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From forester to climate-change scientist

By Richard Waring

When I enrolled in the university, I had no recognized talents, beyond an ability to play a trumpet well enough to join the University of Minnesota's marching band. I didn't realize the advantages of being raised by parents who valued education, although theirs was forced to end at the high school level. My dad was a whole-sale lumber dealer who commuted from Glen Ellyn, a small suburb 25 miles west of Chicago, to his office in the city. He bought and sold carloads of lumber on the phone, and travelled occasionally to mills in the western U.S., bringing back tales of big trees and colorful people. During World War II, we had few opportunities to travel as a family, beyond short vacations north into my father's home state of Wisconsin. On those trips, I learned to identify the major tree species. Later, I found the Morton Arboretum was within biking distance of my home; I enrolled in a course there where we used a hand-lens to identify different types of wood. Much later, at the university, as a teaching assistant, I taught others to use a hand lens to identify woods.

Robert, my fraternal twin brother and I belonged to the Boy Scouts; our father was one of four adults in our troop. He was the oldest leader in the group and the only one who had not served in the military. We learned quickly how to march in step, do first aid, and prepare for overnight camping in nearby forest preserves. By the time my brother and I had reached the rank of Eagle Scout, we had taken three canoe trips through the boundary waters of Minnesota and Ontario, Canada.

In 1951, at the end of my sophomore year in high school, our father's firm was bought by the Georgia Pacific Corporation. This resulted in us moving to Augusta, GA, for a year, until my father could establish his own firm and move back to the Chicago area. In Augusta, my brother and I, as well as my sister, Carol, were enrolled in the Academy of Richmond County, a public school for whites only. All boys were required to enroll in ROTC, given Eisenhower jackets to wear and M-1 rifles to drill with. I soon traded the M-1 for a trumpet to play in the band. My grades improved considerably during this year, and I learned also that my brother was a much better athlete than me. He made the basketball team while I didn't. Not making the team was an important experience for me. I looked for other areas where I might do better. When we returned to Glen Ellyn, I took a required course in speech and was voted "best speaker", based on stories that I told about my adventures in the South. Storytelling, I discovered much later, is an essential attribute when writing grants to support your research.

My father used to say, “If you can’t write in one page what you want someone to read, don’t expect them to read it.” Much later, as a professor, I applied his advice in writing abstracts to long manuscripts in less than a few hundred words. In meetings too, condensing discussions into a few points proved helpful. Later, after graduate school, I joined a Toastmaster Club and learned how important it is to know your audience and to speak with conviction and enthusiasm.

Just before coming to the University of Minnesota, I had a summer job, arranged by my scout master, to work at the Quetico-Superior Wilderness Research Center near Ely, MN (since moved to the Duluth campus). There I met a Latvian scholar, Egolfs Bakuzis, and a Canadian graduate student, Orie Loucks. Both served as mentors when I entered graduate school. I had a good memory at the time, which proved valuable when I worked as a tallyman to record the Latin names of all the plant species that grew on research plots that had been logged or left undisturbed during the war years behind a narrow fringe pine trees left along the shore of lakes (Loucks, 1957).

All foresters in my era were expected to gain summer experience through employment in public agencies or private forestry firms. At the end of my freshman year, I returned to the Quetico-Superior Wilderness Research Center to gain insights about forest genetics and tree water relations. Cliff Algren, the director, gave me a 12-gauge shotgun to shoot-down pollen-bearing twigs from white pine to find out when pollen was ripe for collection. This same weapon would prove handy in sampling branches throughout my scientific career. Mr. Algren sent me out on a marked route through the forest each week to measure microscopic changes in tree diameters through the growing season. He got upset with me once when I showed him measurements that indicated that larch trees, growing in a bog, had lost diameter over the previous week. Much later, shrinkage in tree diameters was shown to be a common response to high evaporative demand.

My most memorable summer job was with the U.S. Forest Service in 1955. My roommate, Dick Manly, and I hitchhiked together from Minnesota to Spokane, WA to work for Dr. Don Leaphart, a forest pathologist at the US Forest Service Experiment Station centered in Spokane, WA. Stands of pole-size western white pine that grew up in the drought years of the 1930s were dying across much of northern Idaho and western Montana. Our job was to collect soil samples and then wash and separate pine roots for Dr. Leaphart to inspect for root-rotting fungi. During that summer, we helped construct a drought experiment to mimic conditions back in the 1930s. We did so by building a slanted, covered platform around a small stand of white pine. The idea was to keep precipitation from reaching the soil. The platform shed rain and snow very well, but the experiment was terminated early, when the platform was destroyed by falling trees. My sojourn to the West allowed me to visit Mt. Rainer, which snow-covered peak could be seen on a clear day from more than 300 miles away. This vision remained in my mind as I returned to Minnesota.

