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HISTORY OF THE DEPARTMENT OF FORESTRY AND ENVIRONMENTAL RESOURCES AT NORTH CAROLINA STATE UNIVERSITY, 1979-2008

IX. RESEARCH—INDUSTRIAL COOPERATIVES AND RELATED PROGRAMS

The Department's research program is by far the most complex and difficult subject with which to deal adequately in this history. It would be nearly impossible to do justice to the work of the over 100 persons involved since 1980, each making his or her own particular contribution to the Department's research portfolio. Some of these were made in the context of the Department's several organized research programs. Others contributed as individuals through their own chosen research areas, some close to main stream forestry and others distant from it. The emphasis in this chapter is placed on the organized research programs, the cooperative research efforts involving Departmental faculty with industries and governmental agencies. The many other excellent research programs in the Department will be covered in the next chapter. Although cooperative research programs were not unique to NC State, it is fair to say that this research model reached its fullest development there during the 1980s and 1990s. This history of research in the Department during the past 25+ years will concentrate on the framework within which research was carried out and with the various directions taken by different research efforts. Specific research findings will be discussed only as they contributed to the overall direction of research and when they constituted major contributions to the science and practice of forestry.

The Department has never had an internal administrative structure for research. The persons closest to filling this role were Bill Johnson and Bob Kellison who served as coordinators of cooperative research programs during the late 1970s and 1980s respectively. In 1980 all administrative and accounting responsibility for research rested in the Dean's Office. During the ensuing 25+ years significant accounting responsibility was gradually assumed by the Department but grant administration and coordination of project development still reside in the Office of the Associate Dean for Research and Extension.

Cooperative Research Programs and Industrial Partnerships

In 1980, the Department had 6 cooperative research programs (industrial and state partnerships). The NC State-Industry Cooperative Tree Improvement Program, established in 1956 through the efforts of Bruce Zobel and Dick Preston, was the first such program in the Department. It was followed in 1963 by the Hardwood Research Cooperative, in 1969 by the Forest Fertilization Cooperative, in 1976 by the Forest Equipment Cooperative, in 1979 by the Southern Forest Research Center, and in May 1980 by The Central America and Mexico Coniferous Resources Cooperative (CAMCORE). In 2007 there were 5 industrial partnerships. Of the 6 such units in 1980, the Tree Improvement Cooperative, Forest Nutrition (originally Forest

Fertilization) Cooperative, and CAMCORE remain, but the Hardwood Research Cooperative has become inactive, and the Forestry Equipment Cooperative and the Southern Forest Research Center have been dissolved. The Forest Biotechnology Research Consortium and the Southern Forest Resource Assessment Consortium have been created. During this same period the Loblolly and Slash Pine Rooted Cutting Cooperative, and the Fusiform Rust Research Cooperative have come and gone as well.

Before discussing each of the Department's Industry-University Cooperative research programs one must recognize that the period from 1980-2000 when there was so much change in forest industry itself was also a period of major change in the nature of the relationship between the Department and its industrial cooperators. As previously pointed out, although the concept of the university-industry cooperative research program was not "invented" by NC State's forestry program[1], it had its greatest growth and development there. By the mid-1980s there were 5 such programs at NC State, and one out of every three industrial dollars spent on cooperative research was spent at NC State.

The original concept of a university-industry research cooperative when they were first formed in the 1950s was based on the facts that: 1) few industries had their own research staffs and that the greatest aggregation of forestry research expertise was located at universities, 2) that benefits of scale existed when a number of industries, their land bases, and the genetic resources of the trees they were growing were brought together to work toward a common objective, and 3) that applied forestry technology was so rudimentary that it was not considered a competitive risk for industries to cooperate with each other in this arena. Of necessity the first research done by the cooperatives was applied research in its finest sense, i.e., research directed toward resolving specific questions directly relevant to growing trees on a commercial scale. During the 1960s and 1970s NC State's cooperatives and those located at other US universities were highly successful and their member industries utilized and benefited from the research results reported to them. Initially at NC State, the dues paid by industrial members of the cooperatives not only paid the expenses of doing research but they also paid a large part of the salaries of the university scientists involved. As pointed out elsewhere in this history, by the 1980s a significant part of the salaries of tenured faculty was paid from the "soft" money derived from cooperative membership dues.

One of the most important by-products of the research cooperatives was the opportunity they offered for training graduate students. Scores of graduate students obtained Masters and PhD degrees based on work done in, and supported by, one of the research cooperatives. Many of these students have gone on to important positions in academic and industrial research throughout the United

[1] Bruce Zobel, however, is regarded as the originator of the industry-university cooperative concept when he started a tree improvement cooperative at Texas A. & M College in the early 1950s.

States and the world. For example, 215 PhD and Masters students have graduated with degree programs done in the Tree Improvement Program alone, with most of those occurring in its earlier years.

By the mid-1980s the climate in which the research cooperatives operated began to change. As dues went up year after year, reflecting the increased costs of doing business and raises for involved faculty, members began to question the financial structure of the cooperatives. Many industrial members began to pressure the Department to increase its financial contribution to the cooperatives. At the same time, increases in State funds provided to the Department were so small that they did not offer any real hope for increased financial support of the cooperatives. The matter of the Departmental contribution to the finances of each of the cooperatives was an issue raised at each annual meeting of the cooperative members. Furthermore, many industries had developed their own research staffs (often staffed by persons with advanced degrees from NC State). Consequently, the nature of the research conducted by the cooperatives became an issue with those industries having their own research staffs pushing the cooperatives to adjust their research programs to become more strongly oriented toward basic research; others with less research capability emphasized the need for continued applied research. In some cases this could be done easily as faculty themselves were eager to make this change, realizing that the future of their programs lay in a better understanding of the basic science underlying their management findings. In other cases this change could not be so easily accommodated, and the desire of some of the cooperative members for more basic research became a source of disagreement not only between faculty and certain industries but among industries themselves. In short, what had been a "trust me" relationship between member industries and the Cooperative staffs ("trust me" in the sense industries paid dues and the Coop staff provided an annual plan of work for the industry's approval) showed signs of strain. Finally, the forest industry sector began undergoing major structural changes in the late 1980s and 1990s with companies merging and others selling off their land bases. These changes reduced the number of companies operating in the Southeast with a consequent reduction in the number of dues-paying members of the cooperatives. Membership in the Tree Improvement Cooperative from 1956 to 2008 illustrates the membership dynamics well (Figure 1). In the first 30 years, membership expanded as companies and state agencies recognized the benefits of intensive plantation management and tree improvement. Starting in the mid 1980s, company mergers were common, and in the 1990s, companies started to divest themselves of forest land. Today, there are 12 full members supporting the entire breeding effort for the region.

