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PERSONAL VIEW

Seeds, seed banks and wetlands

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Mary Allessio Leck (photo by P.O. Quinby).

I agreed to Ken Thompson's request that I contribute to *Seed Science Research*'s Personal View series, thinking I could provide a view of an alternate academic path, where research, though required for promotion, was not the main criterion as it was coupled with teaching and service. Teaching activities were my primary focus, and without graduate students, laboratory preparations were borne alone. Research, motivated by a love of discovery, called for time out of doors in springtime, when otherwise I'd have been at my desk or at a meeting. Research resulted ultimately in development of a sense of place, and 'my' tidal freshwater marsh became a focus of educational activities beyond the classroom.

I shall address how I came to be interested in seeds and seed banks, and provide a short personal history; ultimately all are interconnected. This is a reminiscence. Much appears, in hindsight, to have been serendipitous.

My first seed recollections are from the early 1940s. I was born in 1941 and can remember both black outs with black shades over windows and war-time ration coupons, although shortages, I think, were not serious for those living on a farm. [We lived more than 1100 km (450 miles) from the Atlantic coast. Could an enemy plane have reached that far inland?] Until I was about 10 we lived on a small dairy farm in the rural, rolling hills of western New York. I remember hayfields and pastures, and fields of buckwheat, corn (maize) and winter wheat. The herd was mostly Holsteins; there were chickens, a goat and a dog named Prince. We had a family garden and a few fruit trees – apples, cherries and pears. The house was sided with brown shingles. It was basic.

What do children do on a farm? My brother, a year younger, fell into a cooling tub for milk cans, and I got caught playing with matches on a coal pile. There were many concerns I suppose, such as when to plant or to cut hay, but mine were few. I distinctly recall, however, thinking about what would happen if the grapefruit seed I had swallowed grew inside me! I remember a bucket in the garden, put aside by one of my parents and forgotten, containing germinating peas, and I remember being given the smallest tomato plant and having it grow to the same size as the others. My interest in plants came early; I recall asking my dad the names of the spring flowers as he held me on his lap while driving the tractor and, when I was older, leafing through his wildflower book. The family garden, first in New York and then in Massachusetts, where my parents had returned following a decision on the part of my mother's

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family to sell the New York farm, provided many additional seed memories. My father, one of seven sons in a family of 14, had no place to return to on his family's farm and so took a farming job on an estate in western Massachusetts near his family. It was there that I grew up. As we grew older, my brother and I helped with planting and weeding the garden. (My mother froze or canned the produce, spoiling me forever for supermarket offerings.) Eventually, I selected the flowers for the garden; I can still remember handling the seeds of zinnias, marigolds, *Nigella*, *Portulaca*, *Nasturtium* and *Calendula*, as well as vegetables – carrots, tomatoes, lettuce, Swiss chard, cauliflower, and gaudy purple and pink beans. At the time, I certainly did not consider the significance of their sizes, shapes and germination requirements, but now as I write this, I am aware that they gave tactile and sensory pleasure, the seeds themselves interwoven with memories of colours, tastes and fragrances. The smells of marigolds and tomatoes are now, well, heavenly, and provide connections to those simpler days.

I came to know weeds too, such as lamb's quarters, pigweed, *Galinsoga*, ragweed and purslane. That the weed seeds were already in the soil did not really penetrate my consciousness then, but I do recall observing a progression in species, that not all appeared at the same time. On some level I was aware of differing seed requirements, such as depth and timing of sowing, nominally because the brown paper seed packets provided such information. We always saved the left over seeds and had success in planting them the next season, and so I was amazed much later to find how crops from aged seeds had considerably reduced productivity (Barton, 1961). I suppose those years before college were a time for imprinting (priming?). During school, exposure to seeds was virtually nil. My high school biology course was taught by the basketball coach and there was no lab. I suppose we learned something about plant biology, but I have absolutely no recollection until Introductory Botany at the University of Massachusetts. I entered college in 1958, only a few years after the discovery of the helical structure of DNA in 1953.

