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"Left Behind in Near Time: Assisted migration for our most endangered conifer-now"

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[first para in italics, or call it an Abstract]
We propose that assisted migration for Torreya taxifolia be undertaken immediately, such that this critically endangered conifer endemic to a single riverine corridor of the Florida panhandle is offered a chance to thrive in natural settings further north, and such that the process of assisted migration can be tested as a conservation tool. Given current climate and expected warming, the target range for test plantings of T. taxifolia would center on the southern Appalachians and Cumberland Plateau, with perhaps some sites further north. We intend to work with other volunteers toward this end, by collecting seeds from the grove of T. taxifolia at the Biltmore Gardens in Asheville, by inviting private landowners in the target areas to offer their forested properties for plantings, and by encouraging area teachers to involve their students in all aspects (including long-term monitoring) of this new phase of conservation which, sadly, will become increasingly important as global warming proceeds as geoscientists predict (Alley 2000).
[end italics]

[Josh: You have a B&W line drawing of *T. tax* leaves and fruit in the 1875 Asa Gray article. I also have a decent photocopy of a lovely B&W line drawing of close-up *T. tax* leaf and fruit combination, taken from 1926 edition of "Manual of the Trees of North America" (Charles Sprague Sargent), if you'd like me to send it to you for publication.]

In a companion essay, *Torreya* expert Mark Schwartz concludes that assisted migration should not be attempted for this critically endangered yew-like conifer -- at least not yet. He also advises that any plan for assisting range change of a plant species or population be predicated on clear guidelines. Schwartz's challenge prompted us to develop a set of standards (sidebar), written generically for plants, and against which we here evaluate *Torreya taxifolia* (henceforth, T. tax, or Florida *torreya*).

These standards for assisted migration were developed with the help of a score of people (including Mark Schwartz) who have been conversing via email for half a year (and some of us longer) about the merits and pitfalls of transporting seeds or seedlings (of plants in general and *T. tax* in particular) into natural sites remote from current range. This self-organized "*Torreya* Group" was initiated and networked by Connie Barlow, and it has drawn input from plant enthusiasts, naturalists, horticulturalists, and Nature Conservancy staff, as well as academic and governmental botanists, foresters, palynologists, ecologists, paleoecologists,

conservation biologists, and environmental ethicists. The two coauthors of this article look forward to the wider conservation community debating and reworking the standards presented here, for discerning when it is appropriate to overcome a lack of connectivity or to supplement natural dispersal by employing this powerful conservation tool, and how assisted migration might apply to broader ecosystem concerns in a time of human-induced global warming.

Moving Endangered Plants: Easy, Legal, and Cheap

Assisted migration as a conservation tool is both fascinating and frightening for anyone focused on plants, for this reason: [begin ital] *Assisted migration for endangered plants can easily, legally, and at virtually no cost be implemented by whoever so chooses, with no need for any particular expertise, and no governmental approval - provided that private seed stock is available and that one or more private landowners volunteer their properties toward this end.*[end ital] This cheap-and-easy route for helping imperiled plants is in stark contrast to the high-profile, high-cost, and governmentally complicated range recovery programs ongoing for highly mobile animals, such as the Gray Wolf, Lynx, Peregrine Falcon, and North American Condor.

Another potential use for assisted migration as a conservation tool looms as well, expressed in email conversation (4/2/04) by Peter Wharton, curator of the Asian Garden of the University of British Columbia Botanical Garden: "The *Torreya* question is a door to immense issues relating to how we facilitate global 'floraforming' of vegetational zones in a warming world. It is another layer of responsibility for those of us who have a passion for forests and wish to promote the ecologically sensitive reforestation of so many degraded forest ecosystems worldwide."

Forest ecologist Brian Keel (in press), who coined the term "assisted migration," sums up the situation this way: "The triple problems of rapid human-caused climate change, landscape fragmentation, and habitat destruction will put many plant species at risk of extinction. For plants to survive climate change, they must either adapt to changing climatic conditions where the species is presently growing or track suitable habitats as the climate changes, that is, migrate. For plant species that cannot adapt, landscape fragmentation and habitat destruction may prevent migration, and human intervention in the form of assisted migration will be necessary to prevent extinction."

