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Sinking ships: conservation options for endemic taxa threatened by sea level rise

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Abstract Low-elevation islands face threats from sea level rise (SLR) and increased storm intensity. Evidence of endangered species' population declines and shifts in vegetation communities are already underway in the Florida Keys. SLR predictions indicate large areas of these habitats may be eliminated in the next century. Using the Florida Keys as a model system, we present a process for evaluating conservation options for rare and endemic taxa. Considering species characteristics and habitat, we

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assess central issues that influence conservation options. We contrast traditional and controversial options for two animal and two plant species giving special emphasis to perceptions of ecological risk and safety from SLR and suggest courses of action. Multiple strategies will be required to spread extinction risk and will be effective for different time periods. Global climate change presents an uncertain, perhaps no-analog future that will challenge land managers and practitioners to re-evaluate equilibrium-state-conceived laws and policies not only for these taxa, but for many facing similar threats. To embrace conservation in a changing world will require a new dialogue that includes controversial ideas, a review of existing laws and policies, and preparation for the oncoming change.

1 Introduction

Global climate change (GCC) is predicted to cause rapid species-level extinctions (Thomas et al. 2004). Recent estimates that take into account Greenland and Antarctic ice melt indicate that sea level rise (SLR) could exceed 1 m by 2100 (Overpeck and Weiss 2009; Donoghue 2011). With increased sea surface temperature, models also show a high probability of more intense storms (e.g., Bender et al. 2010), which will likely exacerbate storm surge flooding especially along low elevation coasts and islands (e.g., Karim and Mimura 2008; Mousavi et al. 2010). These predictions present dire threats for natural and human communities residing in low-elevation coastal areas and particularly low elevation islands. Island species are isolated, such that appropriate habitat to which species could move may be separated by many kilometers of life-threatening matrix (e.g., Ross et al. 2009). Hence, rare species on low-elevation islands have particularly high vulnerability to GCC threats.

Evidence of rare species' population decline, shifts in plant communities, and multi-trophic effects already have been documented on the low-elevation islands of the Florida Keys. For example, high salinity is associated with the precipitous decline of the federally endangered Key tree cactus (*Pilosocereus robinii*) in the Florida Keys (Maschinski et al. 2009). SLR has caused vegetation shifts from mesophytic pine rockland toward halophyte-dominated communities on Sugarloaf Key (Ross et al. 1994, 2009). Following heavy damage from Hurricane Wilma in 2005, the federal candidate Florida leafwing butterfly (*Anaea troglodyta floridalis*) could no longer be found in the lower Florida Keys. It is believed that slow recovery of the leafwing's host plant following the storm affected the butterfly's ability to recolonize the lower Keys (USFWS 2009).

Using the Florida Keys as a model system, we present a process for evaluating conservation options for rare endemic species threatened by SLR and intensified storm activity. We identify current knowledge of species ecology and review central ecological issues that influence conservation options. Contrasting traditional and controversial options for two animal and two plant species, we consider perceptions of ecological risk and safety from SLR and suggest courses of action. We describe multiple strategies that will be required to avoid extinction and conserve these species over an immediate and long-term timeframe. Although this work focuses on the Florida Keys, it is applicable to other low-elevation islands such as the Maldives in the Indian Ocean, Kiribati and Tuvalu in the Pacific Ocean, and sky-island mountains whose rare populations face analogous situations.

2 Study site

The Florida Keys are an archipelago that extends 338 km southwest of Florida, U.S.A. (Fig. 1). Although the continental U.S.A. shelf included the Keys 20,000 ybp (Williams et al. 1990), with rapid SLR following the last Pleistocene glaciation, most of the Keys became separated from the mainland by the shallow waters of Florida Bay about 4–5 K ybp (Fig. 1; Lidz and Shinn 1991). Since separation, Keys terrestrial species have been relatively isolated and have continued along separate evolutionary trajectories from their mainland counterparts (Crouse 2005). Current separation between adjacent islands ranges from <1 to 11 km, and from islands to mainland distances range from 1 km to 100 km.

Though located in a subtropical region by latitude, the climate is considered tropical (Ross et al. 1992). The Florida Keys are divided into three regions (upper, middle, and lower) with different mean elevation, precipitation and underlying geology. The Lower Keys are effectively isolated from the Middle Keys by the 11 km Moser channel (Crouse 2005). From 1913 to 1990 sea level has risen at a rate of ~2.4 cm per decade at Key West in the Lower Keys (Ross et al. 1994), and recent data show the rate of SLR is increasing (Walton 2007). Because most of the land area in the Florida Keys is below 2 m (Ross et al. 1992) and the highest elevation is 5.5 m, scenarios projected for SLR (Mitrovica et al. 2009) indicate that most terrestrial habitat may be eliminated within the next century (Fig. 1; Zhang et al. 2011; Stanton and Ackerman 2007).

The Florida Keys support diverse plant communities arranged along an elevation gradient from the coastal salt-tolerant mangroves, to transitional buttonwood forest and salt marshes that receive periodic inundation and have moderate salt tolerance, to salt-intolerant tropical hardwood hammock and pine rocklands at higher elevations, where the most diverse flora and fauna are found (Ross et al. 1992, 2009).