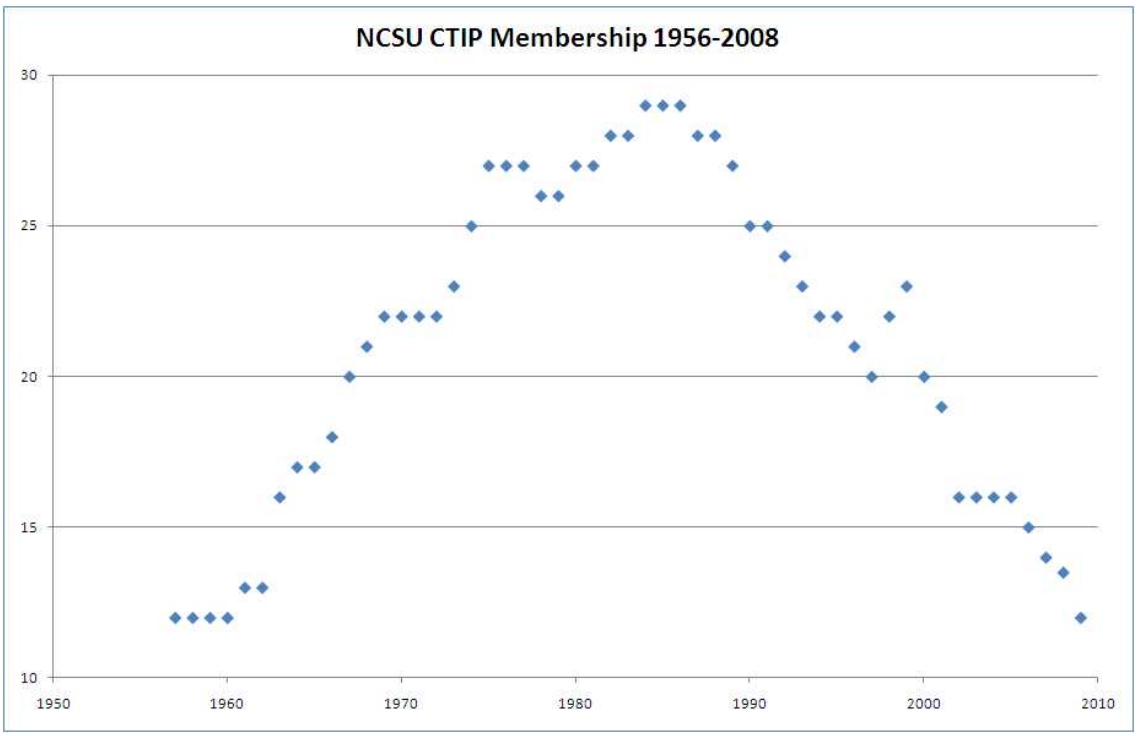

Figure 1. Cooperative membership in the Tree Improvement Program at NC State has changed dramatically from the beginning. See **http://www.cnr.ncsu.edu/tip/files/reports/50thAnnualReport(2006).pdf** for more details.

The net result of these changes caused some cooperatives at NC State (and elsewhere) to simply go out of business. In other cases, by changing its modus operandi and the thrust of its research, a cooperative was able to continue, but with a research program substantially different from that with which it began. The best example of this outcome is the Forest Nutrition Cooperative which now operates with more members than it has ever had and with a research program vastly different from that with which it started. In yet other cases, new programs, often with different operating ground rules, arose to provide research expertise in new areas of forest management and science.

Tree Improvement Cooperative

The Cooperative Tree Improvement program is the "granddaddy" of all organized research programs in the Department. It was organized in 1956 by Bruce Zobel and Dick Preston with 12 charter members, which agreed to support research on forest genetics, selection, breeding and testing, and technology transfer for an initial period of 5 years. In the 50 succeeding years, although members have come and gone (Figure 1), the focus of research has changed, and the Raleigh research staff has undergone a complete turnover, the Tree Improvement Program remains as one of the nation's most successful industry-university cooperative programs. Bruce Zobel was the founding director, remaining in that position until 1979 when he "retired" (Zobel continues in 2008 as the Department's oldest active

emeritus member). Bob Weir became Director in 1979 and served until 2000 when he retired and was replaced by Tim Mullin who served until 2005. Steve McKeand and Bailian Li were named co-directors in 2005 and served together until Li became Vice-Provost for International Affairs in 2006; McKeand now directs the program. Other scientists directly affiliated with the Program and integral to its success included Bob Kellison (1963-1977), J. B. Jett (1968-1994), Floyd Bridgwater (1978-1995), John Talbert (1978-1983), and Jerry Sprague and Alice Hatcher from 1970-2000. Throughout their tenures at NC State, US Forest Service employees Gene Namkoong and Jim Roberds worked independently with faculty members and graduate students in tree improvement, adding much to the theoretical basis of the work of the Cooperative.

