Cooley's Meadowrue (*Thalictrum cooleyi*)

5-Year Review:
Summary and Evaluation

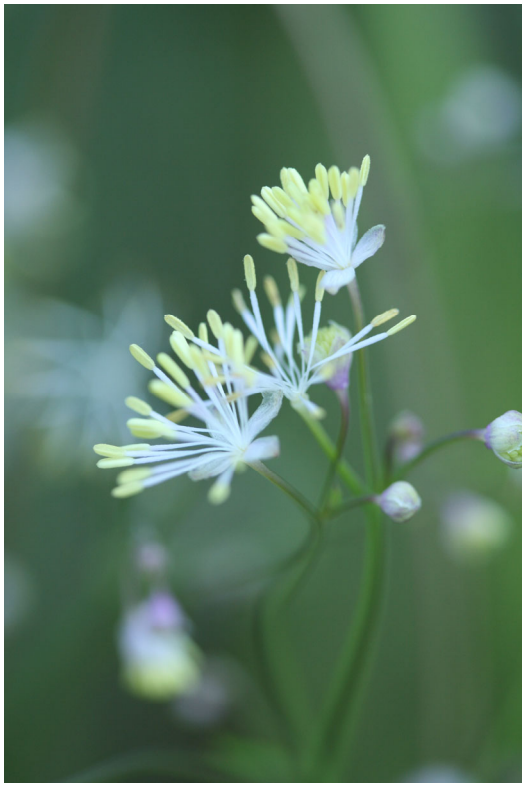


Photo by Dale Suiter, USFWS

U.S. Fish and Wildlife Service
Southeast Region
Raleigh Ecological Services Field Office
Raleigh, North Carolina

† Please see Addendum 1 at the end of this, our original 5-year review document. The Addendum provides new information we have gathered for our most recent 5-year review for this endangered plant which was initiated in the Federal Register (March 12, 2018, 83 FR 10737).

5-YEAR REVIEW
Cooley's Meadowrue (*Thalictrum cooleyi*)

I. GENERAL INFORMATION

A. Methodology used to complete the review

Little information has been published on *Thalictrum cooleyi.* The information used to prepare this report was gathered from peer reviewed scientific publications, status reviews by Rayner (1980) and Leonard (1987), current data from the North Carolina Natural Heritage Program (NCNHP), Florida Natural Areas Inventory (FNAI), Georgia Natural Heritage Program (GNHP), correspondence from botanists knowledgeable of the species and personal field observations. The review was completed by the lead recovery biologist for *Thalictrum cooleyi* in the Raleigh, North Carolina Field Office. The recommendations resulting from this review are a result of thoroughly assessing all available information on *Thalictrum cooleyi.* Comments and suggestions regarding the review were received from peer reviews within and outside the U.S. Fish and Wildlife Service (Service). A detailed summary of the peer review process is provided in Appendix A. No part of the review was contracted to an outside party. Public notice of this review was provided in the Federal Register on April 26, 2007, and a 60-day public comment period was opened. Comments received were evaluated and incorporated as appropriate.

B. Reviewers

Lead Region:
Kelly Bibb, Southeast Region, 404-679-7132

Lead Field Office:
Dale Suiter, Raleigh, N.C., Ecological Services, 919-856-4520 extension 18

C. Background

1. FR Notice citation announcing initiation of this review:

April 26, 2007 (72 FR 20866)

2. Species status: Stable

In the 2008 Recovery Data Call, the status of *Thalictrum cooleyi* was listed as stable. The last status survey for *Thalictrum cooleyi* was completed in 1987, prior to the species becoming federally listed as endangered. While various botanists have visited most of the known populations since that time, no formal status surveys have been conducted since 1987.

3. Recovery achieved

Thalictrum cooleyi = 2 (25% - 50% of species recovery objectives achieved)

4. Listing history

Original Listing
FR notice: 54 FR 5935
Date listed: March 9, 1989
Entity listed: Species
Classification: Endangered

5. Associated rulemakings:

There are no associated rulemakings.

6. Review History: Since *Thalictrum cooleyi* was named as a distinct species in 1959 and listed as endangered in 1989, very little information has been published on this species. The Service conducted a five-year review for this plant in 1991(56 FR 56882). In this review, the status of many species was simultaneously evaluated with no in-depth assessment of the five factors or threats as they pertain to the individual species. The notice stated that the Service was seeking any new or additional information reflecting the necessity of a change in the status of the species under review. The notice indicated that if significant data were available warranting a change in a species' classification, the Service would propose a rule to modify the species' status. No change in *Thalictrum cooleyi's* listing classification was found to be appropriate. A status survey for *Thalictrum cooleyi* was completed in 1987. Between 2005 and 2007, NCNHP staff or other botanists have conducted visits to 12 of 25 subpopulations of *Thalictrum cooleyi* in North Carolina.

7. Species' Recovery Priority Number at start of review (48 FR 43098):

Thalictrum cooleyi has been assigned a recovery priority number of 2, indicating a high degree of threat, a high potential for recovery, and a taxonomic status of full species.

8. Recovery Plan or Outline

The *Thalictrum cooleyi* Recovery Plan was issued on April 21, 1994.

II. REVIEW ANALYSIS

A. Application of the 1996 Distinct Population Segment (DPS) policy

The Endangered Species Act (Act) defines species as including any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate wildlife. This definition limits listing DPS to only vertebrate species of fish and wildlife. Because the species under review is a plant and the DPS policy is not applicable, the application of the DPS policy to the species listing is not addressed further in this review.

B. Recovery Criteria

1. Does the species have a final, approved recovery plan containing objective, measurable criteria?

Yes

Thalictrum cooleyi shall be considered for removal from the Federal list when the following criteria are met:

1. It has been documented that at least 16 self sustaining populations exist and that necessary management actions have been undertaken by the landowners or cooperative agencies to ensure their continued survival.

2. All of the above populations and their habitat are protected from present and foreseeable human-related and natural threats that may interfere with the survival of any of the populations.

To date, five subpopulations comprising four populations of Thalictrum cooleyi have been protected in North Carolina. One *Thalictrum cooleyi* population in Georgia is protected by The Nature Conservancy and the only known population in Florida occurs on the Nokuse Plantation and is in an area protected.

C. Updated Information and Current Species Status

1. Biology and Habitat

a. Abundance, population trends, demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

This species was discovered new to science in 1957 and named a distinct species in 1959. Aside from presence/absence surveys to update Natural Heritage Program records, little work has been done on this species since then. Its growth habit as a weak upright or leaning perennial typically found in areas that are completely covered with grasses and other herbaceous vegetation makes quantitative surveys very difficult.

Between 2005 and 2007, NCNHP staff or other knowledgeable botanists have visited 12 of 25 North Carolina subpopulations (representing 10 populations) of *Thalictrum cooleyi*. Of the 25 subpopulations known from North Carolina, one is believed to be extirpated and no *Thalictrum cooleyi* plants were observed at four other subpopulations during the last visit to the site (by a competent botanist during the appropriate season; NCNHP denotes these populations as F – Failed to Find). We have little population data from the known sites in Georgia with the exception of the Nature Conservancy's Dry Creek Swamp Preserve a 20 acre preserve which is monitored annually. According to Dr. Matthew Aresco, director of Nokuse Plantation, Bruce, Walton County, FL (pers. comm.), the single known Florida population was burned on April 24, 2008. He reported seeing several plants before the prescribed fire and will monitor the site through the growing season. With the exception of the Dry Creek Swamp

Preserve in Georgia, there is no regular monitoring program in place for this species at any of the other known sites.

