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Assisted Species Migration of Joshua Trees

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ABSTRACT

The Joshua tree evolved in a complex way with its environment, pollinator, and seed dispersers over millions of years. Its survival as a species is now imminently threatened by climate change. Many factors prevent it from migrating to a cooler range quickly enough to keep up with the planet's current rate of warming. This paper explores the viability of assisted migration for the Joshua tree, where humans help it move to escape extinction. Several studies are examined. One persuasively shows that the Joshua tree had a range contraction when the climate warmed at the end of the Ice Age and that present warming will cause a similar, drastic range reduction. Other studies look at factors such as soil, CO2, pollinator mutualism, and seed longevity to determine if assisted migration would be successful. The ethics of assisted migration is also explored. This paper concludes that humans must try to assist the Joshua tree to migrate but that it will be difficult given the complexities of its evolution, its relationship to its environment, and a migration lag that is not completely understood.

Introduction

Yucca brevifolia, known as the Joshua tree, is a type of yucca native to North America's southwestern area and is characterized by its heights of over 20 feet and its green spiked leaves, shorter (brevi) than most other yucca species. The Joshua tree is iconic and regarded as one of the most unique plants of the Mojave Desert for not only its structure, which reminded early settlers of the biblical figure Joshua reaching up to heaven, but also for its remarkable finickiness to grow and survive in the wild, harsh conditions of the desert. Its populations span across four states: California, Nevada, Utah, and Arizona. It is most well known in California because of Joshua Tree National Park. But the landmark study, "Past and ongoing shifts in Joshua tree distribution support future modeled range contraction", shows that, based on sound science and future global warming estimates, Joshua trees will not not survive in their current low and intermediate range. By the end of this century they will only remain in a few pockets, or climate refugia (Sweet et al. 2019), at high elevation in their namesake national park. With their increasingly threatened status due to climate change, lack of conservation methods are becoming a major issue for the species. Different conservation measures have been looked into, but because only a few of them actually protect against climate change, the viability of such measures is debatable. Assisted species migration is one such method and is being looked into for this project.

In addition to the natural threats of a harsh desert, drought, predation, lightning fires, and flash floods, Joshua trees face many threats caused by humans. Chief among them are climate change, fire, and development. They face human destruction by development. Humans also cause fire, either directly through campfires or indirectly through pollution and carbon dioxide, which the invasive species from Europe, cheatgrass, thrives upon. This grass grows between the rocks and everywhere it can take hold, allowing fires to spread instead of dying out in just a few acres like they once did (Zizka 2005). Climate change is also already exacerbating heat and droughts. The recent 2020 Dome fire, in what looked like an area that couldn't burn, devastated 1.3 million Joshua trees on 43,273 acres (Boxall 2020). But the biggest threat is global warming, which has been shown to wipe out their current lower range and will eliminate their current intermediate range by the end of the century (Cole et al. 2011). Normally, plants can gradually migrate on their own and extend their range as climate changes. There is some evidence and research to support that species can even quickly adapt to a new environment, a process known as rapid evolution (Root 2015). But based on the ever-increasing rate of temperature change, the Joshua tree will not be able adapt fast enough; their generation is just too long, only flowering after 30 years (Wilkening, et al. 2020), and they don't even flower every year, one of the mysteries of the desert. So, the only solution appears to be assisted migration.

Assisted species migration is the act of humans taking an endangered species and moving it to a different climate range and ecosystem, so as to protect it from anthropogenic climate change or other man-made problems, such as fire and habitat destruction (McLachlan 2007). Assisted species migration is a solution to a problem that has grown since the Industrial Revolution and is now at a tipping point. The research question for this paper is how viable is assisted species migration as a conservation method for the *Yucca brevifolia*?