Initially, the Coop involved 12 members who agreed to fund a forest genetics program involving superior pine tree selection, breeding, testing, and technology transfer. The agreement was for an initial period of 5 years. The work, particularly on development of seed orchards based on superior tree selections, was so successful and its research quickly became such an integral part of southern pine forestry that the program became a permanent fixture. In 1980 the Coop had 27 members and its peak membership was in 1984-86 when it had 29 full members. With mergers and land divestitures in southern forestry companies, the membership has declined continuously so that in 2007 it was back to 12 full members, although not the original 12 (Figure 1). These changes have led to other, in the long run potentially more damaging, changes in tree improvement research in the Southeast. The lack of research expertise in tree improvement that existed in 1956, when the Cooperative was started, is true again today. Steve McKeand, Director of the NCSU cooperative, estimates that in tree improvement the forest industry sector in the Southeast has lost half of its tree breeders in the last 10 years. His liberal estimate is that there are 15 breeders among the Cooperative's 12 members today, compared to 33 breeders among the 22 full members in 1998.

During the 1970s seed orchard management was improved so much that gains from using seed orchard seed far exceeded the initial expectations with 15% gains in yield from plantations originating from improved seedlings as opposed to that from unimproved seedlings. By 1980 the Tree Improvement Coop had completed a first generation of selection and breeding and was well into work on a second generation. By the early 2000s a third generation had been completed. When the Cooperative celebrated its 50th anniversary in 2006, over 94 million mass-control pollinated full-sib seedlings had been planted, over $95 million had been spent by members of the Cooperative on genetic improvement of loblolly pine, and more than 17 million acres in the south had been regenerated with genetically improved seedlings.

Over the last 25+ years the research program of the Cooperative has evolved from the initial mission of production of genetically-improved seedlings to an emphasis on forest genetics in the broadest sense. Studies were conducted on integrating tree improvement into

silvicultural systems, development of optimal selection strategies, understanding the genetic and environmental control of growth and wood properties, and understanding the genetic control of, and variation in, disease resistance. In cooperation with the Forest Nutrition program genetic material from the Tree Improvement program was used in studies of stand ecophysiology. One of the Cooperative's most significant areas of cooperation in recent years has been with the biotechnology program that developed in the Department during the 1990s. The integration of biotechnology with breeding strategies and the Cooperative's extensive loblolly pine genetic material contributed significantly toward making NC State's forest biotechnology program one of the national leaders in this important new area of forest science.

Hardwood Research Cooperative

The Department's second industrial cooperative program, the Hardwood Research Cooperative (HRC), came into existence on July 1, 1963 with Robert L. McElwee as its Director. The creation of the Hardwood Program was a result both of increasing interest in the management and use of hardwoods in the Southeast and of the impact of increased interest in hardwood tree improvement due to the emerging success of the loblolly pine improvement effort in the Tree Improvement Cooperative. The program's initial objectives covered the full gamut of issues relating to hardwoods, including:

1) the management of hardwood stands to promote regeneration of desired species; 2) assessment of the wood properties and quality of key hardwoods; 3) determination of site requirements; 4) determination of patterns of variation in wood properties, growth and yield, and adaptability for principal species; 5) strengthen knowledge of reproduction from seed; and 6) develop studies of the genetics of key hardwoods to serve as the base for a genetic improvement program. Initially research was confined to the Coastal Plain and Piedmont with studies later carried out in the Mountains. Species of initial interest included Sweet gum, Willow oak, Southern red oak, Sycamore, and Tulip poplar. Its first major program was a region-wide Sweet gum improvement program.

McElwee, aided by Ed Jones in Extension and later by Bill Johnson, remained as Director of the Program until 1971. He was replaced by Bruce Zobel, who directed both the Tree Improvement and Hardwood Cooperatives from 1971-1977. Bob Kellison assumed the Directorship of the Hardwood program in 1977 serving until 1985 when the Directorship was turned over to Russ Lea. When Lea left to become the College's Associate Dean for Research in 1991, Kellison returned as Director, remaining until he retired in late 1995. Mike Young was Interim Director until Dan Robison became Director in 1997. Robison served through termination of the Program in 2004. Bill Gardner served as liaison silviculturist with the Program from 1977-1981 when he left to join the Extension Forestry staff. Dennis Mengel and Mike Young among others were also important members of the Hardwood staff during the 1980s and 1990s.

The Hardwood Cooperative was a robust and well-supported program with as many as 20 members during the early 1980s. In addition to Kellison, Lea, and Gardner, Doug Frederick, who joined the faculty in the summer of 1977, developed an active program of research on hardwood silviculture. Frederick's appointment, largely supported by teaching funds, was made primarily to broaden both teaching and research in silviculture in response to numerous criticisms from external constituencies that the Department's programs had become almost entirely "pine oriented." Kellison's retirement in 1995 and Robison's hiring, unfortunately, coincided with the period of major change and restructuring in forestry industry in the Southeast. Beginning in 1999 members began to drop out because of mergers, financial constraints, a desire to focus on pine management, and a perception that the program had dropped below a critical mass of members. Thus, the program became dormant in 2004 and it remains so today.

Nonetheless, the Hardwood Cooperative has a 40-year record of successful and significant research. When it began its work in 1963 numerous "Region-Wide" studies across 13 Southern states were installed on member lands. These studies were primarily oriented toward hardwood silviculture and tree improvement. This approach entailed the adoption of a uniform experimental methodology, which was then used by the members to install, maintain and measure studies on their own lands. Data from Region-Wide studies were sent back to the HRC staff for collective analysis and dissemination to HRC members and the broader scientific/forestry community. These studies were primarily directed toward regenerating and managing natural hardwood stands.