In the spring term of my junior year, I had the opportunity to practice what we had been taught at the Cloquet Forestry Center. We gained new skills observing, trapping, and making ‘study skins’ of wildlife. My success at the latter was documented by Doris

Carlson, who I was courting, when she reported that the 'stuffed' field mouse I gave her had been dispatched by the cleaning lady at Westley Foundation by the whack of a broom. We also applied our knowledge of remote sensing by estimating tree heights and mapping forest types using stereo-pairs of aerial photographs. In addition, we thinned stands of red pine using two-man cross-cut saws, chainsaws were not readily available at that time, nor were hardhats.

We thought we were pretty tough by being able to start fires in wood-burning stoves in our below-freezing cabins each morning, by rushing out into the snow to cool off from a 220^{o}F Finnish sauna and by snow-shoeing through the woods at subfreezing temperatures. My limit to cold, however, was reached when I fell through the ice with snowshoes on.

That summer, I took a position at the U.S. Forest Service Experiment Station in Grand Rapids, MN. I worked with a variety of people, testing 2,4-D herbicide on shrubs, measuring responses of red pine stands to thinning, and recording water levels in wells that had been established across a series of bogs.

My undergraduate education included courses in surveying, hydrology, fisheries, wildlife, pathology, entomology and soils, in addition to those in forestry. This breath of practical coursework gave my classmates and me advantages to those trained more narrowly in other disciplines. With a good memory, I did well academically. In recognition, I received a travel scholarship from the Homelite Chainsaw Company to attend a national meeting of the Society of American Foresters in Memphis, TN. Professor Donald Duncan, who I had worked for at the U. of M., introduced me to many of the participants. In preforming that role, he taught me the importance of having a senior person to introduce young people to their peers at such meetings. The whole experience was so important to me that, upon retirement, my wife and I established an endowment to support travel scholarships for a half-dozen students each year at Oregon State University.

My senior year was a whirl of activity. I was editor of a forester's yearbook, and very active in my fraternity, Alpha Gamma Rho, where I was the rare forester among majors in agriculture. I graduated a quarter early to discover, when I was called up for the draft, that playing on the tennis team in high school had injured one foot sufficiently that I didn't qualify for service. With joyfulness, I returned to Cloquet during spring term as a field instructor and a mapper of forest types for Professor Merle Myer. In June, I married Ms. Carlson (Fig. 1) and we went together to Itasca State Park where I assisted Dr. Henry Hansen in educating the Class of '61 in all things ecological. That summer, I also got reacquainted with Egolfs Bakuzis. I served as his driver and helped him identify species of plants that he used in his Ph.D. thesis to infer *qualitative* gradients in light, moisture, temperature, and soil fertility across the state of Minnesota. I followed his approach in my M.S. thesis in the 'Arrowhead' region of northeastern Minnesota after getting more coursework in botany, ecology, soil physics and glacial geology.

Egolfs knew four languages and with them introduced me to research from France, Germany, and Russia that I had never heard about in my undergraduate education. At

Fig. 1. My marriage to Doris Carlson, June 16th, 1957

that time, all graduate students were required to read at least one foreign language, I chose German. Later, I went on to read French, but it was German that helped me become an international scientist. Dr. Donald Lawrence, who taught an excellent graduate course in plant ecology, recommended I continue my graduate education with Dr. Jack Major, a professor at the University of California, Davis. I wrote to Dr. Major, and was accepted at Davis but without financial support during the academic year. That problem was solved when the College of Forestry at Berkeley offered me a teaching assistantship for the academic year.

We left Minnesota in a snowstorm in April and arrived in Berkeley to find the grass green and eucalyptus trees in flower. During the first summer, I worked for various professors at Blodgett Forest Research Station in the Sierra Mountains. This was quite an experience because we had power for only a few hours each evening, provided by a diesel-powered generator. Fortunately, my bride had been brought up on a farm without electrical power until her senior year in high school. She knew all about using a wood-stove to cook food and heat water for showers. She soon became adapted to driving on steep, winding roads with logging truck drivers who loved to rev their motors close behind her.

