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ABSTRACT: The U.S. Department of Defense is in the process of restructuring military assets in the Pacific Basin that includes moving more troops to Guam. As a result of this process, the potential risk of vertebrate invasive species may increase across Micronesia. We identified the pathways through which goods and materials are moved throughout the Pacific basin and then developed a list of the most likely invasive vertebrates that could be moved in these pathways. We reviewed the available literature, interviewed experts, and evaluated pathways according to a fixed set of criteria to determine the risk of the pathway to transport invasive species. Some of the potentially high-risk pathways are military and commercial aircraft and vehicles, mail, shipping containers, and aquaculture. The following are species that may spread or become established in the Pacific without the implementation of measures to reduce risk: brown tree snake, habu, Asian beauty snake, common wolf snake, anole, gecko, coqui frog, cane toad, red-vented bulbul, Indian myna, and Indian mongoose.

KEY WORDS: *Acridotheres tristis*, anole, *Anolis sagrei*, Asian beauty snake, biosecurity, *Boiga irregularis*, brown tree snake, *Bungarus fasciatus*, cane toad, *Carlia fusca*, common wolf snake, coqui frog, *Elaphe taeniura* ssp., *Eleutherdactylus coqui*, gecko, Guam, habu, Hawaii, *Hemidactylus frenatus*, *Herpestes javanicus*, Indian mongoose, Indian myna, invasive species, *Lycodon capucinus*, Micronesia, military, Pacific, pathways, *Protobothrops mucrosquamatu*, *Pycnonotus cafer*, red-vented bulbul, risk

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INTRODUCTION

The Department of the Navy has been directed by the Office of the U.S. Secretary of Defense to develop an Environmental Impact Statement / Overseas Environmental Impact Statement (EIS/OEIS) in support of the anticipated Guam and Commonwealth of the Northern Mariana Islands (CNMI) Military Relocation to occur starting in 2010 and ending in 2016. The draft version of this document has been released to the public (Dept. of Navy 2009) and addresses the impact of moving the 3rd Marine Expeditionary Unit from Okinawa, Japan to Guam, the construction of new pier facilities on Guam to host a transient carrier battle group (CSV), the construction of housing and training facilities on Guam and the island of Tinian in the CNMI, and the location of an Army Air and Defense Task Force to Guam. This will require the construction of facilities to support the permanent relocation of 8,600 Marine Corps personnel, 630 Army personnel, and their combined associated 9,000 dependents (Dept. of Navy 2009). Facilities to support the ships and the approximately 7,200 transient sailors will also have to be constructed, although the sailors will generally be housed aboard ship when in harbor (Dept. of Navy 2009). Construction activities are anticipated to peak in 2014, requiring approximately 18,000 construction workers. Estimates for the maximum amount of material flowing through the Port of Guam to support the construction phase of the relocation are for a peak shipping container volume of 190,000 containers per year and a bulk cargo volume of 320,000 tons in 2014/2015 (Dept. of Navy 2009). This includes both civilian and military commercial traffic. The increase in troops, dependents, and contractors would result in an increase in the population of Guam by more than 20%.

The increase in movement of people and materials provide numerous opportunities for the inadvertent transport of invasive species throughout the region. Guam is a central hub in the movement of goods between Asia and the continental United States (CONUS). The two major shipping companies in the Micronesian region are Matson and Horizon. Much of the commercial ship traffic for these shipping lines transits between the west coast of the United States through Hawaii and Guam to/from Asia (PB International 2007). Additionally, there are commercial fishing fleets from Asia that call on the Port of Guam (PB International 2007). Guam is a regional shipping hub for goods being transported to islands in the CNMI and the Federated States of Micronesia (FSM) (PB International 2007, Dept. of Navy 2009). We have been identifying the pathways by which the people and associated materials and goods will move through the region and evaluating those pathways for the risk of unintentionally transporting vertebrate invasive species throughout the region.

METHODS

The risk analysis process we are using was developed jointly by the National Invasive Species Council Prevention Committee and the Aquatic Nuisance Species Task Force, collaborating as the Pathways Work Team, in support of the NISC Management Plan (NISC Pathways Work Team 2005, NISC Pathways Committee 2007). The risk analysis focuses on a pathway, the means by which an organism is transported, not the organisms themselves. Because of a lack of data for most pathways, the analysis is numerical based but is not truly quantitative for number of organisms transported by various pathways. All of the major pathways that animals may be transported around Micronesia were identified and then refined to provide a complete picture of animal movement (classification based on Olson et al. 2001, Table 2).