Despite recent visits to approximately half of the known subpopulations, they have not been monitored in enough detail or with sufficient frequency nor has enough detailed data been collected to predict long term population trends. Due to the growth habit, appearance and general nature of this species, stem counts are rarely conducted in the field. Any reports of stem counts should be considered with great uncertainty unless detailed methodology are described since it would be very easy to overlook many individual plants during a cursory, low intensity count. It is doubtful that we have a clear understanding of how many individual plants occur at any one subpopulation or population. Therefore, it would be more appropriate to record the species status as unknown at this time.

b. Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

Little genetics research has been done on this species. Park (1992) found that *Thalictrum cooleyi* has the highest chromosome number in the genus, 2n = 210, a ploidy level of 30x compared to the base chromosome level of 7 in *Thalictrum*.

The Georgia Natural Heritage Program recognizes seven element occurrences of *Thalictrum cooleyi* in Georgia. Six occurrences are in Worth County and one is in Doughtery County. These occurrences or subpopulations likely only represent two metapopulations. Research by Dr. Wayne Parrott and his graduate students (University of Georgia) indicates that the Georgia populations of *Thalictrum* applied to the species *cooleyi*, might actually be part of a hybrid swarm (Tom Patrick, Botanist, Georgia Natural Heritage Program, 2003, pers. comm.). LeBlond (Retired Botanist, North Carolina Natural Heritage Program, 2008, pers. comm.) visited this site in the 1990s with Bruce Sorrie and Jim Allison and he does not believe the plants are strictly *Thalictrum cooleyi*, but may be more closely related to *Thalictrum revolutum*. The Service agrees that further genetics research, including anatomical, morphological, determination of chromosome number, etc., will be necessary to compare plants from Florida, Georgia and North Carolina before a final determination can be made. In the meantime, state and federal agencies in Georgia are taking a conservative approach and treating the plants as if they are the endangered *Thalictrum cooleyi*.

c. Taxonomic classification or changes in nomenclature:

There have been no changes to the taxonomic classification or nomenclature since *Thalictrum cooleyi* was listed as endangered in 1989.

See section II.C.1.b., above, for additional information regarding the potential for the Georgia populations to be a hybrid swarm.

d. Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):
When the recovery plan was written in 1994, *Thalictrum cooleyi* was known from 12 sites (these sites are now considered subpopulations) in the coastal plain of North Carolina and one population in the Florida panhandle. Since that time, additional occurrences have been found in North Carolina, and several sites of uncertain taxonomy (described above) have been found in Georgia. Our records currently indicate a total of nine extant populations including 24 extant subpopulations in NC. Of the 25 subpopulations once known from North Carolina, one is believed to be extinct and no *Thalictrum cooleyi* plants were observed at four other subpopulations during the last visit to those sites (by a competent botanist during the appropriate season); however, those four sites have not been labeled extirpated yet by the NCNHP. Two populations (consisting of seven subpopulations) are known in Georgia. The one population consisting of one subpopulation is still extant in Florida. This information is summarized in Table 1 and Appendix C. Distribution maps are available in Figures 1 and 2.

Table 1. Number of extant populations and subpopulations of *Thalictrum cooleyi* at the time of listing (February 7, 1989) and current (May 10, 2008).

	NC	GA	FL	Total
No. extant populations at listing	?	0	1	?
No. extant subpopulations at listing	12	0	1	13
No. extant populations in 2008	9	2	1	12
No. extant subpopulations in 2008	24	7	1	32

e. Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):
All of the known *Thalictrum cooleyi* populations occur in the Coastal Plain Province. The recovery plan states that the species grows in circumneutral soils (pH near 7) in wet pine savannas, grass-sedge bogs and savanna-like areas, often at the border of intermittent drainages or swamp forests. It is found on fine sandy loam soils that are at least seasonally (winter) moist or saturated and are only slightly acidic (pH 5.8-6.6).

f. Other relevant information about the species (propagation, etc.):
The N.C. Botanical Garden is the designated Center for Plant Conservation repository for this species. They have several plants in

cultivation that were grown from Florida and North Carolina collected seeds. Seeds from two North Carolina populations (Natural Heritage Program Element Occurrence Numbers 4 and 8) are stored there for long term preservation of genetic material, for research and reintroduction. They hope to increase seed accessions and conduct research on seed production, seed ecology, storage and germination as funds become available.

In summary, despite recent visits to approximately half of the known subpopulations, *Thalictrum cooleyi* sites have not been monitored in sufficient detail to predict long term population trends. Little genetics research has been done on this species. Further genetics research that compares plants from Florida, Georgia and North Carolina will be necessary to make a final decision on the relationship of the populations in Georgia. In the meantime, state and federal agencies in Georgia are taking a conservative approach and treating the plants as if they are the endangered *Thalictrum cooleyi.*

Further, when the recovery plan was written in 1994, *Thalictrum cooleyi* was known from 12 sites (or what are now considered subpopulations) in North Carolina and one population in Florida. Since that time, additional occurrences have been found in North Carolina, and several sites of uncertain taxonomy (described above) have been found in Georgia. One population is still extant in Florida. Our records currently indicate a total of nine extant populations represented by 24 extant subpopulations in NC. Of the 25 subpopulations previously known from North Carolina, one is believed to be extinct. In addition, no *Thalictrum cooleyi* plants were observed at four additional subpopulations during the last visit to the site (by a competent botanist during the appropriate season). Two populations, consisting of seven subpopulations, are known in Georgia.

2. Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

a. Present or threatened destruction, modification or curtailment of its habitat or range:

According to Misty Buchanan (Botanist, NCNHP, Raleigh, NC pers. comm.) several subpopulations of *Thalictrum cooleyi* have suffered from habitat modification and/or destruction. *Thalictrum cooleyi* is threatened by fire suppression and the ecological succession (competition and/or shading by woody species) that occurs in areas that are not burned on a regular basis. *Thalictrum cooleyi* is also threatened by timber operations such as harvesting, bedding and ditching. Sites located within utility rights-of-way are threatened by herbicide use or mowing during critical growth periods. Habitat destruction, the result of development or land conversion, also threatens this species, but to a lesser degree than the other

factors listed above. High human population growth rates (recorded and predicted) in Pender and Onslow counties will most likely increase habitat fragmentation and decrease suitable habitat for *Thalictrum cooleyi* (North Carolina State Demographics http://demog.state.nc.us/).

A total of five subpopulations comprising four populations are protected in North Carolina. In 2006, the N.C. Division of Parks and Recreation (NCDPR) was granted permission to create the Sandy Run Savannas State Natural Area and began acquiring land from The Nature Conservancy (TNC) and other local landowners soon thereafter. When complete, the Sandy Run Savannas State Natural Area will protect a variety of fire dependent plant communities including areas that are important for the recovery of *Thalictrum cooleyi.* Currently, the NCDPR protects the Neck Savanna, Watkins Savanna and the Sandy Run Savannas (including the Cooley's Meadowrue Powerline Site and the Pine Plantation Survey Site). One site, the Haws Run Mitigation Site, is owned by the N.C. Department of Transportation and is managed by the N.C. Ecosystem Enhancement Program (NCEEP). The Southwest Ridge Savanna site, is owned by the State of North Carolina and managed by the Wildlife Resources Commission as Holly Shelter Game Land. Another site, Shaken Creek Savanna, is owned by TNC.