Graduate school at Berkeley differed in two major ways from my former experience. First, I was expected to understand *why* trees grew as they did and secondly, *how* systems operated as a whole. These two requirements challenged me to find ways to measure how light, water, temperature, and soil fertility affect growth *quantitatively* and to collaborate with other graduate students to master techniques and to assist each other in understanding how forests as a whole interact with the environment.

The first integrative project I worked on was in Humboldt Redwood State Park. Four professors and their respective graduate students were provided funds to find out why 2,000-year-old redwood trees were dying or being undercut by the Eel River. Dr. Paul Zinke, a soil scientist, and his graduate student, discovered that 30 feet of silt had been deposited around redwood trees following periodic fires in the headwaters of the Eel Basin. Why hadn't those trees died? Dr. Ed Stone, a plant physiologist, and his graduate student, Richard Vasey, showed experimentally that new redwood roots could survive burial under a foot or two of silt. Larger annual deposits, however, were detrimental, and caused the stream to undercut its banks (Stone and Vasey, 1968). Taking advantage of my experience as a forester, I used a plane table, diameter tape, and a surveyors' chain to help map the location and diameters of every redwood tree in Rockefeller Grove.

Dr. Herbert Baker, a botanist, and his graduate student, Jim Griffin, identified those plant species that were adapted to flooding and those that were not. I worked with Dr. Major to understand the environmental limits to growth of redwood throughout the region (Waring and Major, 1964). Our team concluded that the increased mortality of redwoods was caused by excessive erosion from logging activities outside the park's boundary. https://islandpress.org/blog/kill-redwood

Orie Loucks, my friend from the Boundary Waters, thought the contents of my thesis broke new ground. At his request, I presented my first invited lecture before his graduate class at the University of Wisconsin. In that class sat Paul Riser, who, years later, as president of Oregon State University, recalled the lecture when he spoke at my retirement in 2000.

Early in my career, I learned to recognize my strengths as well as my weaknesses. I had a scholar's memory for detail and could distill ideas. My practical background in forestry was valuable in knowing how to sample efficiently and be resourceful and safe in the field. Although no mathematician, I loved algebra and calculus and had sufficient coursework in statistical design and sampling to make fieldwork efficient. Best of all, I found that I could distill information and reformulate it into testable ideas at a conference or workshop.

Following my graduation in 1963, we moved from Berkeley to Corvallis, where I accepted a full-time (12-month) position as a forest ecologist at the Forest Research Laboratory at Oregon State University, with a salary of $12,000 a year. Today, that salary would be equivalent to nearly $100,000. With no school debt and support from my spouse's jobs, first as an urban extension agent in Minnesota, and later as a junior high school home economics teacher in Vallejo, CA, we put a down payment on a house that cost $22,000. With my first real job, after six years of marriage, we started our family. Our son, Lance, was born in 1964, and our daughter, Lise, in 1967.

My reputation as a scientist got a boost by taking advantage of a pressure-chamber technique to measure water stress in live trees in the field (Fig. 2). Scholander et al. (1965) demonstrated the elegance of the technique during daylight hours, shooting foliage samples down with a high-powered rifle. I knew that trees are in hydraulic equilibrium with water available to their roots at night but not during the day when trees are transpiring water. To sample at night, a shotgun worked much better than a rifle; the results proved a means to quantify the extent that different types of forests experienced drought (Waring and Cleary, 1967).

Fig. 2. Measuring water stress in twigs with a portable pressure chamber.

My first, and most memorable sabbatical, began in 1969 at the Botanical Institute in Innsbruck, Austria, at the invitation of Professor Walter Larcher. I was on half-salary and could only afford to live in an apartment that was heated by coal stoves in the kitchen and living room. We enrolled our 5-year old son in kindergarten, and I started to speak German, because very few of my university colleagues, and none of the shop keepers spoke English at the time. The pressure chamber, which I brought with us, was of immediate interest to plant physiologists (Fig.3). Invitations from two German professors, Werner Koch and Otto Lange, provided opportunities to lecture about the instrument, not only in their land, but a dozen others. Professor Koch completely rewrote a manuscript in

German for me, agreeing to only an acknowledgment of his contribution (Waring, 1970). This was very generous, and later, I provided the same service for a number of foreign students.