This too from conservation biologist Anathea Brooks, assistant director of the NASA Goddard Earth Science and Technology Center: "With the advent of climate change, and the discontinuity of habitat due to our sprawling urban growth, does humankind have a moral responsibility to assist species to migrate? If so, what criteria do we use to select those who can board the Conservation Ark? After hearing [Louis] Iverson talk about the potential distribution range of tree species, and everything I've heard at NASA about

the likelihood of major climate modifications, we need to have this discussion without delay." (7/19)

***T. tax* and the Ecological Standards**
(refer to sidebar)

STANDARD # 1, NEEDINESS: "The world's most endangered conifer" is the way a Nature Conservancy pamphlet (1997) introduces *Torreya taxifolia*. The Florida Chapter of the Nature Conservancy, the State of Florida (*Torreya* State Park), a number of botanical gardens, and dispersed academic researchers are all actively involved in its recovery, guided by a USF&WS recovery plan and pursuant to the Endangered Species Act. *T. tax* is an evergreen conifer that historically is found only within a short and narrow stretch along the Apalachicola River of northern Florida and a sliver of southern Georgia. Despite extreme endemism, the species was once a prominent mid- and under-story member of its forest community, which includes an odd mix of north and south: towering beech and hickory next to tall evergreen magnolia, and surrounded by stubby palmetto palm.

In the 1950s, the species suffered a catastrophic decline, the ultimate cause still unexplained. By the mid 1960s, no large adult specimens -- which once measured more than a meter in circumference and perhaps 20 meters tall -- remained in the wild, felled by what seemed to be a variety of native pathogens. Today, the wild population persists as mere stump sprouts, cyclically dying back at the sapling stage, such that seeds are rarely, if ever, produced. *T. tax* thus joins American Chestnut in maintaining only a juvenile and diminishing presence in its current range. (Digital photos of Apalachicola specimens in the wild are posted at www.*torreya*guardians.org).

STANDARD # 2, LOW RISK FOR RECIPIENT ECOSYSTEMS: Mark Schwartz and others
who know the tree through years of professional engagement agree that T. tax is very unlikely to become noxious in recipient ecosystems to the north. Sharon Hermann, however, cautioned that *T. tax* transplanted to the north might serve as host for a pathogen that would then spread to other plants (3/1/04 email). Josh Brown (12/9/03) wondered whether *T. tax* might be a "highly interactive species," following Soule et al. 2003. This prompted discussion as to whether *T. tax* might serve an ecological function similar to that of Eastern Hemlock: providing evergreen shade along streams and streamlets within deciduous forests. A suggestion that *T. tax* be evaluated as a possible replacement for our native hemlock, which is now stressed by global warming and locally extirpated by exotic insect (woolly adelgid), generated a wave of protest. Talk of finding an ecological replacement for a struggling and much-loved native conifer is as unwelcomed by some as would be talk of replacing a dying spouse or child. Overall, the ecological interactivity (for good or ill) of *T. tax* in recipient ecosystems will become apparent only when test plantings in natural forest habitats to the north are carried out and monitored.

There is a large gray area to explore with respect to risks in recipient ecosystems. Palynologist Hazel Delcourt made this suggestion in email conversation: "I also have reservations about introducing *Torreya* to the southern Appalachians without understanding its functional role in the new ecosystems that may result from its introduction. . . Would it be prudent
of us to suggest that some experimental plant ecology be undertaken in limited and controlled trials, not arboretum environments but in more natural surroundings? . . . The question of whether it is appropriate to plant it all over the southern Appalachians -- just because we can -- is one that I believe we all need to think about carefully." (2/24/04)

STANDARD #3, IRREVERSIBLE PROBLEMS IN CURRENT RANGE.
On this point there is disagreement. Mark Schwartz and others maintain hope for recovering *T. tax* in reproducing, self-maintaining populations in its current range. Since 1997, staff at the Atlanta Botanical Garden have been experimentally taking healthy *T. tax* grown from seed at the garden and planting these trees at the periphery of the existing range and somewhat further north in Georgia. The efficacy of applying fungicides and supplemental fertilizers to these transplants is now also being tested (author, 2002). The transplants are all progeny of "potted orchards" established from cuttings taken from wild specimens in Florida in November 1989.