The only known population in Florida occurs on the Nokuse Plantation and is in an area protected by a conservation easement (Amy Jenkins, Botanist, FL Natural Areas Inventory, pers. comm.). One *Thalictrum cooleyi* population in Georgia (of uncertain genetic lineage) is protected by The Nature Conservancy and managed as the Dry Creek Swamp Preserve (Tom Patrick, GA Natural Heritage Program, pers. comm.).

b. Overutilization for commercial, recreational, scientific, or educational purposes:
There is currently no evidence to suggest that *Thalictrum cooleyi* is being overutilized for commercial, recreational, scientific or educational purposes.

c. Disease or predation:
No signs of predation or disease have been observed in this species; however, it seems reasonable to believe that herbivores may eat the leaves or flowering stems of this plant while grazing on adjacent vegetation.

d. Inadequacy of existing regulatory mechanisms:
Because of its federal endangered status, *Thalictrum cooleyi* is protected on federal lands; however, there are no known populations on federal lands. *Thalictrum cooleyi* is listed as state endangered by North Carolina under the Plant Protection and Conservation Act of 1979, but this protection is largely limited to the regulation of collecting and trade

(North Carolina Department of Agriculture 02 NCAC 48F.0301). One incident of unlawful collection occurred in 1996. Information in the Raleigh Field Office files indicates that the two collectors were fined $500 each and the plants were turned over to the NC State University Herbarium. *Thalictrum cooleyi* is also listed as State Endangered in Florida and Georgia.

The U.S. Army Corps of Engineers (USACE) regulates placement of fill in waters of the United States including wetlands (Section 404 of the Clean Water Act) and is responsible for ensuring that such permits do not jeopardize the continued existence of federally protected species. Since *Thalictrum cooleyi* occurs in wetland habitats, it is important that the USACE determine that potential permitted activities would not negatively affect this species, prior to the issuance of a permit.

To the best of our knowledge, the USFWS office has never consulted with another federal agency regarding potential impacts to this species.

e. Other natural or manmade factors affecting its continued existence: No other natural or manmade factors affecting the continued existence of *Thalictrum cooleyi* are known at this time.

Summary

In summary, the most important factors that justify its endangered status are related to its extreme rarity due to habitat loss from fire suppression and subsequent ecological succession, forestry practices and development due to the inadequate regulatory mechanisms to protect listed plants on private lands. *Thalictrum cooleyi* sites located within utility rights-of-way are threatened by herbicide use or mowing during critical growth periods. Six populations consisting of a total of seven subpopulations are protected on conservation lands in North Carolina, Georgia, and Florida. There is currently no evidence to suggest that *Thalictrum cooleyi* is being overutilized for commercial, recreational, scientific or educational purposes. No signs of predation or disease have been observed in this species. There are no known populations on federal lands. Thalictrum cooleyi is listed as state endangered in North Carolina, Georgia and Florida.

D. Synthesis

In summary, despite recent visits to approximately half of the known subpopulations, *Thalictrum cooleyi* sites have not been monitored in sufficient detail to predict long term population trends. Little genetics research has been done on this species. Further genetics research that compares plants from Florida, Georgia, and North Carolina will be necessary to make a final decision on the relationship of the populations in Georgia. In the meantime, state and federal

agencies in Georgia are taking a conservative approach and treating the plants as if they are the endangered *Thalictrum cooleyi.*

In 1994, when the recovery plan was written, *Thalictrum cooleyi* was known from 12 sites (or what are now considered subpopulations) in North Carolina and one population in Florida. Since that time, 12 additional subpopulations have been found in North Carolina, and seven sites, granted of uncertain taxonomy but currently considered *Thalictrum cooleyi,* have been found in Georgia. The one population is still extant in Florida. To summarize, at the time of listing, we knew of 13 sites or subpopulations, range-wide and now we believe that *Thalictrum cooleyi* is extant at nine populations comprising a total of 32 sites or subpopulations.

The most important factors that justify its endangered status are related to its extreme rarity due to habitat loss from fire suppression and subsequent ecological succession, forestry practices and development due to the inadequate regulatory mechanisms to protect listed plants on private lands. *Thalictrum cooleyi* sites located within utility rights-of-way are threatened by herbicide use or mowing during critical growth periods. Six populations consisting of a total of seven subpopulations are protected on conservation lands in North Carolina, Georgia and Florida. There is currently no evidence to suggest that *Thalictrum cooleyi* is being overutilized for commercial, recreational, scientific or educational purposes. No signs of predation or disease have been observed in this species. There are no known populations on federal lands. *Thalictrum cooleyi* is also listed as state endangered in North Carolina, Georgia and Florida.

Due to the small number of populations and threats to the species such as fire suppression, forestry practices and the destruction or modification of habitat and the inadequacy of existing state or federal laws to protect plants on non-federal lands, we believe *Thalictrum cooleyi* still meets the definition of endangered under the ESA.

III. RESULTS

A. Recommended Classification:

_X_ No change is needed

IV. RECOMMENDATIONS FOR FUTURE ACTIONS

A list of recommendations for future actions that will contribute to the recovery of *Thalictrum cooleyi* include:

- revisit known populations that have not been visited in the past three years; monitor the habitat condition of each site including threats; discuss conservation options with landowners where appropriate; update Natural Heritage Program files with this information,

- search for additional populations,
- prioritize known sites for protection,
- protect additional populations,
- develop management plans for all protected populations,
- develop monitoring protocols, initiate long term population monitoring and determine the criteria for sustaining populations,
- conduct research on general biology of the species including life history and reproductive biology (breeding systems, seed production and seedling survivorship),
- compare, genetically, the populations of questionable taxonomy in Georgia with those known from North Carolina and Florida
- work with North Carolina Botanical Garden to conserve seeds and develop propagation protocols.

V. REFERENCES

Leonard, S. 1987. Inventory of populations of *Thalictrum cooleyi* and its occurrence sites in North Carolina. Report to the North Carolina Natural Heritage Program. Raleigh, NC. 16pp.

Park, M.M. 1992. A biosystematic study of *Thalictrum* section *Leucocoma* (Ranunculaceae). Ph.D. dissertation, Pennsylvania State University.

Rayner, D. 1980. Status report on *Thalictrum cooleyi* Ahles, submitted to U.S. Fish and Wildlife Service, Atlanta, GA.

A complete bibliography for *Thalictrum cooleyi* is included in Appendix B.

U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW OF *COOLEY'S MEADOWRUE (THALICTRUM COOLEYI)*

Current Classification _Endangered_
Recommendation resulting from the 5-Year Review

__X_ No change is needed

Review Conducted By _Dale Suiter, Fish and Wildlife Biologist_____

FIELD OFFICE APPROVAL:
Pete Benjamin, Lead Field Supervisor, Fish and Wildlife Service

Approve _____ Date 12/10/08

Janet Mizzi, Cooperating Acting Field Office Supervisor, Fish and Wildlife Service

Approve _____ **Date** 12/11/08

Sandy Tucker, Cooperating Field Office Supervisor, Fish and Wildlife Service

Approve Sandra Tucker Date 12/12/08

REGIONAL OFFICE APPROVAL:
Lead Regional Director, Fish and Wildlife Service

Approve _____ Date 1/8/09

Acting Assistant Regional Director
Ecological Services

APPENDIX A
Summary of peer review for the 5-year review of Cooley's Meadowrue (*Thalictrum cooleyi*)

A. Peer Review Method:
In early May, a draft copy of the five year review was emailed to botanists with the N.C. Plant Conservation Program, N. C. Natural Heritage Program, the N.C. Botanical Garden, the Georgia Natural Heritage Program and the Florida Natural Areas Inventory. Since *Thalictrum cooleyi* occurs within the work area of two other Service Ecological Service offices, the Panama City, Florida and Athens, Georgia Field Offices were asked to review this document. Reviewers provided comments by email, modifications to the original document and/or in "track changes." Some of the peer reviewers used know the species and are familiar with the habitats where the species occurs and the threats to its long term survival. The other reviewers do not know *Thalictrum cooleyi*, specifically; however, they are familiar with the general flora of the areas where the species occurs and they are also familiar with state and federal regulations, plant conservation issues and the threats to rare species.