Fig. 3. My German colleagues admired the portable pressure chamber I brought to a site where Werner Koch (with hat) was measuring photosynthesis. Udo Benecke, in the sweater, went on to lead research in New Zealand, where we collaborated years later.

In the 1970s, the National Science Foundation sponsored, as part of the International Biological Program, a nation-wide effort to build computer simulation models to describe the flow of carbon, water, and nutrients through forests, rivers, lakes, grasslands, and deserts. In the Pacific Northwest, faculty at the University of Washington headed the program, but eventually Oregon State University took the lead in studying forests as integrated ecosystems in the region. How that happened is instructive. One reason was that there were many more members of the Ecological Society on campus at O.S.U. than at the U. of W., and many of those had previously worked together to host a national meeting. This group included members of the U.S. Forest Service Pacific Northwest Experiment Station, in particular, a close friend and brilliant leader, Dr. Jerry Franklin. The Forest Service had established a number of gauged watersheds on the H.J. Andrews Experimental Forest located in the western Cascade Mountains. Gauged watersheds were perfect for monitoring water and nutrient flows before and after logging.

With National Science Foundation funding, nearly 100 faculty and graduate students at OSU joined forces with Forest Service scientists to measure, monitor, and model as many flows of material as possible at one of the gauged watersheds. Another major advantage that we had over the University of Washington, besides a central site for all our research, was the decision to hire a dozen post-doctoral students. Nearly all of the post-docs had degrees in other fields than forestry. We taught them the essences of forestry while they educated us in the processes that control decomposition, nitrogen-fixation, rock weathering and erosion, as well as the roles that litterfall and insects play in the productivity of streams. These post-doctoral students could work in the field and laboratories year around. They had no courses to take and were outstanding representatives of integrative science at national and international meetings. Other universities soon followed in hiring post-doctoral students, in many cases extending their positions to permanent research appointments.

Although the system models proved too complicated for general use, the knowledge gained in assembling them allowed me to write a textbook on forest ecosystems (Waring & Schlesinger, 1985). Jerry Franklin and I wrote an article about the forests in the Pacific Northwest Region that explained how the mild, wet winters, and long dry summers in the combined to favor the growth of long-lived giant conifers, where elsewhere, hardwoods would be expected to dominate (Waring and Franklin, 1979). Waring, R.H. 1982. Land of the giant conifers. Natural History 91:54-63.pdf

We didn't give up on models; we began to develop simplified ones to predict transpiration (Running et al., 1975) and photosynthesis (Emmingham & Waring, 1977). I learned new ways to measure water and carbon flow through plants using both stable and radioactive isotopes (Fig. 4), and used these methods in Oregon (Kline et al., 1976; Yoder et al., 1994), in Europe (Waring et al., 1980), and in New Zealand (Waring & Silvester, 1994).

A B

Fig. 4. (A) With a Geiger counter and a measuring stick, I determined the rate that water moved upward though the sapwood of trees injected with radioisotopes of tritium and phosphorus (B). Photo taken in Scotland in 1976.

In science, as in other fields, you meet many people who you grow to respect, and some become life-long friends. As a professor, I made it a policy to treat my graduate students as family from the start. All but one came from other states or countries. My family knew, from our experience in Europe, how challenging a new environment is and how valuable a single contact can be. In the early 1970s, while attending a meeting in Great Britain, I met three tree physiologists with whom I became life-long friends (Fig. 5). We continued throughout our careers to exchange ideas and offer insights as to what types of projects would move our field of science ahead most rapidly. We fostered an experimental approach to science to confirm assumptions in models and to validate their predictions.