3 Endemic species at risk

For purposes of our examination, we selected two rare plant and two rare animal taxa that are endemic or near-endemic to the Florida Keys. The two plant taxa, Big Pine partridge pea (*Chamaecrista lineata* (S.W.) Greene var. *keyensis* (Pennell) H.S. Irwin & Barneby) and sand flax (*Linum arenicola* (Small) H.J.P. Winkler), are candidates for listing under the U.S. Endangered Species Act (ESA) and have G5T2, G1G2 global ranks, respectively. Both occur in pine rockland habitat on Big Pine Key, have low to moderate fecundity, and limited dispersal capability. Sand flax has 10 addition occurrences on additional Keys and mainland Florida (USFWS 2009). Both require open habitat, have low competitive ability, and low tolerance to salinity and inundation (Bradley and Saha 2009). Clearing pine rocklands has eliminated much of their habitat; fire suppression has reduced the health and resilience of the remaining habitat; and fragmentation limits natural migration or range expansion. No genetic studies have been done on these plant species. Big Pine partridge pea has a Caribbean origin, with close relatives in Florida, Cuba, the Bahamas, and Hispaniola, whereas *Linum* is a widespread temperate genus.

The two animal taxa, the Key deer (*Oedocoileus virginianus clavium*) and the Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*), are listed as endangered

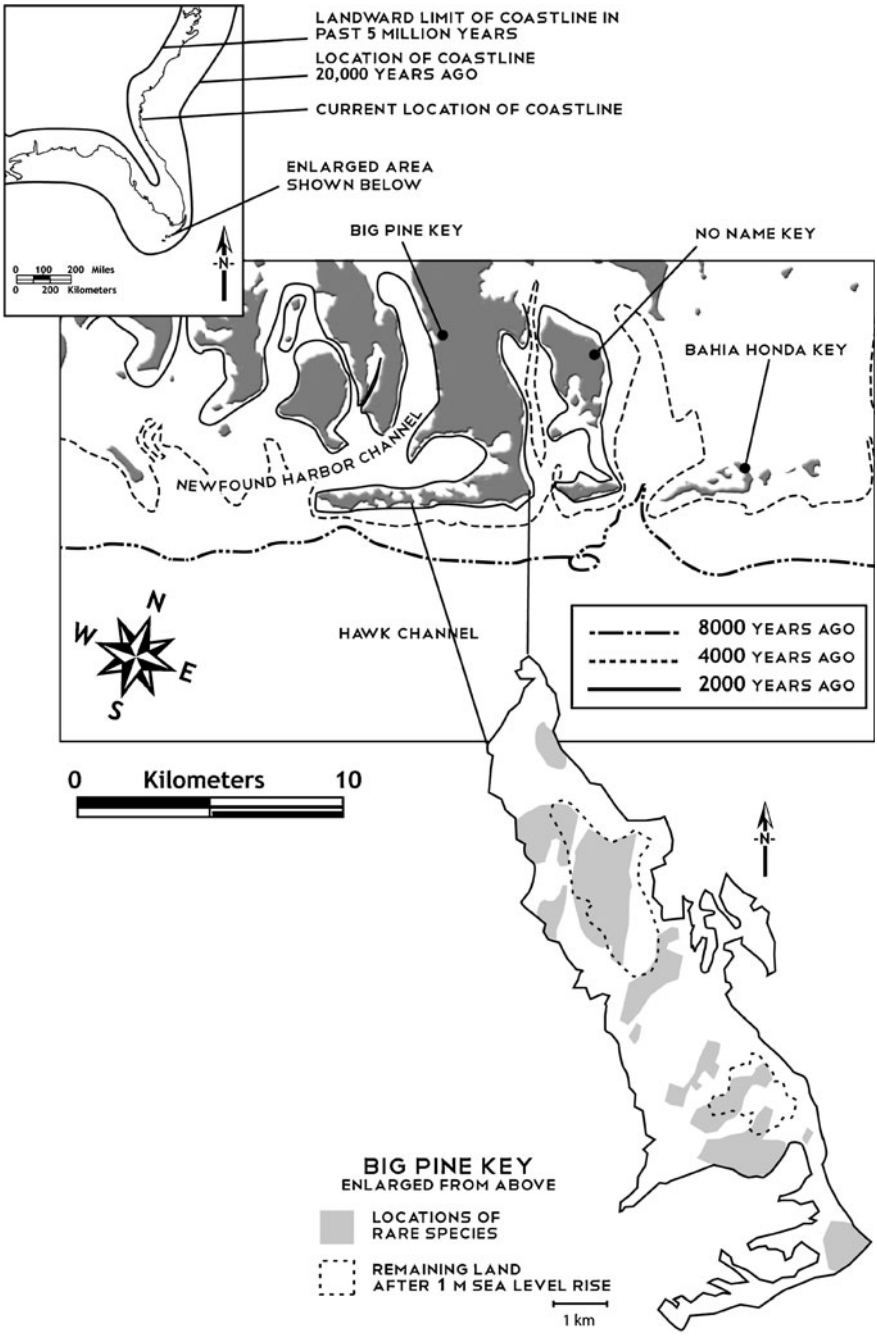

Fig. 1 Map of Florida Keys showing historic and future shorelines. Insert of Big Pine Key shows general habitat of all four target taxa in relation to present and projected future shorelines. Note that Big Pine Partridge pea only occurs on Big Pine Key, while the animals have natural and reintroduced populations on other keys, and sand flax has populations on other keys and mainland Florida. Modified from Williams et al. (1990), Lidz and Shinn (1991), Forys and Humphrey (1999b) and Liu et al. (2005)

under the ESA. These animals have few individuals, low fecundity, and small home range sizes (USFWS 1999). Protection has improved population growth of Key deer; a population viability analysis (PVA) conducted for 1998–2000 indicated populations were at or approaching carrying capacity, such that they were negatively affecting vegetation (Lopez 2001). In contrast, a PVA for the Lower Keys marsh rabbit predicted extinction in <40 years (Forys and Humphrey 1999a).