History of the *Yucca brevifolia*

Joshua Trees have evolved in a complex way over millions of years, with two distinct species diverging around 5 million years, one found in present day Nevada, *Yucca jaegeriana*, and the other in California, *Yucca brevifolia*. They each co-evolved with a different pollinator moth, one of the best examples of mutualism found in nature. Each moth is exactly suited for the different flowers found on the two different species. Obligate pollination mutualism is where "both plants and their pollinators are reliant upon one another for reproduction"(Smith et al. 2008). The moth will nocturnally pollinate, with an ovipositor that has evolved to be an exact fit, the flower and deposit her eggs. The fruit develops in a pod, containing many seeds along with several moth larvae. The larvae eat some but, more importantly, not all of the seeds. For a while the seed pod contains the future of two species. The pods drop to the ground, the larvae create underground cocoons, and rodents disperse the seeds. An environmental signal causes the larva to pupate into the moth (Baker 1986), emerging to mate and pollinate only when conditions are perfect and the Joshua trees bloom, which is not every year. Many factors must align perfectly for the Joshua tree to reproduce in the harsh Mojave Desert. Another coevolutionary partner of the Joshua tree, although there is some disagreement amongst scholars, is the extinct Shasta ground sloth. Joshua tree seeds have often been discovered in its petrified dung so the theory is that the sloth, about the size of a black bear, ate much of the fruit and distributed the seeds. It was a megafaunal disperser. Today, green fruit pods fall around the base of the Joshua trees and remain uneaten, which seems to confirm this theory. Early humans hunted the sloths to extinction (Steadman et al. 2005), and removed a key way for the Joshua tree to spread. Without its coevolutionary partner, the Joshua tree would be considered an evolutionary anachronism (Barlow 2002). Today, the Joshua tree must rely on granivorous rodents, like packrats, kangaroo rats, or ground squirrels, to store seeds in underground caches. They forget a few, or are eaten by an owl so they can't eat them all, and some seeds grow into trees. Joshua trees are slow growing, only 3-4 cm/year, and don't reach sexual maturity until about 30 years old. This is important to remember since this is now their Achilles heel, preventing them from moving their range fast enough. The Joshua Tree has evolved to become a keystone species. It is an integral part of its ecosystem. If it dies, many other species follow.

Assisted Migration

Assisted Migration, also known as "conservation translocation of species," is the process by which humans assist in "relocating threatened species to new locations before their historical ranges become inhospitable due to climate change(Minteer and Collins 2010). When research first started on assisted migration it was not yet clear, or accepted, that climate change was occurring and at what rate. Many of these papers urged caution, looking at ethical or economic considerations, ecosystems, and invasive species. Some version of the butterfly effect was often brought up: how a slight change or introduction of one species could radically change an entire recipient ecosystem. Since then, climate change has accelerated. “Indeed, one influential review predicts that, depending on the rate and magnitude of planetary warming, up to 35% of the world’s species could be on the path to climate-driven extinction”(Minteer and Collins 2010). Changes thought that could occur in 50 years are happening presently. Our models are better, computing power better. Models were recently re-calibrated to allow for the quicker disappearance of ice at the Arctic and subsequent accelerated warming, known as Arctic amplification, so now all models have accelerated timelines (Rantanen et al. 2022). There is more urgent attention to the assisted migration of many species. This paper will look at (1) direct research creating models which can be applied to assisted migration (2) smaller, pragmatic studies that are part of the solution to finding a practical way for assisted migration to work (3) research into the ecological ethics of assisted migration for many different species. Combining these studies will make an assessment of the viability for assisted migration of the Joshua tree. There are gaps in the current literature: While there is an abundance of articles on global warming, ecology of the Joshua tree, and some on assisted migration, there is not a comprehensive examination. Also, many previous studies view the Joshua tree’s predicament from a removed, abstract point of view. As the author on “ Move it or lose it? The ecological ethics of relocating species under climate change” states, it is now time for action. So, in a way, there is a gap in the approach and conclusions for many of these articles, as many were written before climate change became so accelerated and manifest.

Methodology

The methodology used in this paper is a systematic review, best suited to answer the question of viability of assisted migration since there are many articles on the Joshua tree, climate change, and to a lesser degree, assisted migration. Sources have been compiled from the databases JSTOR, BioOne, and Ecological Society of America. These studies are the main landmarked studies of the topic. The key terms used to search the databases were *Yucca brevifolia*, yucca moth, assisted migration, and managed relocation. Joshua tree is not specific enough and gives names of the authors while managed relocation and assisted migration are essentially the same thing, thus suiting the study’s purpose. From there, the studies were screened for appropriate source material. Inclusion criteria were broad, allowing articles that mainly discussed the Joshua tree and/or assisted migration. The search was widened to include yucca moths and, after deliberation and preliminary research, the inclusion covered abstracts along with full text, not just full text. Exclusion criteria were articles dated prior to 2000, apart from the prominent 1986 study “Yuccas and Yucca Moths-A Historical Commentary”. Some sources were gained through the citations of other papers and also scanned for eligibility. Limitations were the lack of field studies on the subject.