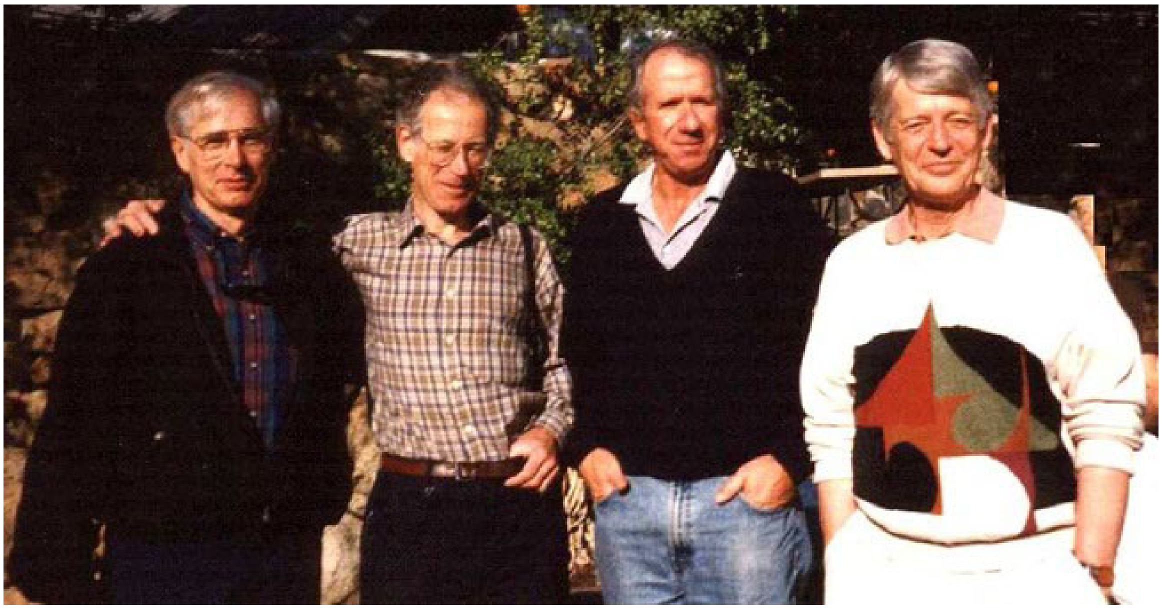

Fig. 5. (Left to right) Me with my life-long colleagues from Scotland (Paul Jarvis), Australia (Joe Landsberg), and Sweden (Sune Linder). Photo taken by Beverly Law in 1997 at a scientific workshop in South Africa.

My background in forestry proved valuable in designing and in conducting field experiments. For example, at Cloquet we had done stem analysis on a tree to understand how growth was allocated to the stem and branches. We knew sapwood, which carries water, tapered from the base of a tree to the top (Fig. 6). Our process studies of transpiration, at home and abroad, showed that the area of sapwood at the base of a tree's crown supports a fixed amount of foliage that differs by species (Waring et al., 1982). We used this relationship in an experiment to demonstrate that bark beetle attacks could be minimized by fertilizing and thinning a stand of pine or enhanced by not thinning and immobilizing the availability of nitrogen (Waring and Pitman, 1985). The key measure of whether a tree would succumb or survive attack from beetles was determined with a diameter tape and increment borer, from which growth per unit of leaf area was calculated (Christiansen et al., 1987). https://islandpress.org/blog/great-bark-beetle-experiment

Fig. 6. The outer, lighter colored sapwood, carries water to the leaves, and is proportional to the amount of leaf area. Photo taken by Peter Weinfurter in 1972.

Individual studies are valuable, but to scale principles to landscapes some type of remote sensing is required. We learned at Cloquet the value of stereo-pairs of aerial photographs. Since 1972, NASA has launched a series of Landsat satellites to record seasonal and yearly changes in land-use (Goward et al., 2017). I got involved with NASA when they asked me to advise, as a tree physiologist, how to design an instrument that would measure changes in the photosynthetic capacity of vegetation. To test a variety of instruments, I helped design and manage a research project across a transect of vegetation in western Oregon that ranged in productivity by ten-fold, from the most productive coastal rainforest to the least productive juniper woodland on the eastern side of the Cascade Mountain Range (Peterson & Waring, 1994). The goal was to test the extent that models predicting forest productivity could be driven entirely from data collected via remote sensing (Running, 1994).

My responsibility was to provide all the terrestrial-based data for modeling and check the accuracy of remotely sensed measurements of canopy leaf area and foliar chemistry. Seasonally, data were collected from three satellites, a half-dozen different planes, and a dozen instruments on the ground. The group of scientists involved came from a half-dozen universities, two NASA centers and the Oak Ridge National Laboratory. It was the largest project I was ever involved in, and, because it was successful, we all enjoyed and profited from the experience (Fig. 7). I spent the following 18 months as a visiting senior scientist at NASA headquarters as a grant administrator for a program in 'Land-Atmospheric Interactions'.