Genetic studies indicate that Key deer are genetically distinct from mainland *O. virginianus* (USFWS 1999). The Lower Keys marsh rabbit (*S. palustris hefneri*) has island populations that are genetically distinct and have lower heterozygosity than mainland conspecifics; there is genetic structuring between eastern and western portions of the Lower Keys populations (Crouse 2005). Though both taxa share common ancestry with mainland conspecifics, genetic studies have not been linked to molecular clocks, so the timing of separation is unclear.

Key deer are capable of dispersing between islands, but studies conducted within the last decade indicate that they tend to have small home ranges and strong home site fidelity (Lopez 2001). Lower Keys marsh rabbits can swim when pursued (USFWS 1999), but swimming is rare (Crouse 2005). Male marsh rabbits have moved 827 m from their natal site, while females tend to remain in their natal patch, moving only 82 m (Forys and Humphrey 1999b). Habitat fragmentation limits range expansion; habitat loss and roads threaten both taxa. The greater the distance between suitable patches the less likely successful migration will be (Forys and Humphrey 1999b). With SLR, both animal species can perhaps migrate to higher ground within islands, but this option is time-limited. SLR will also reduce fresh water availability, which will likely cause mortality (Lopez 2001). Because standing fresh water is only available in the interior of Lower Keys islands (Ross et al. 1992), the total available suitable habitat with 1 m SLR will be very restricted (Fig. 1).

Although no translocations have been attempted with the plants, the animal translocations have met with mixed success. A trial translocation of three adult female Key Deer resulted in two of three deer crossing a 2.4 km channel to return to their home site after only 1 month (Lopez 2001). Two Lower Keys marsh rabbit reintroductions had at least short-term success. Faulhaber (2003) introduced 13 rabbits into 13 ha of suitable habitat and had 81% survival after five months. Perry (2006) introduced seven rabbits to Water Key and reported 100% survival and evidence of reproduction after five months. Individuals showed release site fidelity, staying within 100–300 m. Long-term success of these translocations is unknown.

4 Central issues influencing conservation options

4.1 Demography

Fecund species with large and numerous populations have a higher probability of withstanding stress or catastrophe than species with low fecundity, few individuals, and few populations. Larger populations tend to have greater genetic diversity, with some exceptions (Reed and Frankham 2003). Standardized minimum viable population (MVP_{st}) sizes needed to sustain adequate genetic diversity for survival, adaptation, and evolution have been estimated to be 4,824 individuals for plants and 3,876 for mammals (Traill et al. 2007). Small populations have high extinction risk from site-specific demographic and environmental stochasticity (Lande 1993), and

populations at the edge of a species' range are especially prone to environmental stochasticity as they may be at the edge of their physiological and adaptive limits (Baguette 2004). Fifteen to 20 well-connected patches are generally regarded as the minimum number of interacting local populations necessary for a metapopulation to maintain a balance between local extinctions and recolonizations (Hanski et al. 1996), but fragmentation seriously undermines metapopulation capacity (Hanski and Ovaskainen 2000). In general, conservation strategies that support increasing population size, increasing the total number of populations, and connecting habitats of existing populations are supported by theory.

4.2 Genetics

Genetic diversity and the speed at which species can adapt to GCC is a significant concern for species threatened by SLR. Theoretically, high genetic diversity can enhance species' persistence in a changing environment (Lynch and Lande 1993), but species-specific genetics, history, and habitat needs will influence whether a species can withstand GCC and SLR (Bouzat 2010). Rapid evolutionary shifts in many traits, including phenology, body size, growth rate, morphology, resistance to pesticides and herbivory, and tolerance to metals and pH have been documented for plants, invertebrates, birds, fish, and lizards in response to changes in environment (reviewed in Ashley et al. 2003; Stockwell et al. 2003; Kinnison and Hairston 2007). Yet, significant genetic variation in quantitative traits alone will not guarantee a species' ability to adapt to changes in climate, because some species may have low fecundity and/or low heritability for specific combinations of quantitative traits needed to withstand climatic change (Etterson 2004). Tolerance to both salinity and inundation—possible plant adaptations to SLR—has not been successfully achieved in intentional crop breeding programs (Barrett-Lennard 2003), and has evolved in few salt marsh and mangrove plant taxa. Alternatively, dispersal evolution for animals and plants is possible as a response to SLR (see discussion below).

Understanding gene flow among populations has implications for selecting appropriate conservation strategies to preserve the long-term viability of rare taxa faced with GCC (Storfer 1999; Stockwell et al. 2003). While gene flow can reduce inbreeding and accumulation of deleterious mutations of some isolated populations (Lande 1995), for others it can disrupt co-adapted gene complexes and counteract local adaptation to the specific conditions responsible for diversification (Stockwell et al. 2003). These conflicting concerns emphasize the care needed to maintain Evolutionary Significant Units (ESUs), defined as historically isolated and independently evolving sets of populations (Moritz 1999). The often recommended conservation strategies of ex situ holdings and reintroductions strive for genetic diversity. Thus, it is essential to understand genetic structure of target species and endeavor to capture a genetically diverse founding population prior to making ex situ collections or selecting source stock for reintroduced or introduced populations. Captive populations may experience inbreeding depression or rapid evolution to ex situ conditions that may influence subsequent survival in captivity or upon repatriation to the wild (Templeton et al. 1986; Guerrant et al. 2004). Ongoing genetic management may be required. For reintroductions, selecting nearby stock is generally recommended because of potential local adaptation (Falk et al. 1996; IUCN 1998; Vallee et al. 2004; Maschinski and Haskins 2011). Using stock from habitat similar to the recipient site is

also advised. Mixing stock from multiple populations to increase genetic diversity, or crossing distantly related individuals to overcome problems of inbreeding depression (e.g., Johnson et al. 2010) are more controversial measures. Removing stock from small wild populations with high extinction risk may further threaten the viability of the wild populations (e.g., Menges et al. 2004), therefore under those conditions ex situ propagation or captive breeding is advised to generate stock for reintroductions. The vast array of potential outcomes from gene pool selection emphasizes the need for refined genetic data to make appropriate conservation decisions for endangered species.