The risk of establishment or spread of invasive species for each pathway is evaluated based on a three-step nested process that assigns a risk factor based on aspects of the pathway and the animals that may be transported. First, pathways are populated from a list of potentially invasive species that might gain access to the pathway. The animals that may be transported provide a risk impact category. Risk impact categories are assigned based the highest impact of the invasive species being transported and include human health, economic, and ecological risks in descending order. Thus, a species that poses a human health risk is assigned the highest category, even though the number of people that are affected by the health risk is small compared to those affected economically. Second, the scope level of the pathway is evaluated based on the geographic area potentially affected by the pathway. This ranking uses the number of incidents that may occur and how large an area may be affected. A pathway that provides for multiple invasive species across internationally boundaries is ranked the highest, whereas a pathway limited to a single potential event in a localized area is ranked the lowest. Third, the pathways are then evaluated according to a fixed set of criteria (16 questions) that captures the capacity of the pathway to transport invasive species and the likelihood that the invasive species will move through the pathway undetected in sufficient numbers to establish an incipient population (Table 1). A level of risk and a level of uncertainty are assigned for each question and an average numerical risk estimate value is calculated. Each pathway is assigned a risk score based on the combination of these three steps: risk impact category (ecological, economic, health); a pathway scope level (local to international); and a numerical risk level. The pathways are categorized according to the risk scores as no harmful impact, ecologically significant impact, economically significant impact, and human health impact. The final numerical score provides a rough index for prioritizing the pathways for significance and incorporates a summary of the uncertainty in the analysis.

RESULTS

We followed the pathway structure proposed by the NISC Pathways Committee (2007). Examples of pathways for each of the categories are presented in Table 2. The list of pathways in Table 2 is not exhaustive. We developed detailed descriptions of single pathways that might allow for the introduction of invasive species with a specified point of origin, and point of destination based on literature reviews and interviews with regional experts. Pathways have Guam as both a possible final destination and as a point of origin. There may be significant risk in transporting an invasive species from, or through, Guam to Hawaii, or the west coast of the United States. Examples of invasive species considered during the analysis are presented in Table 3.

Table 1. Criteria evaluated in assigning risk for a pathway and the associated uncertainty in that risk estimate (NISC Pathways Committee 2007).

What is the level of risk of this pathway:

1. Introducing invasive species on a frequent basis?
2. Transmitting a large number of different viable species?
3. Transmitting a large number of viable individuals per invasive species?
4. Introducing invasive species into hospitable ecosystems or habitats?
5. Introducing invasive species at multiple entry points?
6. For transmitting invasive species, based on standard treatment measures?
7. To assist spread of invasive species to uncontaminated shipments during transport or storage?
8. For transmitting invasive species based on current screening techniques?
9. Transporting an invasive species that is difficult to detect once in the destination ecosystem?
10. Transmitting invasive species that are capable of surviving in multiple habitats?
11. Transmitting invasive species into ecosystems conducive to natural spread?
12. Transmitting invasive species that are further spread by human activities?
13. Introducing invasive species that are known to be invasive in similar ecosystems but are not yet in the U.S.?
14. Transmitting invasive species that are novel and have limited scientific data upon which to develop control methods?
15. Transmitting an invasive species in which existing control options are too expensive to implement? and,
16. To what degree does the pathway's own ecosystem enhance the viability of opportunity for transmission of invasive species?

Table 2. Pathways identified as having significant risk for the establishment of an invasive species.

Transportation	Living Industry	Miscellaneous
Aircraft	Aquaculture	Ecosystem Disturbance
Construction Equipment	Cut Flowers	Garbage
Baggage	Christmas Trees	Natural Spread of Populations
Packing Materials	Landscaping	Aquatic Waterways, Drainage Systems
Mail	Materials/Plants	
Travelers/Troops		
Consumables		
Shipping Containers		
Vehicles		
Construction Materials		
Ships		

Table 3. **Species that have been identified as potentially invasive and are being used to populate the pathways in the risk analysis.**