In the early 1980s the Cooperative's research direction began to change. The first "national energy crisis" led to numerous sources of grants for the study of "wood for energy." Frederick, and other faculty associated with the Hardwood Program, obtained several grants to study the production of biomass for energy by both natural and plantation stands of hardwoods. These studies continued throughout the early 1980s. Issues associated with harvesting and regenerating bottomland hardwoods led the Co-op staff to direct a major research effort to this complex situation. One important study of bottomland hardwood ecology and management was established on Scott Paper Company land in Alabama. This study involved Lea and Awatif Hassan, dealing with the impact of harvesting regimes on site properties. Another similar long-term study was developed with Georgia-Pacific on the Edisto River in South Carolina. Frederick developed several studies dealing with the use of young hardwood plantations as discharge sites for partially-treated municipal sewage. These studies, plus other similar ones, led to the Co-op staff assisting in development of wetland management practices designed to comply with Federal regulations. As a result of this work, Lea and Frederick were widely sought-out to provide guidance to both industry and regulators on bottomland hardwood management. Frederick's interests in wetland

silviculture and restoration ecology, together with plantation culture of hardwoods for energy production, continue to the present.

Throughout its existence genetic improvement of hardwoods was an area of continued research. In the early 1980s a breeding program was adopted with emphasis on Sycamore and Sweet gum. These efforts were accompanied by attempts to introduce non-native hardwoods such as Eucalyptus spp., Alnus, and Paulownia to the Southeast. However, with industry interest focused almost entirely on management of natural hardwood stands, little opportunity existed for establishment of plantations and tree improvement research became a progressively less important part of the Co-ops' research portfolio. This same effort was redeveloped in the mid-1990s, and unfortunately again met with declining industry interest due to the lack of adequate weed control techniques to ensure plantation success.

An interesting outgrowth of the Hardwood Cooperative's work in wetlands was development, in the 1980s and early 1990s, of studies of the use of planted hardwoods in the restoration of degraded sites or as mitigation for destruction of bottomland hardwoods in other locations. Two early studies were located on the property of Texas Gulf Company near Aurora, NC, and at Coddle Creek near Concord, NC. These studies eventually led Ted Shear, who was hired on soft money to assist with research on mitigation, to develop his own research program in this area. Shear's program will be discussed in Chapter 10. Since the late 1990s Robison and colleagues have worked extensively on the ecology and management of very young natural hardwoods stands, rooted cutting systems for sweetgum and oaks, and brought to conclusion the plantation and natural stand hardwood growth and yield efforts begun as early as the 1960s.

Despite the fact that the Hardwood Cooperative is now dormant it is still listed on the Department's web page as an ongoing area of research with objectives essentially the same as those stated when it was started in 1963; Dan Robison continues an active research and graduate program in this area.

Forest Fertilization, now Forest Nutrition, Cooperative

The Forest Fertilization Cooperative, since 1986 the Forest Nutrition Cooperative, was organized in 1969 to bring together representatives of NC State, forest industry, and fertilizer manufacturers to "determine the economic feasibility of forest fertilization" for loblolly pine in the Piedmont and northern southeastern Coastal Plain. Field trials were begun in 1970-71. Wayne Haines, Bob Kellison, and Russ Ballard served as Directors during the 1970s, with able assistance from Mike Kane. Lee Allen has directed the program from 1981 to 2008 when he was retired and replaced by Jose Stape. Dan Kelting served as co-director from 2000-2003 and Tom Fox from VPI currently serves with Allen as co-director. Rafael Rubilar from the University of Concepcion in Chile became associate director for South American in 2006. The Nutrition

Cooperative is the only such program in the South ever to have its direction and programs determined by Directors from different institutions.

During its first 15 years the Cooperative concentrated on fertilizer trials in the Southeast. However, as its name change to Forest Nutrition Cooperative implies, the program altered its research effort to a wider emphasis on forest production, silviculture, and soils and to a wider geographic scope that now includes Argentina, Chile, and Columbia. Another significant change occurred in 2003 when NC State and VPI, and two years later the University of Concepcion, entered into a partnership to provide joint university leadership for its cooperative research work. Today there are 40 members in 3 classes (land owning/managing, contributing, corresponding) of the Cooperative who own and manage over 20,000,000 acres of pine plantations in the Southeastern US as well as 3 million acres of pine and eucalyptus plantations in South America.

The Nutrition Cooperative has not always had its current robust membership and research program. During the early 1990s as forest industries began to merge and change direction, membership in the Cooperative sank to below 10 members. A membership of this size provided barely enough membership funds for the program to operate and Cooper and Allen began discussions as to what would be done if the program "folded." Due in no small part to Allen's aggressive efforts to develop a forward-looking research program with emphasis on the physiological ecology of pine productivity the membership trend reversed and the program now rests on a solid foundation of membership and research, both basic and applied.

The field fertilization trials established by the Cooperative, as well as similar studies established by the Cooperative Research in Forest Fertilization Program at the University of Florida clearly showed that growth of most loblolly and slash pine plantations in the Southeastern U. S. was limited by the availability of both nitrogen and phosphorus. Mid-rotation fertilization with nitrogen and phosphorus increased growth by 25% in Loblolly pine on the majority of soil types with this response typically lasting for at least 6-10 years. These findings led to an increase in the number of acres of pine plantations receiving mid-rotation fertilization from 15,000 annually in 1988 to about 1.2-1.4 million acres per year since 2000. By the end of 2004 over 16 million acres of pine plantations in the Southeast had received mid-rotation fertilization. Recent studies have shown that deficiencies of other nutrients occur on certain soils and that growth increases after application of these nutrients. Results such as these have led to the solid membership base that the Nutrition Cooperative now enjoys. Much of the recent work of the Nutrition Cooperative involves demonstration of the role of fertilization as one component of an integrated system of plantation pine management that also includes tree improvement and planting, site preparation, and competition control.