4.3 Dispersal ability

The ability to migrate and colonize a new site is related to species' life history characteristics, habitat connectivity, and the matrix through which the organism must travel to reach a new site (Travis et al. 2010). Fragmented landscapes impede movement and may overwhelm the capacity for adaptation to GCC (Jump and Peñuelas 2005). Because the cost of dispersal increases with distance and the probability of reaching an unsuitable patch, selection may favor reduced dispersal in patchy isolated habitats. Some species that have evolved on islands have shorter dispersal distances than mainland counterparts (Travis et al. 2010 and references therein). To facilitate migration and dispersal, corridors or other forms of landscape connectivity are recommended (Noss 2001). The total number of connected patches greatly influences overall metapopulation persistence, especially in heterogeneous landscapes where directional dispersal is probable (Vuilleumier and Possingham 2006).

There is some evidence that dispersal characteristics are labile in some taxa and could possibly undergo rapid evolution with GCC. However theoretical models indicate that both evolutionary suicide and evolutionary rescue occurred in simulations with the same parameter values (Travis et al. 2010), thus predicting the direction of any evolutionary change of dispersal characteristics in response to SLR is difficult.

It is generally believed that many species will not move fast enough to track the rapidly changing climate of the future (Thomas et al. 2004; Jump and Peñuelas 2005; McLachlan et al. 2007), especially if there is rapid SLR. Successful colonization requires reproduction and next generation establishment, which may take decades (e.g., Maschinski and Haskins 2011).

4.4 Suitable habitat

Several conditions influence a species' persistence in its wild location or its ability to colonize another site. These include functional ecosystem processes, ongoing management to remove threats and maintain ecosystem health, and appropriate associated species, including competitors, predators, herbivores, and above and below ground mutualists (e.g., IUCN 1998; Vallee et al. 2004). Without ongoing management and threat abatement, neither extant nor newly reintroduced populations would persist. Identifying available and suitable recipient habitat requires knowing and understanding these factors and is essential prior to moving any species into a new location (Gordon 1994). There is no net biodiversity gain if a translocated species would harm a recipient community.

4.5 Legal considerations

Land management agency policies regulate in situ management and mandate conservation of listed species and their habitats. Changing climatic conditions and growing pressures from human populations increasingly challenge an agency's ability to preserve viable habitats and rare species' populations (Halpin 1997). State law and the U.S. Endangered Species Act (ESA) protect listed species from being collected and housed without permits. The ESA affords animals more comprehensive protection than plants, as plants are not protected on private land (Regan 2004). With appropriate certification, licensure and permits, endangered animals and plants can be harvested and kept in captivity if it is demonstrated that the species potential to survive will clearly be enhanced by these actions.

The ESA allows relocating federally listed species inside and outside of the current range if it is demonstrated to "further the conservation of such species" (16 U.S. C. §1539(j)) and outside of current range if "…the primary habitat of the species has been unsuitably and irreversibly altered or destroyed" (50 C.F.R. §17.81(a); Shirey and Lamberti 2010). Alternatively, introducing these species could take place under the "experimental population provision" (Section 10(j)). Under this provision, species do not have the same legal protection as wild populations, a fact that has raised concerns for the long-term viability of this strategy (Chapron and Samelius 2008). However, experimental population status provides leverage for experimentation and potential control if the species were to become invasive in the new setting. Experimental population status is often given to reintroductions of endangered species (J. Maschinski, personal observation). These provisions provide the legal basis for reintroductions and managed relocation, options we discuss below in detail.

Laws governing recipient sites will dictate whether and which species may be potentially established in new locations. Although appropriate habitat exists on mainland Florida, existing regulations preclude receiving the Keys' species on public lands as these taxa were never historically documented there (e.g., Joly and Fuller 2009). In contrast, international policies for Bahamas or Cuba, islands with suitable habitat for the target species, have not been explored. Specific legal precedence between these countries for reintroductions has not been established. Any international agreements would have to comply with the Lacey Act, which requires documentation that transported plants/animals were legally acquired. Although the *Convention on International Trade in Endangered Species* (CITES) regulates movement of many rare species across international boundaries, none of the target Keys species are currently exploited in international trade. Moving any of these species to islands with elevations >1 m within their climatic envelope would require adherence to the laws of individual countries and land management agencies of the recipient sites. Well-documented scientifically sound proposals could probably be accepted legally; the political feasibility would be more of a hurdle.

5 Conservation options and related perceptions of safety and risk

We review traditional and controversial conservation options for the species systematically (Table 1). For each taxa, we examined species characteristics, habitat-specific concerns, and legal issues that determine whether an option is possible.