Common Name	Class: Order	Scientific Name	Origin in Pathway Analysis	Risk Category*
Brown treesnake	Reptilia: Squamata	*Boiga irregularis*	Guam	A - Health
Habu (Taiwan pit viper)	Reptilia: Squamata	*Protobothrops mucrosquamatu*	Taiwan, Okinawa	A - Health
Asian beauty snake	Reptilia: Squamata	*Elaphe taeniura* ssp.	China, Okinawa, Thailand, Vietnam, Philippines	C - Ecological
Common wolf snake	Reptilia: Squamata	*Lycodon capucinus*	Thailand, Vietnam, Philippines, Australia	C - Ecological
Banded krait	Reptilia: Squamata	*Bungarus fasciatus*	India, SE Asia	A - Health
Curious skink	Reptilia: Squamata	*Carlia fusca (syn. C. ailanpalai)*	Southern US, Guam	C - Ecological
Brown anole	Reptilia: Squamata	*Anolis sagrei*	Hawaii, Taiwan, Southeastern US	C - Ecological
House gecko	Reptilia: Squamata	*Hemidactylus frenatus*	Philippines, Hong Kong, Guam	C - Ecological
Coqui frog	Amphibia: Anura	*Eleutherdactylus coqui*	Hawaii, Florida	B - Economic
Red-vented Bulbul	Aves: Passeriformes	*Pycnonotus cafer*	Many Pacific Islands, China	C - Ecological
Indian myna	Aves: Passeriformes	*Acridotheres tristis*	Hawaii, Federated States of Micronesia, Australia	B - Economic
Indian mongoose	Mammalia: Carnivora	*Herpestes javanicus*	Hawaii, Japan	C - Ecological

*The Risk Category is from the Risk Analysis and identifies the level of impact a pathway containing this species might have. Risk category A (Health) assumes both B (Economic) and C (Ecological) may occur. Risk category B assumes C may occur.

Data collection, to address each of the 16 questions for each of the pathways we have identified, is ongoing. Discussions of general invasive species issues with regional experts have led us to conclude that military aircraft and vehicles used in training exercises, commercial aircraft, the U.S. Mail, the handling of commercial shipping containers, and aquaculture are likely to be high-risk pathways for the introduction and or movement of invasive species in the region or to the continental United States.

DISCUSSION

The risk analysis we are conducting is pathway driven, as there is no easy way to identify species that will be invasive in a new location. Early investigators of invasion held that up to 10% of species would be successful if translocated to a new location (Williamson 1996, 1999; Holmes 1998; Smith et al. 1999). However, summaries of species invasion (Bomford 2003) have found that nearly 30% of all bird species and 60% of mammal species establish populations when translocated to new locations. The successful establishment of a species in a new location is based on traits of the animal being transported, characteristics of the environment, and the frequency and number of animals being transported (Pitt and Witmer 2007). Traits associated with the animal include reproductive rate, food preferences, ability to avoid detection, and the potential competitors and predators of the invading animal. The methodology we are using attempts to capture many of these factors in the analysis. The risk analysis methodology we use addresses the unintentional release of potential invasive species by pathway. It does not assess the risks associated with the pet trade or smuggling. Many invasive species have been intentionally or unintentionally released as result of a species being brought in to a new location via the pet trade (Kraus 2003).

The pathway risk analysis approach is sensitive to the species identified as potentially being transported through the pathway. Those species perceived as posing a health or economic risk elevate the level of risk. Some of the species we consider to be of considerable concern in our risk analysis are identified in Table 3. Many of these species have already been introduced into Pacific islands, but highlighting the risk of invasive species pathways may slow their spread. Some species' effects are already well documented such as brown treesnakes, coqui frogs, and mongoose. Brown treesnakes have decimated the birds and lizards in Guam, have significant economic affects, and pose risk to human health. Coqui frogs and mongoose have had significant and varied economic and ecological effects in Hawaii. However, more subtle changes have occurred ecologically as house geckos have displaced native lizards and affected native insects (Rödder et al. 2008). Species identified as having ecological risk may still be of high priority, as it has been demonstrated that when new species establish in a location, approximately an equivalent number of local species becomes extinct (Elton 1958, Vitousek et al. 1997). This has the potential to invoke Section 7 of the Endangered Species Act when the local population is the only population of that species.

One of the areas we would like to explore in developing the risk analysis is the possible movement of sympatric species in the same or parallel pathways. With regard to herptiles, it may be possible to move both a predator and a sympatric, prolific prey species to a new location. This area of future work seems important in developing the Micronesian Biosecurity Plan as traditional approaches have focused on detection of a single high-risk species.

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