The other major direction of the Nutrition Cooperative's research has been toward understanding Loblolly pine plantations as

ecosystems. One major study, done in conjunction with the Phil Dougherty of the US Forest Service, involved the interaction of water stress and nutrition on Loblolly pine. Other research examined the effects of nutrition on leaf area production in an effort to determine how management practices such as fertilization actually affect the responses of trees that result in greater growth rates. Similar studies later involved different Loblolly pine genotypes developed by the Tree Improvement Cooperative in an attempt to elucidate why one genotype is more productive than another. Studies such as these, which go beyond simply determining what results various management practices achieve and seek to understand why certain responses occur have been one of the major factors in the dramatic success of the Nutrition Cooperative in the last 15 years. They reflect the understanding that Allen and his coworkers have of the criticisms of cooperative programs that members began to voice in the mid-1980s.

Forestry Equipment Cooperative (FECO)

FECO was established on January 1, 1976 with 9 member companies; 2 others joining later. Awatif Hassan, who had joined the faculty the previous August, was the first, and only, director of the Cooperative. Hassan's hiring and creation of the Equipment Cooperative were driven by Dean Eric Ellwood's desire that the School develop a program in forest engineering. Elwood sensed that there was a need for more application of engineering expertise to forest management problems and that there was a place for such a program at NC State. He was also, no doubt, motivated by the existence of a strong forest engineering program at VPI, with whom NC State competed while he and John Hosner were Deans at their respective institutions. FECO also had access to faculty members in Biological and Agricultural Engineering, Mechanical Engineering, Civil Engineering, Operations Research, and the Engineering Design Center

The initial objective of FECO was to design and develop a planting machine capable of operating under various site conditions and to determine the machine's role as a component of a total afforestation system. From the very beginning Hassan's efforts toward this objective were hampered by limited support facilities and even more limited resources. The Department had no shop equipped with the necessary tools and it had no space in which one could be developed. To meet these needs a work space for Hassan was carved out of the Hodges Wood Products laboratory and limited equipment was acquired. Although Hassan became a member of the faculty in Biological and Agricultural Engineering, this contact produced little in the way of the equipment and work space she needed. Examination of FECO budgets show that in virtually every year of its existence the financial contribution of NC State exceeded that of the member industries together. In retrospect, it is clear that these shortages in fiscal and physical resources essentially doomed FECO from the very beginning.

Nonetheless, Hassan did what she and the Coop members set out to do—design and construct a tree planting machine that would operate

under the conditions of Southeastern forest soils. The first prototype of the machine was completed in 1980 and tested during 1981-82. A new, more reliable planting head was constructed and field tested in 1982-83. After a successful demonstration of the machine in 1983 before 6 potential bidders, the rights to the machine were awarded to J. E. Love Company. In June 1984, the School, the Department, and the FECO members agreed to suspend the Cooperative, due to a "lack of funds", on December 31, 1984.

Despite the demise of FECO Hassan continued research on various aspects of machine-soil interaction and on tire size-ground pressure relations in an all-terrain vehicle with a radar system for detection of tire pressure. Together with the Hardwood Cooperative she also engaged in research on the impact of different harvesting regimes on soil properties in bottomland hardwood forests. However, the efforts of the School and Department to develop a forest engineering program essentially died with the closure of FECO.

Southern Forest Research Center

This industry-funded research program began in 1978-79 with Ellis Cowling, who had become the College's Associate Dean for Research in early 1978, serving as Director. The Center was organized under the auspices of the School rather than the Department and was envisioned as a program that would concentrate more on basic research (research with less immediate impact on management) than the research conducted by the Industrial Cooperatives.

At startup the Center supported studies in three areas, two in the Department and one in the Department of Botany. One project in Forestry involved studies of the impact of management practices such as site preparation and harvesting on forest site productivity. There were two separate projects initiated in this area. One, conducted by Chuck Davey and his students, dealt with biological fixation of nitrogen in forest soils. Objectives were to determine tolerance of N-fixing bacteria for the properties of forest soils and to isolate strains of bacteria particularly adapted to forest soils. The second in this area was initiated by Russ Ballard, Director of the Fertilization Cooperative. It involved two sites, one in the Piedmont and one in the Coastal Plain, on which were established studies of the impact of intensive forest management practices on site productivity. The other project in Forestry was carried out by Bill Hafley and Bill Smith and involved development of a bioeconomic model of growth of Loblolly pine as it is influenced by management practices prevalent in the South. The third project, located in the Department of Botany, involved pioneering efforts in the vegetative reproduction of Loblolly pine using tissue culture reproduction. Ralph Mott and Henry Amerson were the principal investigators.

Davey's research on clover as a source of nitrogen in forest soils resulted in isolation of a strain of Rhizobium that would fix nitrogen under the conditions in forest soils. Field tests of this bacterium, alone and with fertilizer, were established. They showed

that use of clover as a source of nitrogen in forest plantations was feasible.

Upon Ballard's departure in the winter of 1981 Lee Allen, the newly appointed director of the Fertilization Cooperative, took over management of the site productivity project. The study was expanded to a third site and Drs. Tom Wentworth of the NC State Department of Botany and Dr. Peter Vitousek of the Department of Botany at UNC-Chapel Hill came on board as research cooperators. Early research results showed that soil compaction in skid trails is severe, that nutrient displacement during windrowing was the most important drain on nitrogen and phosphorus reserves, and that herbicides and insecticides may stimulate nitrogen mineralization and thus nitrogen loss. Larry Morris joined the Fertilization Cooperative in 1982 taking responsibility for the Site Productivity Project. Morris left in 1985 for a position at the University of Georgia and Robert L. Sanford took over directorship of the Program. Sanford's abrupt and unforeseen departure in the late fall of 1987 caused a serious management problem in this Project. Tim White became Project Director in early 1988, continuing through the summer of 1991. No publications ever appeared based on the Project's work; ultimately, it was melded into the work program of the Nutrition Cooperative.

The model of Loblolly pine growth developed by Hafley and Smith was initially limited to unaltered stands. The unthinned model was then used to evaluate thinning responses and evaluation showed it conformed closely to data from thinned stands. Modifications were developed that incorporated fusiform rust impacts and allowed differentiation of stands into products. A technical report summarizing this study was released in 1982.