Table 1 Conservation strategies for the four target taxa

Options	Effectiveness and feasibility	Sand flax	Big pine partridge pea	Key deer	Lower Keys marsh rabbit
Take no action	Recommended?	No	No	No	No
	Effective against SLR?	Long-term no	Long-term no	Long-term no	Long-term no
	Logistically feasible?	Yes	Yes	Yes	Yes
	Legally possible?	Yes	Yes	Long-term no	Long-term no
Ex situ conservation	Recommended?	Yes (I,II)	Yes (I, II)	Yes (I)	Yes (I)
	Effective against SLR?	Yes, seeds can be stored long-term	Yes, seeds can be stored long-term	Short-term yes; long-term no	Short-term yes; long-term no
	Logistically feasible?	Yes as seed, not whole plants	Yes as seed, not whole plants	Explore inter-situ options	Explore inter-situ options
	Legally possible?	Yes	Yes	Yes	Yes
Augment population(s)	Recommended?	Yes (I)	No, current population has adequate numbers with ongoing management	No	Yes (I)
	Effective against SLR?	No	No	No	Short-term yes; long-term no
	Logistically feasible?	Yes, only if threats controlled	Unnecessary, existing pop adequate size with fire	No, pop already at carrying capacity	Yes, only if threats controlled
	Legally possible?	Yes	Yes	Yes	Yes
Improve ecosystem health	Recommended?	Yes (I)	Yes (I)	Yes (I)	Yes (I)
	Effective against SLR?	Short-term yes; long-term no	Short-term yes; long-term no	Short-term yes; long-term no	Short-term yes; long-term no
	Logistically feasible?	Yes	Yes	Yes	Yes
	Legally possible?	Yes	Yes	Yes	Yes

Table 1 (continued)

Options	Effectiveness and feasibility	Sand flax	Big pine partridge pea	Key deer	Lower Keys marsh rabbit
Reintroduce within historic range	Recommended?	Yes (I)	No	No	Yes (I)
	Effective against SLR?	No	No	No	Short-term yes; long-term no
	Logistically feasible?	Yes, existing pops small	No, historic range is currently occupied Key.	No, the areas where fresh water is available are already saturated.	Yes, existing pops small, but limited suitable habitat is available.
	Legally possible?	Yes	Yes	Yes	Yes
Introduce outside of range to adjacent islands	Recommended?	Yes (I)	Yes (I)	No	No
	Effective against SLR?	Possibly if moved to elevation >1 m	Possibly if moved to elevation >1 m	No	No appropriate habitat above >1 m
	Logistically feasible?	Yes, though little habitat >1 m is available	Yes, though little habitat >1 m is available	No unoccupied pine rockland habitat with fresh water is available	n/a
	Legally possible?	Yes with permits	Yes with permits	n/a	n/a
Introduce outside of range to mainland FL	Recommended?	Yes (I)	No	No	No
	Effective against SLR?	Short-term yes; long-term no	Short-term yes; long-term no	Short-term yes; long-term no	Short-term yes; long-term no
	Logistically feasible?	Research crosses among mainland and Keys populations	Problematic due to conspecifics and limited appropriate habitat		
	Legally possible?	Appropriate habitat is regulated by policy restricting receiving species never historically present			
Introduce outside of range to islands farther away and higher elevation.	Recommended?	Yes (II), if research indicates risk to recipient community is low and political acceptability has been achieved			
	Effective against SLR?	Possibly if moved to elevation >1 m			
	Logistically feasible?	No congeners in Caribbean pine rocklands	Problematic due to congeners and limited appropriate habitat		
	Legally possible?	International laws would apply			

Actions that are effective in the short-term and long-term are indicated by I and II, respectively

5.1 Take no action

The species can persist for the short-term in current habitat. But in the long-term, this approach is likely to lead to extinction, which at least for the animals, would not comply with the U.S. Endangered Species Act or land management agency policies. Although some migration will occur naturally, as distances increase between islands, natural dispersal is likely to be minimal. Our target species are intolerant of inundation by salt water and have restricted dispersal, thus there is extremely low perception of safety for this option (Fig. 2, Table 1).

5.2 Ex situ conservation

An important tool for preserving rare plants (Guerrant et al. 2004) and animals (Rabb 1994) is ex situ conservation. Zoos and botanical gardens have long been homes for some of the world's rarest species and they are taking more important roles in preserving breeding lines and restoring rare populations to the wild (Guerrant et al. 2004; Armstrong and Seddon 2008). Seed banks throughout the world are stepping up activities to safeguard seeds of rare species in cryogenic storage or freezers (Vitt et al. 2010), and zoos are being asked to increase their work with captive rare animals (Coonan et al. 2010).

The perception of the safety of ex situ storage either in seed banks or living collections is somewhat misguided if it is perceived to be a permanent solution to a conservation problem (Snyder et al. 1996). Healthy, properly desiccated seeds can be stored at low temperatures for many years reliably and economically, but

INCREASING RESOURCE DEMANDS

Management Options	Benefits	Concerns	Effectiveness Against SLR
Take no Action: Leave in Place	• No immediate expense • Opportunity for adaptation	• Illegal • Loss of Species • Unethical	• None
Ex Situ	• Culturally acceptable • Easy access for researchers • Controlled setting • Low cost (for seed banks)	• Progeny maladapted to wild • Forever in captivity? • Genetic erosion • Limited lifespan of individuals • No adaptation • Selection to captive conditions	• Safe but short-term
Build Resilience In Situ			
Increase #s in Extant Pops	• Opportunity for adaptation	• Not effective against SLR	• Very short-term
Improve Ecosystem Health	• Demonstrated to be effective	• Requires continuous maintenance	• Very short-term
Reintroduce Within Range	• Spreads risk • May improve metapopulation persistence	• Costly • May be uncertain success rate	•Short-term
Introduce Outside Range	• May save species from extinction • May give it more time before inundation	• Unknown consequences for recipient community • Hybridization potential	• Depends on elevation

Fig. 2 Conservation options for rare taxa threatened by sea level rise, benefits and concerns. Note that resource demands increase in descending order. It is likely that more than one option will be appropriate for any species

seeds still have a finite lifespan (Walters 2004). Similarly, even healthy, properly maintained plants and animals cannot be kept as living collections in botanical gardens or zoos indefinitely. If species have difficulty reproducing in captivity, captive populations will not be sustainable (Mullan and Marvin 1999). Because frozen or living organisms will be subject to selection by conditions in the captive environment, subsequent generations may be maladapted to surviving in the wild. For plants, an additional drawback is that in botanical gardens they may be at risk of hybridizing with congeners within the collection (Maunder et al. 2004) or escaping from cultivation and becoming invasive (Reichard and Campbell 1996). The risks for species reintroduced outside their historic range are the same as those above (Fig. 2, Table 1).