B. Peer Review Charge:
Peer reviewers were asked to provide written comments on the information presented in our analysis of the status of the *Thalictrum cooleyi* and to provide comments on the validity of the data. Peer reviewers were asked not to provide recommendations on the legal status of the species.

C. Summary of Peer Review Comments/Report:
Two reviewers replied back and said that they did not have any comments or suggestions on the document. One reviewer provided comments regarding Cooley's Meadowrue plants that are currently in propagation at the N.C. Botanical Garden. Another reviewer provided comments related to the genetics, taxonomy sections and provided additional recommendations for research needs for Cooley's Meadowrue. They also asked that the review include more detailed population data.

D. Response to Peer Review:
The primary author agreed with nearly all comments and concerns received from the peer reviewers and tried to address every comment as appropriate. Since there as been very limited detailed monitoring of this species, it is not possible to provide detailed data, including number of individual plants, at each population or subpopulation.

APPENDIX B
Bibliography of documents mentioning *Thalictrum cooleyi*

Ahles, H.E. 1959. *Thalictrum cooleyi* sp. nov. Brittonia 11:68-70, April 1959.

Coile, Nancy C. 2000. Notes on Florida's Regulated Plant Index (Rule 5B-40), Botany Contribution 38. Gainesville, Florida: Florida Dept. of Agriculture and Consumer Services, Division of Plant Industry.

FNAI. 2000. Field Guide to the Rare Plants and Animals of Florida online. Florida Natural Areas Inventory.

Hardin, D.; White, D. L. 1989. Rare Vascular Plant Taxa Associated with Wiregrass (*Aristida stricta*) in the Southeastern United States. Natural Areas Journal. 9, 4: 1989.

Keener, C.S. 1976. Studies in the Ranunculaceae of the Southeastern United States II. *Thalictrum* L. Rhodora, Vol. 78, 815, 1976 pp 457-472.

Kral, R. 1983. A report on some reare, threatened, or endangered forest-related vascular plants of the south. Tech. publ. R8-TP-2. USDA Forest Service 4:28-431.

Leonard, S. 1987. Inventory of populations of *Thalictrum cooleyi* and its occurrence sites in North Carolina. Report to the North Carolina Natural Heritage Program. Raleigh, NC. 16pp.

Mansberg, L. 1985. *Thalictrum cooleyi*; draft global element ranking form prepared for the Nature Conservancy; North Carolina Natural Heritage Program, Raleigh, NC. 16pp.

The Nature Conservancy. 1986. Lanier quarry Savanna Preserve. The Nature Conservancy News. 36, 6: 28.

The Nature Conservancy. 1997. 1997 Species Report Card: Cooley's meadowrue. Arlington, VA: The Nature Conservancy, Natural Heritage Network (NatureServ). p.21.

North Carolina Botanical Garden. 1995. 1995 Annual report on taxa in the national collection for North Carolina Botanical Garden. Annual report to the Center for Plant Conservation. p.1.

Park, M.M. 1992. A biosystematic study of *Thalictrum* section *Leucocoma* (Ranunculaceae). Ph.D. dissertation, Pennsylvania State University.

Radford, A.E., H.E. Ahles and C.R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. University of North Carolina Press, Chapel Hill, N.C.

Rayner, D. 1980. Status report on *Thalictrum cooleyi* Ahles, submitted to U.S. Fish and Wildlife Service, Atlanta, GA.

Rees, M.D. 1989. Final Listing Rules Approved. Endangered Species Technical Bulletin. 14, 3: 7.

Rome, A. 1987. *Thalictrum cooleyi*; draft stewardship abstract. The Nature Conservancy, Arlington, VA. 9 pp.

USFWS. 1988. Endangered Species Act Protection is Proposed for Nine Species. Endangered Species Technical Bulletin. 13, 5: 3-4.

USFWS. 1989. Determination of Endangered Status for Thalictrum cooleyi (Cooley's meadowrue). Federal Register. 54, 24: 5934-5938.

USFWS. 1994. Cooley's Meadowrue Recovery Plan. Atlanta, Georgia: U.S. Fish and Wildlife Service. p. 29.

Weakley, A. 2007. Flora of the Carolinas, Virginia, Georgia and surrounding areas. Working Draft January 11, 2007. University of North Carolina, Chapel Hill.

Wilczynski, C.J. 1988. Studies on aspects of the species biology of *Thalictrum cooleyi* for management and conservation. University of North Carolina, Chapel Hill. 13 pp.

Wilczynski, C. J. 1988. Species Biology of *Thalictrum cooleyi*: Studies for Management and Conservation (DRAFT). Chapel Hill, NC: Univerisity of North Carolina. p.8.

Wilcyznski, C.J. 1993. A three year study on the population dynamics of Cooley's meadowrue (*Thalictrum cooleyi*) at Lanier Quarry, Pender County, North Carolina. Carrboro, N.C.: The Nature Conservancy. Unpublished.

Figure 1. *Thalictrum cooleyi* populations in North Carolina. Numbers indicate the Natural Heritage Program Element Occurrence (EO) Numbers Map provided by the N.C. Natural Heritage Program.