Another *Torreya* expert, Rob Nicholson (conservatory manager at Smith Garden Botanical Garden, at Smith College in Massachusetts) participated in the 1989 salvage of wild genotypes and their propagation as clonal stock. Nicholson presents a less hopeful view of resurrecting a healthy and self-maintaining population of *T. tax* in its current range. This is drawn from the *Torreya* conservation page of Nicholson's website:

[blockquote]"The number of mature trees in cultivation outside of Florida may number less than two dozen. At the beginning of the twentieth century, there were wild populations of *Torreya taxifolia* estimated at about 300,000 to 600,000. The estimated number of plants in the original habitat is about 500, which means that 99.3 to 99.6% of the population found at the beginning of the 1900s has died. Where 60-foot trees were formerly found, few individuals over 10 feet are now known. Although research into the cause of this decline is ongoing, in situ preservation appears problematic, and management efforts now include the propagation of rooted cuttings from documented wild stands to be grown in ex situ populations." [insert web page; end blockquote]

Virtually all of us who have been conversing electronically about the pros and cons of assisted migration for *T. tax* agree that at some point in the future, human-induced global warming will indeed push *T. tax* (and all too many other plants) to the edge of viability; at that time, assisted migration will become standard practice. For reasons explained below, we

believe *T. tax* is already at that juncture. In a 1990 article, Rob Nicholson speculated, "Is *Torreya* an early victim of global warming and a precursor of a new wave of inexplicable extinctions?"

We ask, as well: [ital] *Why wait until a hundred species are on the brink? Rather, let us undertake assisted migration for Torreya taxifolia today, in part, as a trial run for the decades to come. With T. tax we can explore the ecological and emotional hurdles toward such a radical turn in conservation.* [end ital]

STANDARD #4, SUITABILITY OF TARGET RANGE.

As Rob Nicholson has pointed out, there are very few seed- and pollen-producing specimens of *T. tax* outside of those that have recently matured from rooted cuttings taken from wild stock in 1989 and then nurtured in potted orchards in three botanical gardens. After all, who would think to plant Florida *torreya* in the north, if the tree is clearly native only to Florida? Surely the tree could not survive harsh winters.

Fortunately, in 1939 Chauncey Beadle collected about a dozen specimens of *T. tax* from the Apalachicola and planted these along a streamlet as part of a naturalistic grove of open pine forest -- with a mid-story of hemlock and *Torreya* and an understory of shrubs -- within the vast holdings of the Biltmore Gardens, in Asheville, North Carolina (elevation 2200 feet). Interestingly, the hemlock are prominent on the north-facing slope of this slight ravine, and all the *Torreya* (including self-propagated saplings, probably planted by squirrels) occur and are thriving on the south-facing slope. (Digital photos of the grove are available on-line.) It is not known if the segregation of the two species was intentional or whether it emerged in the ensuing years (Bill Alexander, Biltmore forest historian, pers. comm.) As to *Torreya*'s cold-hardiness, Bill Alexander reports that in the winter of 1985 all *Torreya* specimens survived unharmed an episode of unusual cold; temperatures plunged to minus 16 degrees F.

Rob Nicholson has written: "This Florida native, as evidenced by the few healthy trees in cultivation, seems to thrive on the southern slopes of the Appalachian Mountains and is more cold tolerant than its present range would suggest." Peter White, director of the North Carolina Botanical Garden at the University of North Carolina (Chapel Hill), remarked in an email (3/3/04), "Like others, I have noticed how well *Torreya* grows in cultivation in the mountains, and its current range seems to not represent its climatic envelope." Indeed, famed botanist Asa Gray, who made a "pious pilgrimage" to visit *T. tax* in the wild, wrote in 1875, "One young tree, brought or sent by Mr. Croom himself [its discoverer], has been kept alive at New York showing its aptitude for a colder climate than that of which it is a native."