Fig. 7. A NASA-sponsored project across western Oregon in the late 1990s involved scientists from two NASA labs and a half dozen universities.

Following my return from Washington, D.C. to Oregon, I recruited two graduates and a post-doctoral scientist with background in remote sensing. These were all young women. By the end of the 20th century, women made up the majority of graduate students, and about half the undergraduate enrollment. This was an significant improvement to the field of forestry, considering that neither the University of Minnesota, nor Oregon State University had any women enrolled in the field over the decade when I was a student. Most of these women were excellent writers, and three with whom I had the pleasure of working, held positions as Deans: Dr. Susan Stafford at the University of Minnesota, Dr. Pamela Matson at Stanford University, and Dr. Ingrid Burke at Yale University.

Although I understood how to program computers and the basic physics essential to remote sensing and micro-meteorology, I never tried to master those fields. Instead, I sought to identify at meetings and workshops, and among my students and colleagues, those at a stage in their careers who were ready and able to test new ideas and approaches (Waring, 1998). When I was responsible for managing a program, I tried to hold some funds in reserve do I never had to request budget cuts from colleagues. It also meant that I had a buffer in case some projects warranted additional support.

When I returned from my administrative post with NASA to Oregon in 1991, it was clear that climatic conditions were less stable. We could no longer assume that estimates of productivity, derived from tree height measurements at a known age, were a sound basis to predict future yields. Was there an alternative? Dr. Joe Landsberg, my Australian colleague, thought that there might be. In 1996, when Joe stepped down from heading the CSIRO Division of Forest Research, he arranged for me to spend a year in Canberra with him. There, we pooled our knowledge and outlined a simplified process-based model. Several of those simplifying assumptions were ground-breaking. Joe developed some general equations, applicable to any species, as to how growth of leaves, branches, stems, and roots should be produced under changing (monthly) weather conditions for both managed and unmanaged forests. The resulting model was designed for use by foresters; it predicted changes in tree diameters, basal area, heights, volume and mass, as well as annual mortality, whether natural or from selective thinning (Landsberg & Waring, 1997). Model predictions proved accurate when tested across a wide range of forest types (Landsberg et al., 2003).

Dr. Nicholas Coops, an Australian skilled in remote sensing and computer programming, helped us extend the modeling approach across regions using satellite-derived data (Coops et al., 1998; Waring et al., 2015). When Dr. Coops took a position at the University of British Columbia, he and his graduate students collaborated with me using remote sensing and large sets of Forest Service plot data to predict where species were no longer well adapted to changing climatic conditions (e.g., Mathys et al., 2018). https://islandpress.org/blog/adjusting- forests-wont-stand-still

In 2020, Drs. Landsberg, Coops, and I received international recognition (Fig.8) …the Marcus Wallenberg Prize… which carries a monetary award, from the Swedish Wallenberg Foundation for our modeling work done in the late 1990s (https://www.mwp.org/link-to-mwp-digital-ceremony-and-symposium/). The model we developed has become widely used, in part because we distributed the code without charge after it was significantly upgraded by Dr. Peter Sands, a colleague in Tasmania.

I owe a debt to my whole family, particularly to my wife, Doris, who gave up her profession to allow mine to flourish. As a family, we gained much from our experiences abroad (Fig. 9).

Fig. 9. Lance's wedding, 2012 in Telluride, CO.

Citations

Coops, N. C., Waring, R. H., & Landsberg, J. J. (1998). Assessing forest productivity in Australia and New Zealand using a physiologically-based model driven with averaged monthly weather data and satellite-derived estimates of canopy photosynthetic capacity. *Forest Ecology and Management*, *104*,113-127.

Christiansen, E., Waring, R. H., & Berryman, A. A. (1987). Resistance of conifers to bark beetle attack: searching for general relationships. *Forest ecology and management*, *22*, 89-106.

Emmingham, W. H., & Waring, R. H. (1977). An index of photosynthesis for comparing forest sites in western Oregon. *Canadian Journal of Forest Research, 7*, 165-174.

Goward, S.N., Williams, D.L., Arvidson, T., Rocchio, L.E.P., Irons, J.R., Russell, C.A., & Johnston, S.S. (2017). Landsat's Enduring Legacy: Pioneering Global Land Observations from Space. ASPRS, Publisher.