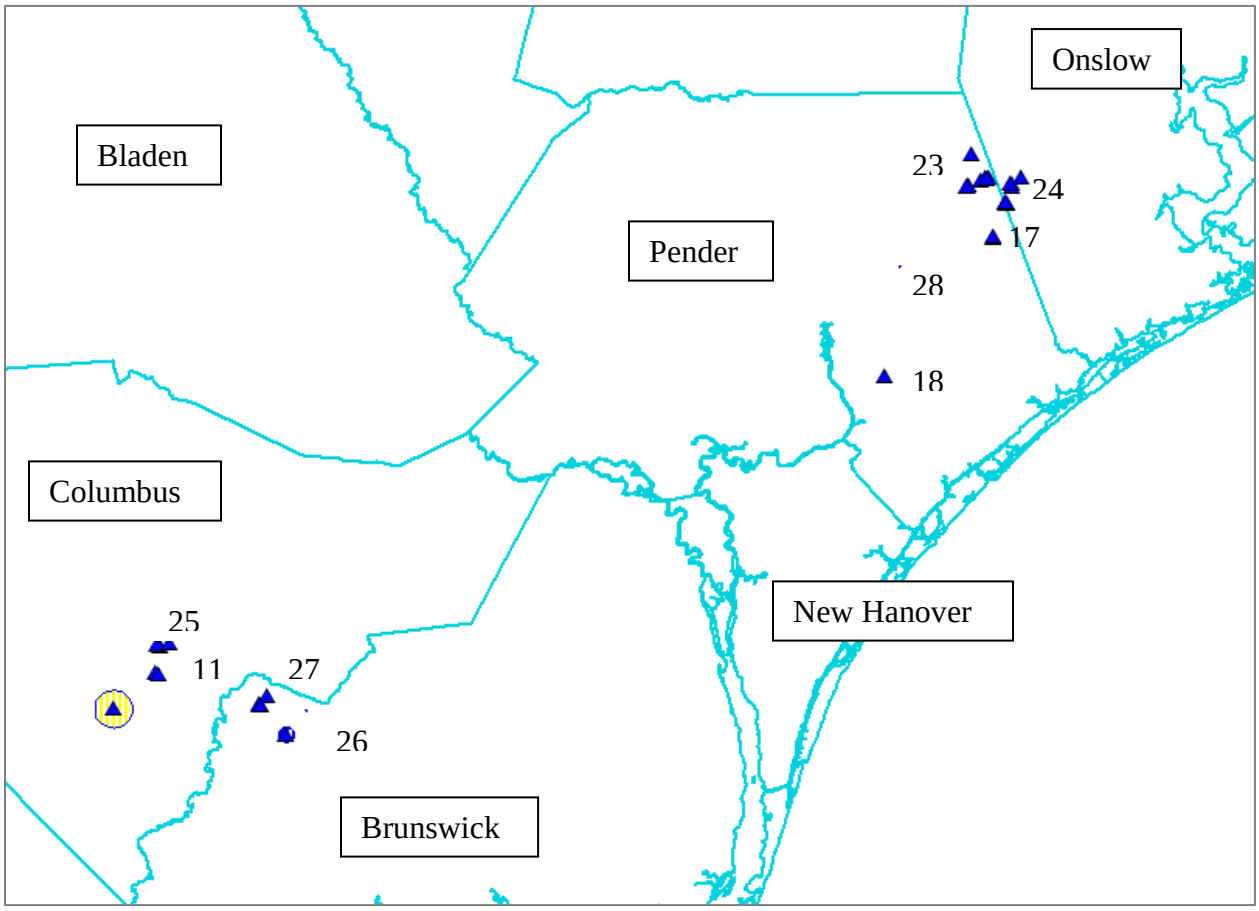
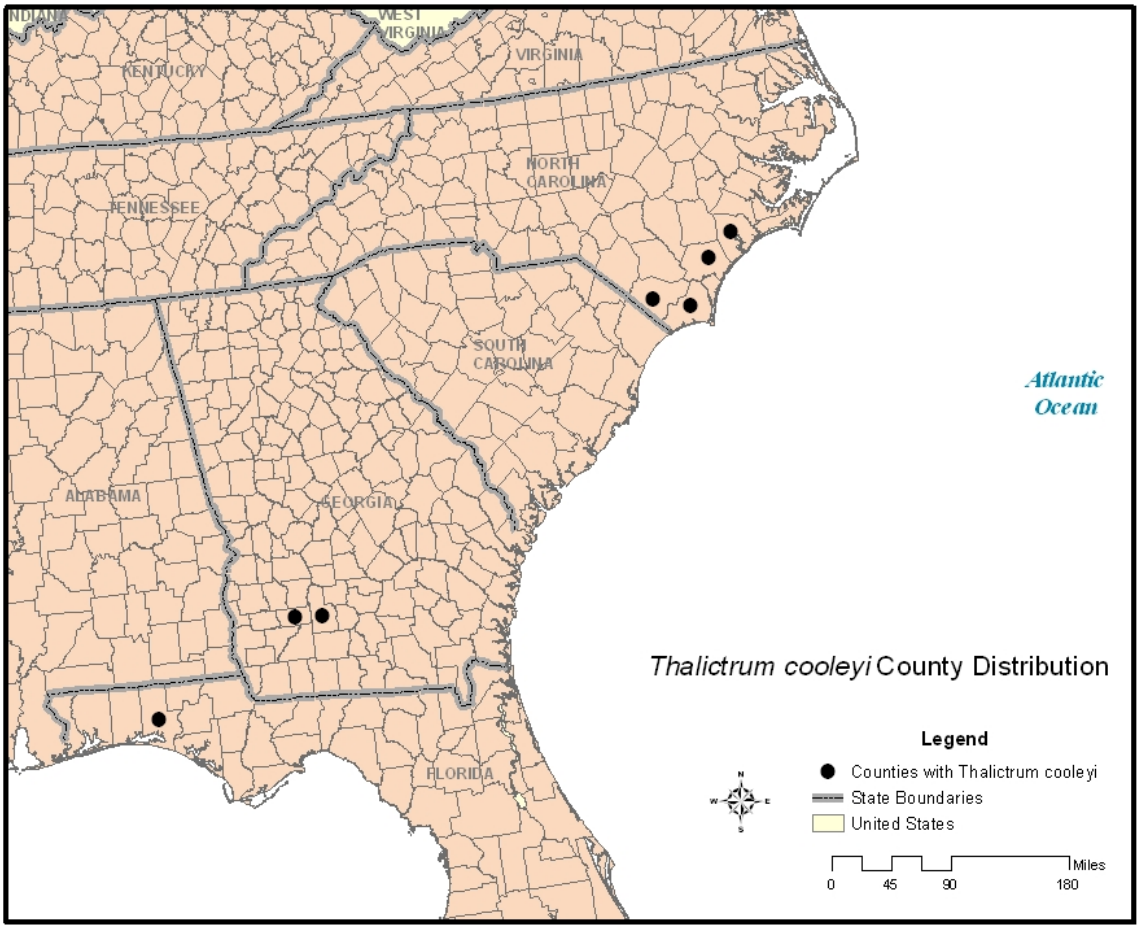


Figure 2. Distribution and state conservation status of *Thalictrum cooleyi* (FWS 2008 map).



5-YEAR REVIEW OF COOLEY'S MEADOWRUE
(*Thalictrum cooleyi*)

ADDENDUM 1. Summary of new information obtained since the 2009 5-year review.

Note: The *Federal Register* notice announcing the initiation of this 5-year review was published on March 12, 2018 (83 FR 10737). No comments were received during the 60-day public comment period following this notice. The U.S. Fish and Wildlife Service (Service) received information about the species, from state natural heritage programs and biologists familiar with the species, in response to requests for specific information. This information and reports from recent research were used to prepare this addendum.

I. GENERAL INFORMATION

B. Reviewers

Lead Region: Southeast Region, Kelly Bibb, 404-679-7132
Lead Field Office: Raleigh, NC Ecological Services Field Office, Dale Suiter, 919-856-4520 ext. 18
Cooperating Field Offices: Panama City, FL Ecological Services Field Office, Vivian Negron Ortiz; Athens, GA Ecological Services Field Office, Michele Elmore

C. Background

1. Federal Register Notice citation announcing initiation of this review: March 12, 2018 (83 FR 10737)

2. Species status: Stable

The last status survey for *Thalictrum cooleyi* was completed in 1987, prior to the species becoming federally listed as endangered. No comprehensive, range-wide status surveys have been conducted since 1987; however, site visits and surveys of populations throughout the range of the species and subsequent updates to natural heritage program databases indicate that this species is stable.

State natural heritage programs and NatureServe have developed a consistent method for evaluating the relative imperilment of species and ecological communities. According to Jame Amoroso (NC Natural Heritage Program [NCNHP], pers. comm., 2019), in 2017, the global and state ranks were re-evaluated from G2S2 to G1S1 using the 2012 NatureServe Conservation Status Assessment. G1 species are critically imperiled globally because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction. Typically, there are five or fewer occurrences or very few remaining individuals (<1,000) or acres (<2,000) or linear miles (<10). S1 refers to species that are critically imperiled due to extreme rarity or some factor(s) making them especially vulnerable to extirpation (local extinction) from the state. Typically, these species have five or fewer occurrences or very few remaining individuals (<1,000) (Robinson 2018).