STANDARD #5, BARRIERS TO UNASSISTED MIGRATION

STANDARD # 6, RECONSTRUCTING PAST RANGE

For *T. tax*, these two standards can best be evaluated in tandem. Here is where our own expertise comes into play (e.g., Martin 1957; Barlow 2001), as we search for an understanding of the near-time (15,000 years ago until the time of historical records) and deep-time story of genus *Torreya*.
[ital] *It is this attention to the past that leads us to regard assisted migration for T. tax to the southern Appalachians as not so much relocation for a plant struggling with global warming as repatriation of a once-native. It is thus a form of rewilding that uses a near-time or deep-time baseline*
for determining native range.[end ital]

First we begin with an excerpt from a 2003 draft background document on *T. tax* by Hazel Delcourt, palynologist and author of *Forests in Peril* (reviewed in *Wild Earth*, Winter 2004). She wrote this draft as a *Torreya* Group participant,
before it became clear that a pro-and-con forum, rather than a single article, would best present the issue for the readers of Wild Earth. Delcourt wrote:

[blockquote]
"*Torreya taxifolia* is a classic example of a narrowly endemic plant, long considered by botanists to be a relict of geologic history, surviving for millions of years in a specialized island-like habitat. The genus is a member of the ancient gymnosperm family, Taxaceae, whose ancestors were evolutionarily distinct from other conifers by the Jurassic Period." [end blockquote]

Unfortunately, fossil evidence of genus *Torreya* is sparse. Because *Torreya* pollen is indistinguishable from the pollen of yews (Taxus) and bald cypress (Taxodium), as well as several other conifers, known fossil occurrences of this genus are limited to macrofossils (seeds, leaves, and secondary wood). There are no Cenozoic fossils whatsoever of *Torreya* in eastern north America, not even Quaternary fossils near where it still survives. The most recent macrofossils identified as *Torreya* in eastern North America are upper Cretaceous, and these were unearthed in North Carolina and Georgia. Because worldwide climate during the Cretaceous was much warmer and far less seasonal than that of today, it is not surprising that *Torreya* macrofossils of Cretaceous age have also turned up along the Yukon River of Alaska. In western North America, there is Cenozoic fossil evidence of *Torreya* in the John Day region of Oregon (lower Eocene) and variously in California (Oligocene and late Pleistocene). Just possibly *Torreya* remains undiscovered in the patches of mesic forest with sweet gum (*Liquidambar*), beech (*Fagus*), and yew (*Taxus*) in the Sierra Madre Oriental of Nuevo Leon, San Luis Potosí, and Tamaulipas in northeastern Mexico.

The genus today is highly disjunct. *Torreya* californica survives as a rare tree, locally abundant in a score of isolated populations within the

coastal mountains of central and northern California and on the west slope of the Sierras. It favors moist canyons and mid-slope streamside environments (generally between 3000 to 6500 feet elevation), growing beneath a canopy of taller conifers and deciduous trees. *Torreya* nucifera is found in Japan and Korea. Four other species inhabit China. [ital] *Torreya taxifolia is the only one of the seven that is highly imperiled, and we believe we can explain why*.[end ital]

So what happened? And why is Florida's *torreya* in such bad shape compared to its sibling species?

Near-Time Obstacles to Natural Migration

Torreya taxifolia is a glacial relict, left behind in its "pocket reserve" of rich soils and cool, moist microclimates provided by the steep bluffs and ravines along the east shore of the Apalachicola River. The current richness of North America's deciduous forests is, in large part, thanks to this and other glacial refuges (including the Tunica Hills of Louisiana and the Altamaha River of Georgia) and the bluffs of other large rivers emptying into the Gulf of Mexico and the southern Atlantic coast (Delcourt 2002). For some of the repatriated plants (notably, beech) relict populations still remain in one or more of these refugia, while the bulk of the range is disjunct much farther north.

T. tax was unable to follow the other plant refugees north when the ice retreated, beginning some 15,000 years ago. Why? There are several plausible scenarios.