Research with Joshua Trees

In “Past and ongoing shifts in Joshua tree distribution support future modeled range contraction,” the authors scientifically model and predict the consequences of major climate change on the Joshua tree’s future ranges by looking to the past. The ages and locations of late Pleistocene[12,000 yrs ago] Joshua trees were determined by examining many fossil packrat middens throughout the Southwest. These middens, often in caves or under rock overhangs, often preserve and reveal up to 40,000 years of biotic change. Packrat middens are a time capsule and can contain the Joshua tree’s short, bayonet-shaped leaves from long ago; they also can hold Joshua tree seeds in the fossilized dung from the extinct Shasta ground sloth. These were radiographed, and then compiled and compared with earlier records from deeper layers in the midden. They found that the “Joshua tree had a much larger geographic distribution in the Mojave, Colorado, and Sonoran Deserts between 11,000 and 30,000 years ago” than the current range. What triggered the die off about 11,700 years was “a rapid warming event…thought to have been caused by a sudden shift in the position of the Intertropical Convergence Zone” (Cole et al. 2011). This rapid warming event increased average temperatures about 4 degrees Celsius and it “terminated the Pleistocene and was the beginning of the Holocene. It was also the most recent warming event of similar rate and magnitude to that projected for the near future (Jackson and Overpeck

2000)"(Cole et al. 2011). This past warming event was widespread. It was the end of the geologic epoch called the Ice Age; we now are at the beginning of a new age we have created, unofficially called the Anthropocene, characterized by sudden warming.

Before this past warming event the Joshua tree's range was from 245m-1,800m and today it is 400m-1,800m, so its range contracted by 155m on its low end. By "8,000 years ago, no fossil records are found to the south of, or down slope from, the current local limits of any stand"(Cole et al. 2011). This past warming event contracted the Joshua tree's range significantly, and the authors speculate the extinction of the Shasta Ground Sloth around the same time period also slowed its ability to migrate to a cooler range, then and now. Assuming a generous, natural migration of around 2 km for the next 60-90 years, the authors create general circulation models based on past range and temperature: "Because GCM models project a climate warming of a similar pace and magnitude to that of the early Holocene over the next 60 to 90 years, the Joshua tree could undergo a similar decline in its southernmost populations to that of the early Holocene"(Cole et al. 2011). They would have too much migration lag (Corlett and Wescott 2013), or the inability to migrate as fast as climate warms, and this would leave only "perhaps 10% of existing stands remaining." These scientists were "lucky" enough to have (1) historical records of the Joshua tree's range going back 30,000 years thanks to the packrat (2) a record of the Joshua tree's response to a historical warming event 12,000 years ago (3) that past warming event is similar in degree to that which is occurring now. The science here is compelling and, if the past is prologue, the Joshua tree will lose much of its lower and intermediate range over this century.

While the previous study looks broadly at field observations of many packrat middens and draws profound conclusions, other, smaller and more focused studies are needed to see if assisted migration is viable for the Joshua tree. In "Adaptive management of landscapes for climate change: how soils influence the assisted migration of plants" the authors caution that "edaphic factors such as pH, soil moisture, depth play a role in successful establishment and growth of migrated provenances. Biotic factors such as the relationship of ectomycorrhizal fungi with host plants are also important…" Any number of these factors could prevent the Joshua tree from migrating into a new range and would need to be considered for the viability of assisted migration. This could explain why Joshua trees have not migrated further north since their range started contracting 12,000 years ago, something that perplexed the authors of the previous research on range contraction.