6. Review History: The Service completed 5-year reviews for this plant in 1991 (56 FR 56882) and 2009 (72 FR 20866). The 2009 review recommended the species remain classified as endangered because of its "extreme rarity due to habitat loss from fire suppression and subsequent ecological succession, forestry practices and development due to the inadequate regulatory mechanisms to protect listed plants on private lands" (Service 2009).

II. REVIEW ANALYSIS

B. Recovery Criteria

3. List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information.

Thalictrum cooleyi will be considered for delisting when the following criteria are met:

1. It has been documented that at least 16 self-sustaining populations exist and that necessary management actions have been undertaken by the landowners or cooperative agencies to ensure their continued survival.

2. All of the above (16) populations and their habitat are protected from present and foreseeable human-related and natural threats that may interfere with the survival of any of the populations.

As of 2019, six populations (made up of 19 element occurrences (EOs) or subpopulations) of *Thalictrum cooleyi* are protected in NC (NCNHP 2019). An EO is a current or historical location where a species occurs (or occurred). In GA, three populations occur on protected land (GA Department of Natural Resources [GADNR] 2019). There is still only one population known from FL and it is protected on a private nature preserve (FL Natural Areas Inventory [FLNAI] 2019). In total, there are 10 protected populations of *Thalictrum cooleyi* known range-wide at this time. Since only 10 of the 16 populations required to delist the species are protected, the recovery criteria, as defined in the recovery plan, have not been met.

C. Updated Information and Current Species Status

1. Biology and Habitat

a. Abundance, population trends, demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

Since the 2009 5-Year Review, several graduate and undergraduate students have greatly contributed to our knowledge of the abundance, distribution and reproductive biology of this species. Robert Thornhill, at NC State University, discovered four new subpopulations of *Thalictrum cooleyi* during his floristic study of a preserve owned by The Nature Conservancy in Pender County, NC (Thornhill and Krings 2012, Thornhill

2013, NCNHP 2019). These subpopulations are located in close proximity to other *Thalictrum cooleyi* plants and are considered a subset of a population. Renee Fortner, at East Carolina University, studied the reproductive biology and genetics of *Thalictrum cooleyi*. During her research, she visited 15 EOs of *Thalictrum cooleyi* and provided updates to the NCNHP (Fortner 2015, Fortner *et al*. 2015, Fortner *et al*. 2016, NCNHP 2019). In addition, an environmental consultant found a new population of *Thalictrum cooleyi* in New Hanover County, NC, a county where the species was not previously reported. Since the 2009 5-year review, one new population has been found in GA and it occurs on land that is protected by a conservation easement (GADNR 2019). No new populations have been found in FL (FLNAI 2019).

Fortner *et al*. (2016) found that despite male-biased sex ratios, *Thalictrum cooleyi* has low seed production because this species is pollen limited.

In seed germination experiments, Fortner *et al*. (2016) and Dietrick (2016) confirmed the presence of morpophysiological dormancy, a common dormancy type in the plant family Ranunculaceae. They determined that *Thalictrum cooleyi* seeds are dormant at maturity and require a period of stratification (exposure to moist, cold conditions) to break dormancy. In the lab, they determined that seed germination was highest when seeds were exposed to six weeks of alternating warm and cool temperatures (25/15° C in a 14/10 hour light/dark pattern) and then eight weeks of moist cold (1° C) stratification (germination = 33.3%) or only eight weeks of moist cold (1° C) stratification (germination = 26.7%). Stratified seeds exposed to light germinated better than seeds in the dark. Alternatively, they also found that exogenous gibberellic acid breaks dormancy and resulted in germination rates similar to their highest rate obtained for cold stratified seeds (germination = 31.0% with gibberellic acid). Dietrick (2016) also demonstrated the successful germination of *Thalictrum cooleyi* seeds under field setting after exposure of one winter, showing the ability for overwintering and the possibility of a (minimum) short term seed bank.

As mentioned in section I.C.2. above, we believe the status of *Thalictrum cooleyi* remains stable at this time.

b. Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):
Recent genetic studies were inconclusive due to small sample size, but generally indicated low genetic variation both within and among populations in NC. Further, genetic analysis did not support claims that GA populations are a separate species from NC populations or provide evidence that GA populations are hybrid swarms (Fortner 2015, Fortner *et al*. 2015, Fortner *et al*. 2016). A hybrid swarm is a population of morphologically distinct hybrids that has survived beyond the initial

hybrid generation, with interbreeding between hybrid individuals and backcrossing with its parent types.

d. Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):
We define an EO as any current (or historical) location where a species occurs (or occurred), regardless of the spatial relationship with other EOs. We define a population as either a stand-alone EO isolated by distance of unsuitable habitat [separated from other EOs by 2 kilometers (km) (1.2 miles (mi)) or more].

Since the 2009 5-year review, additional EOs of *Thalictrum cooleyi* were found in Pender and New Hanover counties in NC (Thornhill and Krings 2012, NCNHP 2019) and one additional EO was found in Worth County, GA. The New Hanover County discovery represents a new county record for this species and also a new distinct population; however, this population occurs within a few hundred feet of Pender County, a previously known county for this species. Our records currently indicate 10 extant populations including 28 extant subpopulations in NC. In addition, one NC EO is considered historical and two are considered extirpated (NCNHP 2019). Eric Ungberg is conducting surveys for *Thalictrum cooleyi* at several previously known sites in NC. The results of his survey work will be included in the NCNHP database once his survey work is complete (Jame Amoroso, NCNHP, pers. comm., 2019). With the new EO/population found in GA, there are now eight populations (made up of eight EOs) in the state (GADNR 2019). There have been no new populations of this species found in FL (FLNAI 2019). This information is summarized in Table 1.

Table 1. Number of extant populations and subpopulations (or Element Occurrences, EOs) of *Thalictrum cooleyi* at the time of listing (February 7, 1989), in 2008 and 2019 (FLNAI 2019, GADNR 2019, NCNHP 2019).

	NC	GA*	FL	Total
No. extant populations at listing (1989)	unknown	0	1	unknown
No. extant EOs/subpopulations at listing (1989)	12	0	1	13
No. extant populations in 2008	9	2	1	12
No. extant EOs/subpopulations in 2008	24	7	1	32
No. extant populations in 2019	10	8	1	19
No. extant EOs/subpopulations in 2019	28	8	1	37

*In the 2009 5-year review, the GADNR considered the known seven EOs to be part of two populations. Using updated NatureServe criteria, the GADNR now considers these EOs to be unique populations; therefore, there has only been a net increase of one new population in Georgia since 2009.

e. Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):
Culver (2016) confirms earlier reports of soil chemistry that *Thalictrum cooleyi* sites have higher calcium content, cation exchange capacity and base saturation levels compared to sites without the target species. Soils with these conditions likely influence the distribution of this species.

f. Other relevant information about the species (propagation, etc.):
The North Carolina Botanical Garden is the designated Center for Plant Conservation seed repository for this species. They maintain seed collections for research and reintroduction projects and living specimens for educational purposes. The Atlanta Botanical Garden maintains this species at their facilities in Atlanta and Gainesville, GA for safeguarding (Ron Determann, Atlanta Botanical Garden, pers. comm., 2019).

Fortner (2015) and Fortner *et al*. (2015, 2016) found that *Thalictrum cooleyi* was often associated with the woody shrub *Morella cerifera.* This shrub is known as a nitrogen-fixing shrub and may facilitate the occurrence of *Thalictrum cooleyi* in savanna habitats with poor sandy soils.