One possibility (favored by Hazel Delcourt, 2/11/04) is that some plants, *Torreya* among them, were unable to return north not just in this interglacial but in previous interglacials too. The relatively slow onset of the first glacial episode permitted warm-temperate plants to retreat to coastal refuges, but the faster pace of interglacial warmings ever after prevented them from making the return trip. *Torreya*'s isolation thus would have begun some 2 million years ago, with no respite in any of the glacial cycles. Delcourt also wondered whether *Torreya* was perhaps chased out of the southern Appalachians as long ago as the Oligocene cooling, some 34 million years ago. On this question, the fossil record is mute.

Another possibility, favored by the authors of this paper, is that *Torreya taxifolia* probably did return to the southern Appalachians during previous interglacials. The best proxy data for global climate during the ice ages are found in ice cores (for popular treatment, see Alley 2000). As measured in the Vostok Core, Antarctica, the last interglacial -- 110,000 to 140,000 years ago and preceded by many others of equal magnitude -- did not peak at a global temperature much different from that of today. If *Torreya* is having trouble surviving in the northern Florida now, it should have had trouble in multiple interglacials.

So what makes our own interglacial uniquely inhospitable for natural migration? There are only two significant differences between this interglacial and the previous. We shall argue that either of these differences could have posed grave problems for *Torreya*, and together they would have sealed the fate of the unfortunate refugee.

[ital] *One difference is that our current interglacial is uniquely understocked in large herbivorous mammals, both in diversity and in numbers*.[end italics] By 10,000 years ago, the mastodons, the mammoths, the giant ground sloths, and other mammals that powerfully affect the vegetation had vanished. Notably, we lost all our big browsers. Small trees would have been untoppled by elephants, saplings and shrubs gone uneaten. Overall, the landscape would have become a lot brushier, and thus more susceptible to the kind of catastrophic fires that would have ranged widely in the dry and sandy pinelands of southeastern lowlands, even reaching into the shady, moist ravines through which fire-intolerant *Torreya* would have been edging north.

[ital] *A second difference between this interglacial and the next-to-last is that only in the current interglacial has North America been home to a creature that can make fire on demand.* [ital] By the onset of the present interglacial, more commonly known as the "postglacial," paleoindians had arrived. They were new to the Americas. Both accidentally and for many possible reasons they ignited wildfires. To flush out game, to make land easier and safer to cross, and perhaps even to favor plant species that provided food (the acorns of oaks), fires would have been ignited. As an unintended result, they would have ramped up the fire hazard for migrating *Torreya*.

New pollen records from New York State reveal an abundance of charcoal in the fossil record after extinction of large mammals. Palynologists suspect that the end of mastodon and stag-moose herbivory favored luxuriant growth of shrubs, especially in riparian habitats. Post-extinction rebound of browse would favor fires (Robinson 2003).

Fires most likely to eliminate evergreen shrubs would be all but unknown prior to anthropogenic activity -- "the fires of spring," a season when natural ignitions are unusual or unknown and human ignitions would, in an especially dry spring, be a novelty. This scenario may account not only for the suppression of *Torreya* but also for the extinction of a recently described new species of spruce, *Picea critchfieldii* (Jackson and Weng 1999). Late Pleistocene extinctions of plants, to match the devastation suffered by large mammals, are otherwise unknown.

Consider Australia's celebrated native endemic and "living fossil": the Wollemi "pine." *Wollemia nobilis* is the sole remaining species of a genus that originated in the Cretaceous. It is in the Araucariaceae family, which includes only two other living genera: monkey puzzle (*Araucaria*) and Norfolk Island "pine" (*Agathis*). This sole remaining species of a genus originating in the Cretaceous was unknown until

1994, when a grove of just 24 strange but magnificent trees were found hiding out in an all but inaccessible deep canyon in the mountains northwest of Sydney (Woodford 2000). Although a downturn in fossil pollen dated at two to three million years ago suggests that genus *Wollemia* was in decline long before humans reached Australia, *Wollemia*'s brush with extinction, along with the actual near-time exinctions of several other Australian conifers (including two species of Nothophagus), have been attributed to anthropogenic fires by early aboriginal peoples (Kershaw 1984). The surviving trees narrowly escaped firestorms and extinction in the shelter of deep canyons. Propagation of *Wollemia* seed stock has been achieved and seedling trees are being widely distributed.