Ex situ collections alone are not an endpoint solution for conserving a rare species, but are an integrated link to eventual repatriation to the wild (Guerrant et al. 2004; Snyder et al. 1996). Repatriation to the wild requires that suitable habitat is identified and available (Maschinski and Haskins 2011; see reintroduction discussion below). When captive-bred plants and animals are used for reintroductions, concern has been voiced that they may be inferior to wild translocated individuals. For plants, there is little evidence that plants from ex situ sources perform less well in reintroductions than wild-sourced plants (Dalrymple et al. 2011), and there is some evidence that they perform better (e.g., Maschinski and Duquesnel 2007). However, captive-bred animals present unique concerns when they are released to the wild, as behavior plays a major role in their ability to colonize, survive, defend territory, escape predation, and successfully reproduce in a new location (Seddon et al. 2007 and references therein). For animals, like Key deer, philopatry to home sites also may thwart successful colonization in a new site (Lopez 2001). Because of the great expense and mixed success of reintroduction programs, captive breeding may only be possible for a limited number of charismatic endangered species (Snyder et al. 1996). In our opinion, using a charisma requirement to weigh the value of a species is not tenable.

A variant of traditional ex situ conservation is a practice known as inter-situ conservation, where a rare species is placed in a highly managed location such as a nature park or protected area (Milton et al. 1999; Coonan et al. 2010). An inter-situ situation for Key deer or Lower Keys marsh rabbits would likely consist of large enclosed spaces with oversight management, but would not necessarily include supplemental feeding; while an inter-situ situation for the target plants may be an area that receives extra water or weeding. This is a compromise controlled setting that may help improve survival of species with disappearing habitat, where some of the concerns about introductions outside of range, such as risk of invasion, could be addressed (Table 1). However, this option may require agencies to revise policies currently prohibiting introductions of species that were never historically present. Suitable sites for inter-situ holdings exist on agency lands with such policies in place.

5.3 Increase resilience in situ: population augmentation

Increasing the number of individuals within existing populations (also known as augmentation or reinforcement) can rebuild populations, potentially reintroduce alleles lost to genetic drift, increase demographic health, and reduce extinction

risk. Larger populations may have increased possibility for in situ adaptation to environmental change and recovery from disturbance. Augmenting populations is only advised for small populations that have not reached carrying capacity, which is true for the Lower Keys marsh rabbit and sand flax. Augmenting populations is often logistically feasible; however, this option has low safety from SLR. At best this is a short-term solution (Fig. 2; Table 1).

5.4 Increase resilience in situ: improve ecosystem health

Healthy ecosystems can support greater biodiversity, thus a generally supported conservation strategy in the face of GCC is to reduce exogenous stresses and maintain natural disturbance regimes (Halpin 1997). Removing invasive species and using fire management is critical to sustain the plants and Key deer that inhabit fire-dependent pine rocklands in the Florida Keys (Ross et al. 2009). For example, a 3–7 yr fire-return-interval is required to maintain low to medium canopy cover and stable growing populations of Big Pine partridge pea (Liu et al. 2005; Liu and Menges 2005). In the absence of fire, extinction risk is high (Liu et al. 2005).

Recovery plans for the target animals call for habitat rehabilitation by creating and enhancing habitat through planting native plants, removing exotic vegetation, and refilling dredged areas, including mosquito ditches where animals sometimes drown. Creating corridors is also recommended to assist migration and population expansion, while reducing mortality risks (USFWS 1999). Similar efforts would help the target plant species. Restoring connectivity between fragmented populations will enhance the probability of movement between fragments and colonization, thereby decreasing extinction risk (Hanski 1998; Vuilleumier and Possingham 2006) and potentially improving genetic health (Hogg et al. 2006). This option has low ecological risk, but provides only short-term safety from SLR (Fig. 2, Table 1).

5.5 Reintroduce species within historic range

To establish a viable self-sustaining population and increase the total wild populations, reintroducing a species into habitat where it once occurred is often recommended (Maunder 1992). Within-range reintroductions into currently unoccupied habitat are widely accepted by the conservation community; however, historically they have had low success rates for plants (Falk et al. 1996) and animals (Fischer and Lindenmayer 2000; Seddon et al. 2007). Linking species requirements to conditions (environment, associated species, etc.) available at the recipient site is essential (Maschinski and Haskins 2011). Recent advances in understanding the requirements for successful reintroductions indicate that the technique is improving (e.g., Maschinski and Duquesnel 2007; Griffiths and Pavajeau 2008). Still the number of documented sustainable populations is few for plants (e.g., Dalrymple et al. 2011) or animals (Seddon et al. 2007). Following existing guidelines can help improve the success of reintroductions (e.g., IUCN 1998; Vallee et al. 2004; Maschinski and Haskins 2011).