In addition to the seed germination experiments mentioned above, Fortner *et al.* (2016) tested several vegetative propagation methods. Sections of the lower caudex with the original root system intact and no hormone treatment grew the most leaves. Root divisions did not result in new growth.

Humphrey (2016) presented data showing that *Thalictrum cooleyi* (and many species of *Thalictrum*) have heteromorphic pollen. While not a conclusion of the paper, the author presents literature suggesting different

pollen morphs may affect successful germination of pollen and subsequent seed formation. In a pollen limited species such as *Thalictrum cooleyi* (Fortner *et al.* 2016), this pollen heteromorphism and sex ratios may be ecologically important.

2. Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

a. Present or threatened destruction, modification or curtailment of its habitat or range:

As mentioned in the previous 5-year review, the primary threat to this species is habitat destruction or modification, including fire suppression and subsequent ecological succession. Development and the negative effects of timber operations also remain a concern for the recovery of this species. Southeastern NC is experiencing rapid population growth. According to the NC Office of State Budget and Management, all five NC counties where *Thalictrum cooleyi* is found had significant increases in population between 2000 and 2009. For example, Brunswick County increased by 44%, Columbus County by 5%, New Hanover County by 25%, Onslow County by 21%, and Pender County by 25% (https://files.nc.gov/ncosbm/demog/countygrowth_2009.html).

Likewise, according to their projected population changes from 2010 to 2020 the NC Office of State Budget and Management expect populations to increase in four of the five counties where *Thalictrum cooleyi* occurs, including a projected increase of 36.0% in Brunswick County, 18.1% in New Hanover County, 14.9% in Onslow County and 23.7% in Pender County. The population in Columbus County is projected to decrease by 3.2% (https://files.nc.gov/ncosbm/demog/countytotals_2010_2019.html). As the landscape is further fragmented by residential and commercial development, the use of prescribed fire or controlled burning becomes increasingly more difficult due to the increase risk of fires escaping and damaging structures.

The four new EOs found in Pender County, NC are part of a larger previously known population and occur on land owned by The Nature Conservancy. They are protected and managed in a way that supports the conservation of the species. Similarly, the new population discovered in GA also occurs on land protected by a conservation easement. We believe threats to these protected populations that occur on large tracts of managed land are low. However, the new population discovered on private land in New Hanover County, NC is threatened with development as the city of Wilmington expands to the north.

b. Overutilization for commercial, recreational, scientific, or educational purposes:
As mentioned above, several research projects have been conducted on *Thalictrum cooleyi* since the last 5-year review. These projects were reviewed and approved by the NC Plant Conservation Program's rare plant permit review committee to ensure that the research was conducted responsibly and had minimal negative effects on the wild populations. We believe threats under this category are low.

e. Other natural or manmade factors affecting its continued existence:
In addition to the other threats mentioned in the previous 5-year review, climate change is anticipated to threaten many rare species and the habitats where they occur in the coming years. While models of future climate scenarios are not available with fine detail, it is reasonable to expect shifts in temperature and precipitation patterns that define the climatic conditions to which *Thalictrum cooleyi* has adapted. Some models predict an increase in tropical storms and rainfall as well as droughts, both of which could negatively affect this species.

D. Synthesis

In summary, several new EOs have been found in NC, including one entirely new population and four EOs that expand the size of a known population. One new discovery is a county record for New Hanover County, NC; however, it is located within a few hundred feet of the boundary with Pender County, where this species has been known since listing. One new population was discovered in Worth County, GA. Currently, state natural heritage programs recognize 19 extant populations (10 in NC, 8 in GA and 1 in FL). Of these, 10 populations (6 in NC, 3 in GA and 1 in FL) have some level of protection, and are either owned and/or managed for conservation by state agencies or private conservation organizations.

Reproductive studies indicate that *Thalictrum cooleyi* is pollen limited which is likely the reason for low seed production. Seed germination experiments identified which methods result in the greatest germination. Asexual reproduction using sections of the lower caudex with roots was somewhat successful.

Genetic studies were inconclusive but indicated low genetic variation both within and among populations in NC and did not support claims that populations in GA are a separate species or hybrid swarms.

The most important factors that justify the endangered status of *Thalictrum cooleyi* have not changed since the 2009 5-year review. Due to the small number of populations, the number of unprotected populations, the existing threats to the species such as habitat destruction (fire suppression, forestry practices and increased development), the inadequacy of existing state or federal laws to protect

plants on non-federal lands, and climate change, we believe *Thalictrum cooleyi* still meets the definition of endangered under the Endangered Species Act.

III. RESULTS

A. Recommended Classification: No change is needed

IV. RECOMMENDATIONS FOR FUTURE ACTIONS

The recommended actions listed in the 2009 5-year review (page 10 and 11 above) remain important to the conservation and recovery of *Thalictrum cooleyi*. Since the 2009 5-year review, progress has been made on several recommendations for future actions. For example, the Service and East Carolina University professors and graduate students have visited most of the known populations in NC and provided updated information to the NCNHP. According to GADNR and FLNAI records, half of the known populations in GA and the single FL population have been visited since the last 5-year review and natural heritage program records have been updated. Surveys for new populations of *Thalictrum cooleyi* have resulted in the discovery of one new population in New Hanover County, NC and one new subpopulation was discovered near a known population in Pender County, NC. In addition, a new population was discovered in Worth County, GA. Additional surveys across the range of the species are needed and may result in the discovery of new populations. Such surveys could be guided by species distribution modeling. Researchers at East Carolina University recently conducted research on various aspects of the life history and reproductive biology and genetics of *Thalictrum cooleyi*. Their research also increased our knowledge of the propagation and culture of this species which will be used to guide future restoration efforts.

V. REFERENCES

These references are in addition to the citations on page 11 above in our original 2009 5-year review.

Culver, I.C. 2016. The Effects of Calcium Content on the Federally Endangered *Thalictrum cooleyi* of North Carolina Pocosins and Pine Savannas. Honors Thesis, East Carolina University, Greenville, NC. 26 pp.

Dietrick, E.M. 2016. Embryo Development, Seed Bank Potential and Germination of the Federally Endangered Herb of Pine Savannas, *Thalictrum cooleyi*. Honors Thesis, East Carolina University, Greenville, NC. 34 pp.

Florida Natural Areas Inventory (FLNAI). 2019. Element Occurrence Records for *Thalictrum cooleyi* (Cooley's meadowrue). Unpublished report. As of July 15, 2019.

Fortner, A.R. 2015. Insights into the Habitat and Breeding Biology of the Federally Endangered Herbaceous Plant, *Thalictrum cooleyi* Ahles. MS Thesis, East Carolina University, Greenville, NC. 80 pp.

Fortner, A.R., C.L. Jolls and C. Goodwillie. 2015. Critical Biological Knowledge of Cooley's Meadowrue (*Thalictrum cooleyi*) for Conservation and Recovery. Report to U.S. Fish and Wildlife Service in fulfillment of Grant Agreement F12AP01125, East Carolina University, Greenville, NC. 36 pp.

Fortner, A.R., C.L. Jolls and C. Goodwillie. 2016. Important biological knowledge for management of Cooley's Meadowrue (*Thalictrum cooleyi*), a federally endangered endemic of pine savannas. Natural Areas Journal 36(3): 288-301.

Georgia Department of Natural Resources, Wildlife Resources Division, Wildlife Conservation Section (GADNR). 2019. Element Occurrence Data for *Thalictrum cooleyi* (Cooley's meadowrue). Sensitive Biological Data Agreement. Unpublished report. As of July 16, 2019.