Kline, J. R., Reed, K. L., Waring, R. H., & Stewart, M. L. (1976). Field measurement of transpiration in Douglas-fir. *Journal of applied Ecology*, 13, 273-283.

Landsberg, J. J., & Waring, R. H. (1997). A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. *Forest ecology and management*, *95*, 209-228.

Landsberg, J. J., Waring, R. H., & Coops, N. C. (2003). Performance of the forest productivity model 3-PG applied to a wide range of forest types. *Forest Ecology and Management*, *172*,199-214.

Loucks, O. L. (1957). A study of lakeshore reservations of Pine Quetico Provincial Park, Ontario. *The Forestry Chronicle 33*, 213-232.

Mathys, A. S., Coops, N. C., Simard, S. W., Waring, R. H., & Aitken, S. N. (2018). Diverging distribution of seedlings and mature trees reflects recent climate change in British Columbia. *Ecological Modelling*, *384*,145-153.

Peterson, D. L., & Waring, R. H. (1994). Overview of the Oregon transect ecosystem research project. *Ecological Applications*, *4*, 211-225.

Running, S. W. (1994). Testing FOREST-BGC ecosystem process simulations across a climatic gradient in Oregon. *Ecological Applications*, *4*, 238-247.

Running, S. W., Waring, R. H., & Rydell, R. A. (1975). Physiological control of water flux in conifers. *Oecologia, 18*, 1-16.

Scholander, P. F., Bradstreet, E. D., Hemmingsen, E. A., & Hammel, H. T. (1965). Sap pressure in vascular plants: negative hydrostatic pressure can be measured in plants. *Science,148*, 339-346.

Stone, E. C., & Vasey, R. B. (1968). Preservation of Coast Redwood on Alluvial Flats: Because man has altered the environment, active management is now required. *Science*, *159*, 157-161.

Waring, R. H. (1970). Die Messung des Wasserpotentials mit der Scholander-Methode und ihre Bedeutung für die Forstwissenschaft. *Forstwissenschaftliches Centralblatt*, *89*, 195-200.

Waring, R. H. (1998). Lessons learned while extending physiological principles from growth chambers to satellite studies. *Tree physiology*, *18*, 491-497.

Waring, R. H., & Cleary, B. D. (1967). Plant Moisture Stress: Evaluation by Pressure Bomb. *Science*, *155*, 1248-1254.

Waring, R. H., Coops, N. C., Mathys, A., Hilker, T., & Latta, G. (2014). Process-based modeling to assess the effects of recent climatic variation on site productivity and forest function across western North America. *Forests*, *5*, 518-534.

Waring, R. H., & Franklin, J. F. (1979). Evergreen Coniferous Forests of the Pacific Northwest: Massive long-lived conifers dominating these forests are adapted to a winter-wet, summer-dry environment. *Science*, *204*, 1380-1386.

Waring, R. H., & Pitman, G. B. (1985). Modifying lodgepole pine stands to change susceptibility to mountain pine beetle attack. *Ecology*, *66*, 889-897.

Waring, R. H., Schroeder, P. E., & Oren, R. (1982). Application of the pipe model theory to predict canopy leaf area. *Canadian Journal of Forest Research*, *12*, 556-560.

Waring, R. H., & Silvester, W. B. (1994). Variation in foliar δ13C values within the crowns of Pinus radiata trees. *Tree physiology*, *14*,1203-1213.

Waring, R. H., Whitehead, D., & Jarvis, P. G. (1980). Comparison of an isotopic method and the Penman–Monteith equation for estimating transpiration from Scots pine. *Canadian Journal of Forest Research*, *10*,555-558

Waring, R. H., & Major, J. (1964). Some vegetation of the California coastal redwood region in relation to gradients of moisture, nutrients, light, and temperature. *Ecological Monographs, 34*, 167-215.

Waring, R.H., & Schlesinger, W.H. (1985). Forest Ecosystems: Concepts and Management. Academic Press, San Diego, CA, 340 pp.

Yoder, B. J., Ryan, M. G., Waring, R. H., Schoettle, A. W., & Kaufmann, M. R. (1994). Evidence of reduced photosynthetic rates in old trees. *Forest Science*, *40*, 513-527.