Within two years Ralph Mott and Henry Amerson, Botany faculty members who were the lead scientists in the Tissue Culture Project, had developed Loblolly pine plantlets through tissue culture techniques. Problems were encountered in root development and in field trials tissue culture plantlets did not perform as well as seedlings during the early years, largely due to problems with root development. Considerable research was directed to improvement of root development in plantlets and to development of in vitro techniques to screen Loblolly pine plantlets for resistance to fusiform rust and pitch canker. Research was also conducted on the development of rooted cuttings using material from 4-year old plants. By the late 1980s the Tissue Culture Program had essentially run out of new approaches to the issue of vegetative reproduction of plantlets and support of the Program was terminated by its industrial supporters. Although the loss of this program was a serious blow, in the long run it proved beneficial as the Department, with Bob Weir playing the lead role, developed a proposal for a Rooted Cutting project that was accepted and supported by a number of industries (see section on Rooted Cutting Program).

In the fall of 1986 the Department and School undertook a full examination of operation of the research cooperatives. One major recommendation of this study was that the Southern Forest Research

Center be phased out and replaced by a Forest Biology Research Program that would include the Site Productivity Project, the Tissue Culture Program, the newly-established Biotechnology Program, and a new forest physiology initiative. Bob Kellison was named director of this initiative. A total of $70,000 was made available from the Forestry Foundation to serve as seed money for new projects in basic forest biology. Unfortunately, and for a variety of reasons, the Forest Biology Research Program never fully realized the goals that were set for it and it never became a viable operation. Its constituent programs suffered various fates. The Tissue Culture Program, as indicated above, went out of existence, the Site Productivity Project became part of the Fertilization Cooperative's field studies, the Biotechnology Program went its separate way and became enormously successful, and the forest physiology effort ultimately became a successful program, centered on the rooted cutting work of Barry Goldfarb.

Central America and Mexico Coniferous Resources Cooperative (CAMCORE)

In the late 1970s, Bruce Zobel and Carl Gallegos, one of his former students who was employed by International Paper Company, together with forest taxonomists Jesse Perry and Willy Mittak, specialist with the Food and Agriculture Organization stationed in Guatemala, agreed that there was a clear need for an international program directed at the conservation of certain tropical and subtropical trees in Central America and Mexico. Populations of these trees were in danger, through overcutting and expansion of agriculture, of becoming extinct or at the very least having their gene pools so severely depleted they would no longer be viable. The efforts of these visionary men, together with those of the administration of the School of Forestry, resulted in creation in 1980 of the Central America and Mexico Coniferous Resources Cooperative (CAMCORE) as a unit of the Department of Forestry. Initially there were 5 members in South and Central America and the United States. By 2008 membership had grown to 35 institutions spread across 4 continents. In August 1981 Bill Dvorak was named the Director of CAMCORE and he has remained in that position ever since (with the exception of 18 months in the early 1990s when Bob Kellison served as interim Director allowing Dvorak to finish his doctoral degree). Jeff Donohue assisted Dvorak during the program's early years (1988-1996) as did international forestry consultant Bill Ladrach when he was still Director of Research for Smurfit Cartón de Colombia. Camcore increased its ability to do complex data assessment of genetic trials with the hiring of Gary Hodge in 1995.

In simple terms, CAMCORE began as a genetic rescue mission. During much of the 1980s Dvorak, with substantial on-site assistance, collected seed of a number of species of Central American and Mexican pines in order to save their genes. The seed were then planted on the lands of cooperators in trials designed to determine the productivity of these species under plantation conditions. CAMCORE's strength was its ability to establish trials over a number of sites and use sophisticated data analyses to choose the best species,

populations and families. In 1984, CAMCORE began collections of tropical and subtropical broadleaf species in Central America and Mexico. In 1994 CAMCORE extended its scope to include collections of broad leaf species of Gmelina arborea and Eucalyptus urophylla in Southeast Asia. By 2008 the program was working with 40 different species, including pines and broad-leaved species. It has sampled over 11,000 trees in 500 locations and has more than 2500 acres of field trials and conservation banks. The tropical and subtropical pines included in these tests constitute the largest such data base of these species in the world. It has expanded its work to include assessment of wood quality, development of pine hybrids, and research on the evolutionary development of tropical pines and eucalypts.

From its modest beginnings in the early 1980s CAMCORE has grown into the "International Cooperative for Tree Conservation and Domestication" as it was renamed by its Advisory Board in 2001 (the program still retains its acronym CAMCORE). CAMCORE "works around the world with industry partners to identify threatened species and collect seeds from them for use in conservation and growth studies, assess genetic diversity to improve methods of conservation, evaluate the adaptability of trees to new locations and develop long-term improvement programs for ensuring the sustainability of resources." The Program now offers stipends to enable international graduate students to study with the Program and the College of Natural Resources has named a Fellowship in Dvorak's name to support international studies in forestry.

CAMCORE's growth from a shoestring operation to a major player in world forestry is due both to the vision of its founders, particularly Bruce Zobel and Eric Ellwood, and to the dogged persistence and hard work of Bill Dvorak in obtaining funds and expanding the program's scope throughout the world.

The NCSU Forest Biotechnology Research Consortium

To understand the background that led to founding of the Biotechnology Consortium it is necessary to understand the growth and development of forest biotechnology in the Department. In the mid-1980s Deans Ellwood and Cowling made a commitment to development of a forest biotechnology program. This commitment was made only after considerable discussion and with a clear understanding of the substantial personnel, space, and resources that would have to be committed for the program to succeed. In a sense, Ellwood and Cowling were gambling that the College and Department would be able to ride the rising tide of interest in biotechnology and develop such a program in forestry at NC State.