Another piece of the viability puzzle is a smaller, more specific study: "The relative importance of climate change and the physiological effects of CO2 on freezing tolerance for the future distribution of Yucca brevifolia." The authors gather data and create GCM models having doubled CO2 conditions, a likely future condition on earth. They find that their models predict "that a considerable portion of the current range of Y. brevifolia will become climatically unfavorable for this species, but that significant amounts of new habitat may become available." Their model shows that doubled CO2 will increase potential habitats for the species by 14%, which is promising. But they do acknowledge the shortcomings of their model: "biotic processes such as competition, disease, predation, and species recruitment into new habitats are difficult to model at the larger scales relevant to climate change" (Dole et al. 2002). This study shows that doubled CO2, separate from warming, should be considered as a factor in models created by scientists in the future. Unfortunately, this study does not address how Joshua trees can migrate fast enough to those areas indicated in their models.

A field work study can provide more clues to the viability of assisted migration. In "Context-dependent mutualisms in the Joshua Tree-moth system shift along a climate gradient" (Harrower and Gilbert 2018) the author notes that Joshua trees and yucca moths have evolved together and are dependent on each other, a mutualistic relationship. The yucca moth is the Joshua tree's only pollinator. But abiotic changes from climate change can "enhance a mutualism, convert it to antagonism, disrupt it, or force migration of one or both species" (Harrower and Gilbert 2018). The author wants to see if the Joshua tree and yucca moth are likely to move together into different climates; she measures both of their different levels of abundance at three ranges: lower, intermediate, and higher. Many traps were set within Joshua Tree National Park to measure the quantity of moths and transects were established. She finds "The reproductive success of Joshua trees is tightly linked to pollinator abundance, and the conditional outcomes(magnitude of the fitness benefit) of the mutualism change depending on where it occurs on the elevation gradient"(Harrower and Gilbert 2018). She concludes that both the moth and Joshua tree thrive at the intermediate range. She also notes that Joshua trees currently in the top range, where the moths were not found in her traps, are likely reproducing asexually from their roots. This means that there is less cross-pollination and genetic vigor at these elevations; genetic swamping (Minteer and Collins 2010) can occur. The conclusion of this pragmatic study is somewhat inconclusive: Joshua trees will need to move higher for their survival but it is uncertain if their pollinator moth can follow. Considering assisted migration, the feasibility of moving the moth with the Joshua tree is uncertain. Additional studies are needed to determine if they can move together, and in what timeline, i.e. before warming kills the Joshua tree in its lower and intermediate ranges.

One study is performed in the controlled environment of an outdoor lab replicating natural conditions. In "Short seed longevity, variable germination conditions, and infrequent establishment events provide a narrow window for Yucca brevifolia (Agavaceae) recruitment" the authors painstakingly plant Joshua trees seeds in different seasons to "simulate the secondary dispersal of individual seeds by granivorous rodents." They then monitor them for two years in different conditions. They found that Joshua tree seeds "have little capacity for dormancy" and longevity of seeds declined by about 50% per year. Considering assisted migration, this means that it would be best to plant seeds the first season in which they formed. The authors also find that seeds easily germinate in 7 days under moist conditions and they had the greatest chance of survival if they emerged in late summer rather than spring. This is because the "September-emergent seedlings developed deeper roots throughout the fall and winter" and can withstand the next summer's dryness (Reynolds et al. 2012). Joshua trees will likely become established only with an unusually high amount of winter and early spring precipitation. The authors also find that the seedlings at first are protected by a nurse plant from herbivory but later compete with it for moisture. The results of this study shows that conditions must be ideal for the seeds to germinate and for seedlings to make it past their first season. This study provides valuable insight into when and under what conditions Joshua trees seeds could be planted in an assisted migration program. But it also shows the viability of assisted migration is still uncertain since it shows just how difficult it is for Joshua trees to make it past their first couple of years.

More studies like these, pragmatic studies, will likely be done in the field or in nurseries where natural conditions are replicated. Also, a systematic review reveals inconsistencies and more unknowns in common understandings of Joshua trees. There are still mysteries. For instance, some authors still reference that Joshua trees bloom annually, which is not the case. More definitive answers are needed to the following: At what point do the yucca moth larvae emerge from the seed pod, do they fall or float down on silk thread? How long do larvae remain in a fallen seed pod? What are the environmental signals for both the Joshua tree to bloom and the larvae of its pollinator to emerge from the ground? What cold temperatures can both the seeds and larvae withstand? What soil conditions are required? In a stand of Joshua trees, why do some bloom and others not bloom in a specific year? Could the yucca moth be propagated and moved to high ranges where Joshua trees are currently only reproducing asexually? Answers to these questions will help to assess the viability of assisted migration for the Joshua tree and show that much field work still needs to be done.