Healthy recipient habitat is critical for reintroduction success, and this is a major obstacle for the Keys species. Sometimes historical sites have changed such that

they no longer can support the species of concern (Maschinski 2006). Due to low elevation, fire suppression, hurricane storm surge, and succession of tropical hardwood hammock species, little healthy, unoccupied habitat remains within the historic range of these species. Currently Key deer and Big Pine partridge pea are occupying their known historic range, thus to increase the total populations would require moving outside of historically documented range. Lower Keys marsh rabbits (Forys and Humphrey 1999b) and sand flax (USFWS 2009) have unoccupied patches available in the Keys. In addition sand flax has options on mainland FL. This option has low ecological risk, but provides only short-term safety from SLR (Fig. 2; Table 1).

5.6 Move species outside of known historic range

The controversy surrounding the practice of moving species outside their known historic range (a.k.a, managed relocation (MR) among other terms) is extensive and growing weekly (Minteer and Collins 2010; Seddon 2010; Shirey and Lamberti 2010). Avid debates have been published regarding the potential risks of MR (Davidson and Simkanin 2008), the strengths and weaknesses of our scientific knowledge needed to assess MR (McLachlan et al. 2007), candidate species for MR (Hoegh-Guldberg et al. 2008), impacts on recipient sites, and the socioeconomics (Hunter 2007) related to MR. Existing reintroduction guidelines and conservation professionals state that MR should only be considered if there are no viable sites within a species' range (Maunder 1992; Falk et al. 1996; IUCN 1998; Vallee et al. 2004). This practice is rarely endorsed by U.S. Fish and Wildlife Service. However, as more species lose viability in their current range due to climate change (Thomas et al. 2004), MR is likely to gain more consideration as an integrated conservation strategy (Vitt et al. 2010). SLR leaves our target species without suitable sites within their historic ranges and likely extinction in the next century, and therefore we consider the potential benefits and restrictions of MR.

The major objections levied against MR have been the ecological risks of relocated species becoming invasive or introducing new pathogens into the recipient community (Gordon 1994; Ricciardi and Simberloff 2009; but see Schlaepfer et al. 2009). To minimize invasion risks, prior to moving any species rigorous screening and evaluation are advised (Reichard et al. 2011), as are short-distance movements within the same biogeographic region (Hoegh-Guldberg et al. 2008). Gordon (1994) cautions managers to consider threats of hybridization with congeners and interspecific interactions (herbivory, predation, or competition) at the recipient site. For the Keys species, hybridization, herbivory, and predation are greater concerns than invasion (Fig. 2, Table 1). It is unknown whether hybridization would preserve any unique alleles of the rare taxa.

5.6.1 Introduce to adjacent islands

For all of the taxa considered here, suitable habitat with similar geology and vegetative communities is minimal and restricted to the Lower Keys, as the Middle and Upper Keys do not have appropriate habitat or fresh water sources. Adjacent islands have equally low elevations above sea level. Therefore this is a short-term solution, which has low ecological risk, but low long-term safety from SLR.

5.6.2 Introduce to mainland

This option is thwarted by political and biological issues. Suitable habitats appropriate for our target species exist in the southern portion of mainland Florida, and Keys species would potentially thrive there. However, several land managing agencies have policies preventing establishing species that were never historically present into their conservation areas. If the political issue could be overcome, introduction to the mainland would allow the possibility of natural migration once on the continent.

Three of our target taxa, however, have varietal or subspecies status and closely related congeners present on the mainland, with which hybridization may occur. For example, although freshwater marsh habitat is available for Lower Keys marsh rabbit in the Everglades, moving it there imposes the threat of hybridizing with the more widespread subspecies *Sylvilagus palustris palustris*. The consequences of hybridization could be the loss of unique forms or alleles or outbreeding depression. Alternatively, hybridization could have positive effects on fitness, particularly if Keys populations are inbred.

SLR threatens to engulf the lower half of the state of Florida (Overpeck and Weiss 2009), which means that introductions to mainland would have to be north of Lake Okeechobee (26.7 N, −80.7 W) for safety beyond 100 years. This far north is probably outside of the climate envelope of the target plant species under current climate conditions and is outside of the biogeographic region of pine rockland habitats. Hence, this option has high to moderate ecological risk, and low long-term safety from SLR.

5.6.3 Introduce to distant islands with higher elevation

High elevation islands occur in the Caribbean and some have appropriate habitats available (e.g., Ross et al. 2009). This option may keep a species within its climatic envelope or habitat niche. But it carries a range of risks, from its effects on the recipient community, as discussed above, or the possibility of hybridizing with near relatives in the habitat. There are also tremendous political and logistical considerations involved. This is the highest risk approach, and most contentious, as the greater the distance from occupied habitat, the greater the probability of dissimilar conditions and fewer associated species, thus the greater the uncertainty and risk. However, it has possibly high safety from SLR.

Several decision-making tools are currently available to help determine whether a species should be considered for MR (Gordon 1994; Milton et al. 1999; Hoegh-Guldberg et al. 2008; Richardson et al. 2009). Factors to consider include the degree of endangerment, technical possibility, whether benefits outweigh constraints (Hoegh-Guldberg et al. 2008), the impacts of translocated species on recipient communities, and whether site management is compatible with sustaining their populations (Gordon 1994), and whether there are non-pristine, but suitable properties available to use as recipient sites (Milton et al. 1999). Conservation management decisions, particularly for rare and highly threatened species, require assessment by multiple stakeholders whose opinions may be at odds; hence, this will necessitate compromise, which is not always the "best" solution for the species (Richardson et al. 2009). We took these considerations into account when we evaluated conservation options for the Keys endemics.