Obviously, establishment of a biotechnology program had to begin with scientists. Elwood and Cowling had been impressed with Ron Sederoff's work in genetics and that of Anne Stomp in the Tissue Culture Program when he was in the Department of Genetics and she was getting her PhD with Ralph Mott in Botany. When Elwood approached Sederoff about returning to NC State he (Sederoff) was on a sabbatical at the University of California at Berkeley, employed by

the US Forest Service Southwestern Forest and Range Experiment Station. At the same time Stomp was working at the US Forest Service Laboratory at Placerville. Ellwood offered both the opportunity to return to Raleigh and both accepted, Stomp returning in 1986 and Sederoff a year later.

As the Department had no appropriate lab facilities at all, Stomp[2] remodeled and outfitted the lab that Tom Perry had occupied on the second floor of Biltmore Hall. Sederoff, however, on his return in 1987, occupied lab facilities in Polk Hall courtesy of the Department of Biochemistry until the lab located on the 6th floor of Jordan Hall was completed in 1989.

The new forest biotechnology lab on the 6th floor of Jordan Hall quickly developed into a lab capable of cutting-edge biotechnology work and, as we will see, was the site of some highly significant research. However, within a few years it was clear that Sederoff's program had outgrown its space. To resolve this difficulty, space was obtained on the second floor of the Partners II building on the Centennial Campus and the program was moved there in 1998. The University initially paid for this space but after two years the space was financed from overhead funds contained in grants. In 2007 the University resumed the costs of the facility. The Forest Biotechnology Program now operates entirely out of these facilities. The old forest biotech lab in Jordan was allocated to a campus-wide biotechnology teaching program that serves students in a number of biotech programs.

It is a major understatement to say that research in biotechnology is costly and complex and its needs far outstripped anything that the College or Department could provide. Fortunately, the research of Sederoff and his colleagues has been of such high caliber that a steady flow of grants from various sources has kept the Program functioning. This capability was greatly enhanced when Vincent Chiang joined the Department in 2002 and helped lead the program in new directions. Between Sederoff, Chiang, and Hou-Min Chang in the Wood and Paper Science Department, NC State's forest biotechnology program is one of the strongest in the US if not in the world.

The research accomplishments of the Forest Biotech program writ large are substantial. One of its earliest findings, made by David Neale when he was Sederoff's post doctoral at Berkeley, was to demonstrate the paternal inheritance of mtDNA in Sequoia sempervirens, a finding which became part of a dialogue on organelle inheritance in the journal Nature in March 1990. Work on transformation of Loblolly pine by Agrobacterium tumefaciens,

[2] Stomp's work eventually took a very different direction from forest biotechnology. She developed a highly successful program in bioengineering of Lemna (Duckweed) as a source of therapeutic proteins such as insulin. Her work will be covered in more detail later in this history.

actually begun when Sederoff was in Genetics at NCSU and published in Bio/Technology in 1986, is regarded by Sederoff as the program's first major contribution. His co-workers on this project involved not only Stomp, but also Scott Chilton and Larry Moore of the NCSU Department of Botany. Research on Loblolly pine continued with a study of the use of DNA markers. In 1992 Sederoff and his associates, using the RAPD technique, produced in 6 weeks a gene map of Loblolly pine which had been partially completed by others using more time-consuming methods. This eventually led several years later to the location of a gene that conveys resistance to fusiform rust disease. In the spring of 1992 the group, which now included Henry Amerson, David O'Malley, Ben Liu, and Ross Whetten, obtained three USDA competitive grants, showing the high regard in which peers held the NC State program. The RAPD method was used to map each parent in a full sib cross of Eucalyptus. The technique was also used as an integral part of research on fusiform rust, to study inheritance of quantitative traits in Loblolly pine, and to develop a genomic map of the species that will be of enormous importance to future breeding. Research was also initiated on the genetic basis for lignin formation in xylem. By the late 1990s the group had developed genomics of Pines and Eucalypts using EST sequencing and microarrays enabling them to determine the effects of individual genes. This work involved an integration of molecular and quantitative genetics of the role of individual genes in traits controlled by a number of genes. In 1999 the group received an NSF grant of $3.7 million to study the genomics of Loblolly pine. Sederoff estimates that by 2004 the Forest Biotechnology Program had received about $18 million in support.

The North Carolina State University Forest Biotechnology Industrial Research Consortium started in 1988 with 4 members. Largely due to the dramatic record of significant findings emerging from the Biotech laboratory, by 2004 it had grown to 12 cooperating companies from all over the world. Dr. Vincent Chiang, who joined the Department in 2002, was named the Director with coordination assistance from Ron Sederoff and Hou-min Chang. Twelve other researchers from the Departments of Forestry and Wood and Paper Science form the core of the consortium's research expertise. The mission of the Consortium is "to integrate genome technology, metabolic engineering, traditional tree breeding and wood and paper science into a research organization directed to the creation of superior wood as a raw material and as a product." The Consortium uses forest biotechnology to promote advances in forest, wood, and paper science by facilitating cooperation among industry participants throughout the world.

The Consortium operates in a manner different from that used by the Cooperative Programs. The members pay dues to the Consortium and the research to be supported is designated by the Consortium Advisory Committee. The Consortium does not rely on financial contributions from its members alone. Rather, the bulk of its research is supported by competitive grants from major national granting

agencies. Recent grants include two from the Department of Energy, one for $1.9 million dealing with improved wood properties through genetic manipulation and another for $1 million dealing with poplar genetics and carbon sequestration. The National Science Foundation Plant Genome program recently granted $2.7 million to conduct biotechnological studies on the Fagaceae, with particular emphasis on restoring American chestnut. Considering support from the Consortium and these recent grants, total program support now exceeds $30 million.