Ethics: Assisted Migration

In "Move it or Lose it? The ecological ethics of relocating species under climate change" the authors point out potential risks for moving species. "While some scientists think this[assisted migration] is a risk that can be managed, and that the consequences of doing nothing are far worse (e.g., Sax et al. 2009, Schlaefer et al. 2009), many believe the mere threat of creating invasive species through managed relocation(and the threat of disrupting historical evolutionary and ecological processes) disqualifies it as a viable conservation strategy(Davidson and Simkanin 2008, Ricciardi and Simberloff 2009, Seddon et al. 2009)" (Minteer and Collins 2010). Other, potentially negative consequences are: Longer term genetic consequences of transferring species, mainly "hybridization and introgression of relocated and native populations(Ricciardi and Simberloff 2009), as well as worries about the introduction of maladapted genotypes into the receiving system and the "swamping" of recipient-system genetic complexes by relocated populations(Vitt et al. 2010)" (Minteer and Collins 2010). Considering these potential risks, the best strategy would be to only re-locate Joshua trees to the upper edge of their current high range and not to an entirely new ecosystem. This strategy of assisted range expansion would prevent the Joshua tree from itself becoming an invasive species, throwing off-balance the recipient ecosystem it would be migrating into. Also, considering their mutualism with their pollinating yucca moth, the moth should also be relocated to as high of a range as it can endure. If this gradual assisted migration shows success then it should continue with a planting program as climate warms.

There are other ethics concerns for assisted migration: "...successful relocation is a complicated business. And managed relocation will likely be costly and will tax conservationists' financial and political capital. It could divert limited resources from more traditional conservation strategies"(Minteer and Collins 2010). This is a valid argument as to where to spend funds. Would it be better to preserve existing areas having many Joshua trees, knowing they will die off this century? Or purchase and conserve land in their projected higher ranges? Unfortunately, Joshua Trees still wouldn't be able to migrate fast enough on their own, so it would be better to do both: (1) spend funds on more research on the practicalities of assisted migration and (2) protect, manage, and purchase lands in their future ranges and refugia. The authors realize "We simply have no choice but to think beyond the traditional parks-and-preservation model if we wish to save species in an era of rapid climate change." Merely sticking with traditional conservation measures and rejecting, wholesale, assisted migration would be "itself a capitulation: to species extinction"(Minteer and Collins 2010). The author concludes that what is needed is "the development of a more pragmatic ethics of species relocation under climate change…The attention should shift.. from.. the abstract to outlining conditions under which managed relocation should be considered as a realistic option and what criteria are relevant to distinguishing "good" from "bad" relocation proposals, and evaluating good and bad relocation efforts on the ground." The implications here are huge. The entire conservation model needs to pivot towards assisted migration, and become much more proactive and pragmatic, not just for Joshua trees but for many other species threatened by climate change.

Conclusion

Humans can help to diminish the main threats the Joshua Tree faces: development, fire, and climate change. The largest, most existential of these is climate change. These various research studies have shed light on assisted migration for Joshua trees but its viability is still a puzzle. The landmark study on contracted range definitively proves a loss of range in the past and forecasts a severe loss of range in the future. But it also points out that the Joshua tree has had 12,000 years from North America's last significant warming event to move above its 1,800 m. upper range. In that time it has not, possibly because its megafaunal disperser, the Shasta ground sloth, went extinct about the same time. A migration lag of 12,000 years is significant and not mentioned frequently in the body of research on Joshua trees. If the sloth's extinction is responsible for this lag then assisted migration can be more viable: humans would, in a way, be replacing the role of the sloth in species dispersal. Or, seed dispersal by rodents has been historically sufficient but other factors have caused this migration lag. More research needs to be done, which has been the main limitation of this paper: the lack of field-studies.