6 Conservation recommendations for keys endemics

The process we used for developing conservation recommendations began with assessing Keys species' ecology and then considered effectiveness against SLR, logistic feasibility, and legal possibilities within the management option framework (Fig. 2). For each potential option, we determined its efficacy, promise, or limitations. Identifying limitations refined information gaps and potential intermediate steps required for long-term strategies (Table 1).

We recommend a diverse multi-step approach to the conservation of the Keys species to include short- and long-term actions; each solution has a perceived safety balanced against a finite lifespan of effectiveness (Table 1). In the short-term (immediately to 20 years hence) for all the taxa we recommend actively managing habitats to improve resilience, population growth, and potential for natural dispersal. Active management will ensure the largest and healthiest populations possible as a starting point. The odds of making it through a storm (literally and figuratively) increase with higher populations. This will involve controlling exotic predators in Lower Keys marsh rabbit habitat and prescribed burns in pine rockland habitats for the plants and Key deer.

As preparation for SLR and potential reintroductions, we also recommend placing seeds into ex situ seed banks (e.g., Vitt et al. 2010) and pursuing inter-situ options for the animals. Recovery plans advise captive propagation for Lower Keys marsh rabbit and suggest it as a possibility for Key Deer (USFWS 1999). For example, Miami Metro Zoo in Miami, FL USA has appropriate wild habitat for the Key deer and could create a habitat exhibit for Lower Keys marsh rabbit; enclosed space would prevent potential danger of hybridization with common congeners on the mainland.

To build total individuals in the wild we concur with the advice of USFWS (1999) to augment the Lower Keys marsh rabbit populations from captive stock (as long as exotic predators are controlled). Key deer have been introduced to pine rocklands on several Keys from wild stock, but are only thriving in areas where fresh water is available (M. Ross, personal observation). Supplementing water will potentially improve Key deer colonization on some of these Keys. Introducing the plants to pine rockland habitats in adjacent Keys is also advised; however, pine rockland habitat is scarce and is located at elevations threatened by SLR within the next century, thus this action has limited long-term effectiveness.

For the long-term, no option except MR would be effective against SLR (Table 1). Natural dispersal or adaptation that will outpace SLR is unlikely due to the species' dispersal characteristics. Nearby suitable habitat is scarce and has low elevation. Prior to any MR, we recommend intermediate actions: research and political negotiations. We identified hybridization as a high ecological risk, thus researching reproductive isolation between conspecifics and the target taxa is necessary. Some researchers argue that varieties or subspecies that are not reproductively isolated should not receive conservation resources (Templeton et al. 1986) and this topic could certainly be debated with good supporting evidence. For sand flax, investigating population genetic structure and potential benefits or detriments of crosses between mainland and Keys populations are needed. Though we believe invasiveness is unlikely for these taxa, assessing invasive risk is also important. Understanding species-specific habitat requirements and species interactions at potential recipient sites would help ensure a higher probability of successful reintroductions within

range or introductions outside of range. Finally, because mainland parks currently have policies restricting introductions of taxa that were not historically documented on site, negotiations or changes in policy would be necessary for inter-situ holdings or introductions. Moving species to other Caribbean Islands would require mutual agreement between countries. As with traditional reintroductions, it is important that MR be conducted experimentally (Maschinski and Haskins 2011).

7 Conclusions

The process we describe is a valuable exercise that can be used for any species facing threats from GCC and SLR. Our aim was to achieve sustainable evolving populations with high safety from SLR and low risk of negative impacts to recipient communities. The short-term recommendations provide good preliminary measures for preserving the species, while the suggested research and political discussions are essential preparations before any relocations. In the long-term, the picture is grim for all of these taxa without human intervention.

Why is human intervention necessary? Despite evidence of rapid evolutionary change in some taxa, there is no evidence of rapid evolutionary change in long-distance dispersal required by all these taxa, nor of mammalian dispersal behavior that would improve colonization into areas that are safe from SLR. Although MR is controversial, objections could be overcome by hard evidence refuting concerns and by political negotiations. Concern over the impact of moving species to new habitats must be weighed against the risk of their extinction. We must recognize there is no guaranteed absolutely safe solution to prevent the extinction of endemic populations, but the options we recommend can improve the possibility of their long-term conservation. Considering such actions requires moving from the equilibrium viewpoint of biological communities and species distributions that dominates our environmental laws and policies, to one that, out of necessity, embraces the changes imposed by GCC (Craig 2010). It also presents a challenge to land managers, whose missions may have to be reviewed to reflect the reality of change so that they may be able to provide refugia for rare taxa.

Admittedly, the Florida Keys species and their habitats are a dire case study that presents a small glimpse into a growing conservation dilemma. The decisions land managers make on behalf of these species will impact their evolutionary trajectories and will likely impact conservation practice around the globe as these managers will be setting the precedent. Deciding whether to act, how to act, and when to act should be viewed in the context of future GCC and biogeochemical impacts of human activities. GCC has forced us to concede that current conditions may not occur anywhere in the future (Overpeck et al. 1992). GCC presents a grand stage of uncertainty, which challenges not only rare species of concern, but the land managers who are earnestly trying to prevent their extinction. It elevates the argument about MR as one of the few options that would allow these species to adapt to GCC in a natural setting.

Ingrained in human nature is a desire for stability, but nature has taught us that change is a constant. Our conservation challenge in the face of SLR is to move beyond mythical thinking that *someday things will settle down* and the *myth of perceived safety* to an acceptance of change. We call for a new dialogue, a review

of existing laws and policies, and preparation for the oncoming change so that with GCC and SLR we will not be left with an impoverished world. Now is the time to begin devising safe methods and protocols for conducting MR and also establishing the criteria that will deem the practice "worthy" in the eyes of the stakeholders as suggested by Minteer and Collins (2010).

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