The history of the forest biotechnology program illustrates clearly the "genetic" relationship existing among a number of the Department's industry-university programs. The success of the Tree Improvement Cooperative in genetically improving Loblolly pine led supporting industries and faculty researchers to realize the potential value of a means of vegetatively propagating superior genotypes, leading to creation of the Tissue Culture Program. The work of Mott and Amerson led to an understanding of the importance of research in vegetative reproduction and at the level of individual (and groups) genes, thus leading to creation of the Rooted Cutting Program and the Biotechnology Consortium. Realization that the approaches used in biotechnology might hold promise for isolating the gene (or genes) controlling fusiform rust resistance led to creation of a Fusiform Rust Cooperative. Henry Amerson played the lead role in this effort and it existed from 1995 to 2006 when Amerson retired. As pointed out previously, CAMCORE was created because of the realization that the techniques used in the Tree Improvement Cooperative could also be used to save endangered pine genotypes and, ultimately, to genetically improve them through breeding.

Another significant outgrowth of the work in forest biotechnology has been the establishment of companies created to utilize research findings on a commercial basis. The first such company on the NC State campus was Biolex, Inc. created to utilize Anne Stomp's findings to create therapeutic proteins (more on this later). Two other companies have spun out of forest biotechnology research, BioInformatics stemming from Ben Liu's quantitative approach, and ArrayXpress based on research on plant pathogens done by Leonard Van Zyl.

Loblolly and Slash Pine Rooted Cutting Project

As the Tissue Culture Program, supported through the Southern Forest Research Center, was ending, some of the industrial members expressed interest in the rooted cutting work that had been started by John Frampton and continued by Peter Somers. To capitalize on this interest, Bob Weir developed a proposal for continued rooted cutting research. Included was a College commitment for a faculty position. Simultaneously, a search was conducted for a lead scientist to direct the program's research. Barry Goldfarb was chosen and began work in 1993; Bob Weir continued as director. Although this program effectively functioned as a cooperative it differed from the other Departmental cooperatives in that industry funding was committed for phases with each phase requiring the

submission of a renewal proposal. Funding for the program was renewed in 1997 and 2001. In 2004, largely because of industry changes, principally mergers, buy-outs, and land sell-offs, the Program was terminated.

The program succeeded in its primary mission of developing rooted cutting technology for Southern pines. The technology developed has not been widely adopted on a commercial level in the US, primarily because of economics and competition from private biotechnology companies offering vegetative propagation services with an alternative technique, somatic embryogenesis. However, the knowledge generated has been adopted overseas where labor costs are more favorable. In addition, the technique has been successfully applied in research settings, including enabling Department researchers to collaborate on a $6 million NSF Plant Genome grant with three other universities.

Despite the loss of industry support, research continues to be conducted on the process of root initiation and on development of a useful technology for producing rooted cuttings in southern pines. At present, Barry Goldfarb and John King, together with researchers from other departments, are involved. Research in the program is currently being conducted in five areas: 1) genetic selection for rooting is being evaluated for its potential to enhance efficiency in rooted cutting systems and for its effects on genetic gain for growth rate and rust resistance; 2) root initiation and maturation research is concentrating on understanding the molecular and cellular processes that occur during adventitious root initiation and which steps are blocked by maturation-caused loss of rooting ability; 3) stock plant management studies are determining the optimal mineral fertilization regimes for hedged stock plants as well as other management tools to maximize rooting success; 4) refining the rooting environment is being accomplished by studying the effect of environmental factors on physiological processes in the cuttings such as moisture stress, photosynthesis and respiration, and 5) the quality of rooted cuttings is being evaluated by testing the effects of plant hormones and other compounds on root system morphology and also measuring the performance of these cuttings in field tests.

Southern Forest Resources Assessment Consortium (SOFAC)

SOFAC was organized in 1994 at the USDA Forest Service by Fred Cubbage to enhance the analysis of the South’s forest resources. It is a cooperative effort involving Department faculty members, the US Forest Service, southern forest industry, timberland investment organizations, and state forestry agencies. The member organizations contribute funding and participate as voting members in the operation of the consortium. Shortly after, Cubbage came to NC State and became co-director, with financial administrative services still residing at the Forest Service. In 200y, SOFAC was migrated entirely to NC State, and as of 2008 has 18 members. Bob Abt and Cubbage now serve as co-directors.

The mission of SOFAC is to develop forest sector market models for application to forest resource assessments in the South, U. S., and the World.[3] Its goals are:

- To integrate currently available forest resource data from the USDA Forest Service Inventory and Analysis program and economic theory to model timber supply and demand in the South by local area;
- SOFAC economic models will allow use of exogenous or endogenous inputs about supply, demand, land use change, and landowner behavior in the analysis of timber and forest land markets and management;
- SOFAC modelers and members will be able to use the SOFAC suite of models and research to simultaneously project timber inventory, supply, and prices for a variety of regions and a variety of timber products across the South, the U. S., and the World;
- SOFAC will foster discussion among modelers and members about the appropriate inputs and assumptions in forest projection models and employ these in building timber supply models and timber supply scenarios that represent likely conditions;
- SOFAC will continue cooperative university-industry-public agency cooperation in southern and national forest sector economic modeling;
- SOFAC will enhance graduate instruction in forest economics and modeling in the South.

SOFAC has sponsored several research projects addressing timber markets in the U.S. South. SOFAC has been developing core timber market models as well as their components and inputs, including summarizing the best available and developing new growth and yield information for projections, compiling data on annual removals, estimating timberland conversions, and improving pulpwood supply equations. These projects have produced several SOFAC's Working Papers as well as other publications.

SOFAC facilitates continual timber supply analyses for the South with models that are continually updated with most recent research developments. SOFAC's members are provided with annual southern forest resource assessments and timber supply forecasts that are based on most up to date information on timber markets and resource conditions. The timber supply model developed with SOFAC's support--Subregional Timber Supply (SRTS)--was used to assess the current timber supply situation and develop forecasts for the South as a part of the Southern Forest Resource Assessment carried out under the lead of the USDA Forest Service. It has been updated to analyze multiple products and markets and applied to many industrial and policy questions.

[3] These statements are taken directly from SOFAC’s statement of mission and goals.