The smaller, more focused and pragmatic studies this paper has looked into also provide clues to the viability of assisted migration, for instance,

(1) Soil study: A close look at smaller factors, like soil and fungus is required and may shed light on migration lag, past and future.

(2) CO_2 study: climate and range modeling CO_2 only, separate from warming, shows Joshua trees will have an expanded, future range of 14%. Some hope here but does not take into account other factors, such as the ability to migrate.

(3) Moth mutualism study: Migration will be more difficult for the Joshua Tree due to the mutualism it shares with its unique pollinator. Having evolved over millennia it is unknown if the Yucca moth can migrate, or migrate fast enough, with the Joshua tree

(4) Seed and Germination study: In a controlled, outdoor lab, authors find that seeds do not last long. Seedlings start out better within nurse plants, but then compete for moisture. Seedlings survive better when planted early fall, with moist ground. Seedlings need much winter/early spring precipitation.

These studies show that we have some pieces of the puzzle but more research is needed to assess the viability of assisted migration for the Joshua tree. Climate change is at the point where gradual, assisted range expansion, a type of assisted migration, should be started at the top of Joshua tree's current high range and at their identified climate refugia. This would itself become a field study, and data gathered would guide future seeding and planting programs; and this will minimize potential problems for the recipient ecosystem. This could involve gathering thousands of pods and planting them at the appropriate locations. Or it could involve first growing the Joshua trees to a size resisting predation and transplanting them at specific locations, while somehow bringing their pollinating moth along.

Although difficult, assisted migration can work, or at least be tried, for the Joshua tree. It does involve ethical and concerns for recipient ecosystems, but, quite simply, humans are almost too late. At the current rate of warming, something must be done. "Still, one thing seems perfectly clear: We have a rapidly shrinking set of options for saving many species threatened by a warming world. The biological stakes are high. If we value wild species and wish to bequeath a significant fraction of global biodiversity to future generations, radical strategies like managed relocation may well be our last best chance. Although risky, such bold efforts to preemptively move threatened species to new environments may offer the only hope to keep them from moving into museums and zoos–and haunting our ecological conscience"(Minteer and Collins 2010).

There has been success in reversing species loss. As a result of habitat destruction and degradation, illegal shooting, and DDT, the Bald Eagle was going towards extinction until there were only 417 nesting pairs in 1963. Now there are 71,400 nesting pairs with the help of having federal Endangered and Threatened status (Buehler 2000). The California Condor was down to 27 individuals as a result of DDT, poaching, lead poisoning, and habitat destruction. Today there are 500 and growing (California Condor 2022). But the Joshua tree doesn't have to see this much decline before measures like assisted migration are taken to preserve them.

Until now there has been a patchwork of legal protections for Joshua trees. What is needed are broad protections. There have been two petitions and two rebuttals to placing Joshua trees under the protection of the federal 1973 Endangered Species Act. This would mark the first time a plant species would receive this level of protection in CA. The federal government has delegated this decision to the CA Dept. of Fish and Game Commission which is currently deferring to the state of California to see if they pass conservation legislation. This would be better than before but protection would only be in California, when their range covers at least 4 states. Funny how the fate of this keystone species, having evolved over millions of years, rests in the decision of five modern-day humans. Protecting Joshua trees with broad legal protection will go a long way to not just provide immediate protections from destruction, but also fund and spark more research into the practical side of assisted migration as demonstrated in this paper.

Humans have already dealt a blow to the Joshua tree by hunting to extinction its megafaunal seed disperser, the Shasta Ground Sloth. Now, by rapidly warming the climate, we are once again injuring this species. We have a moral obligation to try and assist it to move to a higher range.

This systematic review of the complexities of just this one species in the Desert Southwest shows that climate change is causing a cascade of difficulties, not for just humans, but all the way down to the little moth that tends to the great keystone species, the Joshua tree. And this mutualistic pair are just two species out of many imminently threatened by climate change. Earth's air conditioner, the Arctic, has warmed four times faster than the rest of the world since 1979.(Rantanen et al. 2022) Wouldn't it be easier to reverse climate change now than to deal with all of these consequences we can't even fathom? If we have the technology to seriously consider terraforming Mars, why can't we come up with solutions and implement them on our own planet?

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