmochelys imbricata, Cyclura carinata*
Round Rock	British Virgin Islands	0	6.4	0.0	140.3	140.3	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Spondylurus semitaeniatus, Amphisbaena fenestrata*
Montserrat	Montserrat	4922	10157.4	12571.3	12708.1	136.8	Green iguana, small Indian mongoose	*Dermochelys coriacea, Eretmochelys imbricata, Chelonia mydas, Caretta caretta, Turdus lherminieri, Icterus oberi, Diploglossus montisserrati, Leptodactylus fallax, Anolis lividus, Mabuya montserratae, Iguana iguana* (Montserrat)
Big Sand Cay	Turks and Caicos	0	54.5	0.0	131.7	131.7	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Chelonia mydas, Cyclura carinata, Leiocephalus psammodromus*

Table 1 (continued) The top 25 islands in Caribbean UK Overseas Territories and Bermuda where the invasion of five common vertebrate species could potentially cause the greatest increase in threats to native biodiversity. Note that some invasive species are already present on some islands (i.e. those with current threat score > 0), and only the potential new invaders are listed; islands with a current threat score >0 would also benefit from the removal of already existing invasive species. Human population size and island area are provided for information, as they will affect invasion risk and effort required for biosecurity. The current and post-invasion threat scores are calculated as the sum of all impact scores of invasive species on all threatened native species present on an island before and after potential invasion.

Island	UKOT	Human populn	Island area (ha)	Current threat	Post-invasion threat	Potential increase in conservation threat score	Potential invaders	Globally threatened species at risk from invasion
Six Hills East Cay	Turks and Caicos	0	3.1	0.0	123.0	123.0	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Cyclura carinata, Aristelliger hechti*
Six Hills West Cay	Turks and Caicos	0	6.2	0.0	123.0	123.0	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Cyclura carinata, Aristelliger hechti*
Middleton Cay	Turks and Caicos	0	4.6	0.0	121.5	121.5	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Cyclura carinata, Tropidophis greenwayi*
Long Cay (Turks)	Turks and Caicos	0	18.4	0.0	117.0	117.0	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Cyclura carinata, Leiocephalus psammodromus*
White Cay	Turks and Caicos	0	2.4	0.0	111.8	111.8	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Cyclura carinata*
Indian Cay	Turks and Caicos	0	2.9	0.0	111.3	111.3	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Cyclura carinata*
Plandon Cay	Turks and Caicos	0	15.5	0.0	110.3	110.3	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Cyclura carinata*
Middle Creek Cay	Turks and Caicos	0	41.6	0.0	110.3	110.3	Brown rat, black rat, feral cat, green iguana, small Indian mongoose	*Cyclura carinata*

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