Humphrey, R.P. 2016. Pollen heteromorphism is pervasive in *Thalictrum* (Ranunculaceae). Plant Systematics and Evolution 302(8): 1171-1177.

North Carolina Natural Heritage Program (NCNHP). 2019. Element Occurrence Records for *Thalictrum cooleyi* (Cooley's meadowrue). Unpublished report. As of July 10, 2019.

Robinson, L.G. 2018. Natural Heritage Program List of Rare Plant Species of North Carolina 2018. NC Natural Heritage Program, Raleigh, NC. 175 pp.

Thornhill, R.W. 2013. A Guide to the Vascular Flora of the Savannas, Flatwoods, and Sandhills of Shaken Creek Preserve and Vicinity (North Carolina). MS Thesis, NC State University, Raleigh, NC. 483 pp.

Thornhill, R. and A. Krings. 2012. Discoveries of New Populations of Cooley's Meadowrue (*Thalictrum cooleyi* Ahles) and Golden Sedge (*Carex lutea* LeBlond) at Shaken Creek Preserve, Pender County, NC. Report to U.S. Fish and Wildlife Service in fulfillment of Grant Agreement F11AP00197, NC State University, Raleigh, NC.

U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW OF *COOLEY'S MEADOWRUE (Thalictrum cooleyi)*

Current Classification: Endangered
Recommendation resulting from the 5-Year Review:

___Downlist to Threatened
___Uplist to Endangered
___Delist
_X_No change is needed

Review Conducted By: Dale Suiter, Raleigh Ecological Services Field Office, Raleigh, NC

FIELD OFFICE APPROVAL:
Lead Field Supervisor, Raleigh Ecological Services Field Office, U.S. Fish and Wildlife Service

PETER BENJAMIN Digitally signed by PETER BENJAMIN Date: 2020.04.13 13:06:00 -04'00'

Approve:_____Date:_____
Pete Benjamin

ADDENDUM 1, APPENDIX A
Peer Review
Summary of peer review for the 5-Year Review of
Cooley's meadowrue (*Thalictrum cooleyi*)

A. Peer Review Method:
Initial draft review was requested from three individuals outside the Service who are knowledgeable of *Thalictrum cooleyi* (Jame Amoroso with the NCNHP; Renee Fortner with RiverLink and formerly a graduate student at East Carolina University where she studied this species, and Michael Kunz with the NCBG). Responses were received from all three reviewers. We also requested internal review from Michele Elmore and Vivian Negron Ortiz, botanists in the Service's Athens, GA and Panama City, FL Ecological Services Field Offices.

B. Peer Review Charge:
In order to ensure that the best available information was used to conduct this 5-year review, we conducted a peer review of the draft document. Rebekah Reid of the Service's Asheville, NC Ecological Services Field Office managed the peer review. On September 6, 2019, she emailed a draft copy of the 5-Year Review Addendum to three botanists who do not work for the Service. Specifically, we asked for comments on the validity of the data used, and the identification of any additional new information regarding *Thalictrum cooleyi* that had not been considered in this review. We specifically mentioned that we were not seeking the opinion on the legal status of this species, but rather that the best available data and analyses were considered in reassessing the status.

As part of the peer review process, we must evaluate the potential for conflicts of interest with the subject species or the action. Therefore, we asked each reviewer to fill out a Conflict of Interest form and return it with their comments.

C. Summary of Peer Review Comments/Report:
In general, the peer reviewers provided very few specific comments on the draft Addendum to the 5-Year Review. The general consensus was that the document contained a good summary of the status of the species and a thorough summary of research conducted since the previous 5-Year Review. Jame Amoroso commented that the review reflects updated information in the NCNHP files. She provided information about updated global and state ranks and ongoing survey work at several *Thalictrum cooleyi* sites in eastern NC. Renee Fortner provided a few general comments and reiterated the fact that there are not enough populations in protection to justify a change in status at this time. Michael Kunz commented that "this review is complete and provides accurate information and logically draws accurate conclusions from the provided information." He specifically mentioned that the review includes the most current population data and recently published scientific papers. He believes the information is analyzed correctly and will be useful to the understanding and recovery of the species. He also provided three additional unpublished reports that are relevant to *Thalictrum cooleyi* recovery.

Service internal peer reviewers, Michele Elmore and Vivian Negron Ortiz, are botanists in the Athens, GA and Panama City, FL Ecological Services Field Offices. Michele Elmore provided

helpful edits throughout the document. Vivian Negron Ortiz provided valuable suggestions for the sections on threats analysis and the future recovery actions.

D. Response to Peer Review:

We incorporated suggestions and comments from peer reviewers into the final version of this document.

ADDENDUM 1, APPENDIX B
Bibliography of additional documents mentioning *Thalictrum cooleyi*

A complete bibliography for *Thalictrum cooleyi* was included in Appendix B of the 2009 5-year review. The following publications and reports should be added to that bibliography:

Culver, I.C. 2016. The Effects of Calcium Content on the Federally Endangered *Thalictrum cooleyi* of North Carolina Pocosins and Pine Savannas. Honors Thesis, East Carolina University, Greenville, NC. 26 pp.

Dietrick, E.M. 2016. Embryo Development, Seed Bank Potential and Germination of the Federally Endangered Herb of Pine Savannas, *Thalictrum cooleyi*. Honors Thesis, East Carolina University, Greenville, NC. 34 pp.

Fortner, A.R. 2015. Insights into the Habitat and Breeding Biology of the Federally Endangered Herbaceous Plant, *Thalictrum cooleyi* Ahles. MS Thesis, East Carolina University, Greenville, NC. 80 pp.

Fortner, A.R., C.L. Jolls and C. Goodwillie. 2015. Critical Biological Knowledge of Cooley's Meadowrue (*Thalictrum cooleyi*) for Conservation and Recovery. Report to U.S. Fish and Wildlife Service in fulfillment of Grant Agreement F12AP01125, East Carolina University, Greenville, NC. 36 pp.

Fortner, A.R., C.L. Jolls and C. Goodwillie. 2016. Important biological knowledge for management of Cooley's Meadowrue (*Thalictrum cooleyi*), a federally endangered endemic of pine savannas. Natural Areas Journal 36(3): 288-301.

Goodnight, W.H., III. 1990. Germination strategy and seed bank analysis of the globally rare plant *Thalictrum cooleyi*. MS Thesis, UNC Chapel Hill, NC.

Humphrey, R.P. 2016. Pollen heteromorphism is pervasive in *Thalictrum* (Ranunculaceae). Plant Systematics and Evolution 302(8): 1171-1177.

Thornhill, R.W. 2013. A Guide to the Vascular Flora of the Savannas, Flatwoods, and Sandhills of Shaken Creek Preserve and Vicinity (North Carolina). MS Thesis, NC State University, Raleigh, NC. 483 pp.

Thornhill, R. and A. Krings. 2012. Discoveries of New Populations of Cooley's Meadowrue (*Thalictrum cooleyi* Ahles) and Golden Sedge (*Carex lutea* LeBlond) at Shaken Creek Preserve, Pender County, NC. Report to U.S. Fish and Wildlife Service in fulfillment of Grant Agreement F11AP001r97, NC State University, Raleigh, NC. 13 pp.

Thornhill, R., A. Krings, D. Lindbo and J. Stucky. 2014. Guide to the vascular flora of the savannas and flatwoods of Shaken Creek Preserve and vicinity (Pender & Onslow counties, North Carolina, U.S.A.). Biodiversity Data Journal 2: 1-422.