[ital] *T. tax may thus have been a victim of contact, relegated to a short stretch of riverside ravines by fires set directly by humans and intensified indirectly by humans, owing to the extinction of megafaunal browsers.* [ital]

There is yet a third way in which humans might have stressed local populations of *T. tax. The dispersal agents (squirrels, and perhaps also tortoises) upon which T. tax utterly depended for movement of its large, fleshy seed would likely have been severely reduced in numbers, even extirpated*,[end ital] as these creatures are not only attractive foods; they are safely and easily killed -- even by children (Martin and Szuter 2004; Barlow 2001).

If the advent of people and the consequent setting of anthropogenic fires, loss of big browsers, and local extirpations of dispersal agents are indeed the proximate causes of *T. taxifolia*'s troubles, then why has the California species of *Torreya* been spared? Our answer is that California's *Torreya* (and presumably all the Asian species) were able to track climate change not by moving hundreds of kilometers north but hundreds of meters upslope.

Thus we believe that topographical differences are at cause. Although we are unfamiliar with the habitats of the Asian species, we do know that *T. californica* resides in mountain habitats (and one of us has visited a thriving natural grove). We posit that of all seven species within the genus, *T. taxifolia* is unique in having no nearby mountains to ascend as climate warms. A journey of 400 km (as the crow flies; far more as the ravine meanders) would have been required for Florida *Torreya* to reach the southernmost Appalachians.

One final note in our "Left Behind in Near-Time Story": Because glacial refugees in the east suffered not only increased fire hazards but also the bad luck of mountainless terrain, *Torreya* was not alone in its troubles. Severe endemism of the Florida yew (*Taxus floridiana*, also only along the Apalachicola), historic extinction in the wild of America's only big-blossomed relative of Asian camellia (tea family), *Franklinia*, and near-time extinction of the once-widespread Critchfield Spruce (*Picea critchfieldii*) may all be attributed to the advent of the

fire-makers (Martin, in press). Given the sequence of loss in their pocket reserves, it would seem that Critchfield Spruce was the least warm- and drought-tolerant of the bunch, followed by *Franklinia*, which now thrives in cultivation in the mid-Atlantic states. Next comes *T. tax*, followed by Florida yew, which is not yet sickly in its Florida refuge but is doing a poor job of reproducing.

"Left behind in near time" may thus be a syndrome that applies to a number of extinct, imperiled, and soon-to-be-imperiled plants. For example, how do we understand all the highly endemic populations or species of vascular plants far removed from their peers? What about a cool-adapted and drought intolerant fern residing on shaded cliffs in southeastern Ohio? Might the "left behind" scenario offer insight? And if so, how does this awareness alter our conservation options as climate shifts? Surely, the stories we tell about how and why these plants came to rest in small or unusual places will play a big role in the choices we make to preserve them. What stories will we tell? Perhaps we conservationists will collectively write our own "left behind" series -- compelling stories that move us to reduce the toll amongst innocent green bystanders when we face an Armageddon of our own making.

Organizational Standards:

A self-organizing group, *Torreya* Guardians, has formed to discuss and act in behalf of *Torreya taxifolia*. Significant ideas and plans for action initiated by individuals or subsets of this group will be posted at www.*torreya*guardians.org. Those who wish to volunteer their time or their students, share their insights, have test plantings take place on their own private lands, or help with website management (especially threaded discussion) are encouraged to contact the group through this website.

[blockquote]
"I think we ought to purposefully blur the line between scientists and non-scientists. Some scientists might want to be guardians in your sense. Also, the demands of rigorous science are such (and the funding available low enough) that I doubt that science will ever do the job of large-scale assisted migration. Scientists might inform or inspire it, or do the experimental effort that tests the idea, but I don't think conservation managers should expect scientists to be the most important movers." -- Peter White, director of the North Carolina Botanical Garden, Chapel Hill (7/17/04) [end blockquote]

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