I was terribly naive (my father had only completed the eight grade before it was necessary for him to work on the family farm, and my mother completed schooling to age 18 in Italy). I did not know that a person could major in the study of plants. I went to college to study science and to become a teacher. During my second year, I became a botany major. Seed information was dispersed through the required courses, where I learned about, for example, the R–FR effect on lettuce seeds. We've come to know so much more about the importance of phytochrome in all stages of plant growth, as well as about its biochemistry. For students, now, the topic is considerably more complicated, but it was interesting during the 34 years I taught to see how our understanding of many topics improved. In my third year, I took Systematic Oleroculture (vegetable taxonomy), the class members became the university's vegetable judging team and, in preparation for contests, I learned to identify weed seeds.

For 3 years I learned a great deal, working in John Rowley's palynology lab, and in my third year did an independent atmospheric pollen study with him. However, my academic advisor was Robert Livingston, a student of H. Oosting at Duke University, and it was Dr. Livingston who suggested a senior honours project based on a 'buried viable seed' study by Oosting and Humphreys (1940). Our actual sampling technique was not much different from that used now; ten samples taken with a golf cup cutter were mixed together and subsampled. However, we did not design the study with an eye to statistical analyses. The only hand calculators were slide rules! Copying machines were barely off designers' drawing boards, and I had piles of small note cards with carefully copied information from library articles and books. There were computers, but one needed to learn a computer language to use them. We sampled 16 sites of varying ages in and near Harvard Forest. I found that certain species persisted for varying lengths of time – some for only a short time, others were of intermediate duration and still others were present in all the samples. I also observed a phenological succession in the flats, where species appeared at different times. That study was the basis for Livingston and Allessio (1968). It wasn't until the Thompson and Grime (1979) paper that persistence and transience of seeds in the soil were evaluated systematically. Their paper, along with those by, for example, van der Valk and Davis (1978) and van der Valk (1981), and *Population Biology* by Harper (1977), I think, contributed to a long sustained interest in seed banks of natural systems. Before that, studies were primarily agricultural, and the classics examined the 'vitality' of artificially buried weed and crop seeds (e.g. Goss, 1924; Telewski and Zeevaart, 2002 for the Beal experiment begun in 1879).

For graduate work I elected to accept an NDEA Fellowship in Physiological Ecology at the University of Colorado. The National Defense Education Act was a response of the United States to Sputnik, although it is not clear how a PhD in plant physiological ecology would further national defence (I would struggle with such a decision today). I do not recall how I decided to study the germination ecology of the alpine *Polygonum bistortoides* (*Bistorta bistortoides*, bistort), but at that time Erik Bonde, my advisor, was involved in a survey of germination of alpine species (Bonde, 1965a, b). I compared germination responses

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of three populations over 2 years and attempted to understand seed dormancy using an array of treatments, including light, temperature, stratification, scarification, leaching, chemicals (thiourea, KNO_3, etc.) – your basic shotgun approach. Seed harvesting occurred late in the season; on the last collection date at the end of September at about 3800 m (11,600 feet), the van encountered a snowdrift across the road near the collection site. While backing up, one wheel ended up over the edge of the road, which did not seem too bad until, from a lower vantage point, we could look back up at the stranded vehicle and see how precariously it was balanced (I was not driving!). Contrary to other published reports at that time for other alpine species, the population from the highest elevation gave the best germination (Allessio, 1969). One of the more interesting observations to come from germinating seeds in soil in the greenhouse, was the form of the seedling. Its proclivity for rhizomatous growth was shown when cotyledons were still present, and a swelling occurred at the base of the hollow hypocotyl where the meristem and subsequent leaves developed (Allessio, 1967).

It would be interesting to revisit bistort germination, applying what we now know about the influence of storage conditions. I would think more broadly about how responses fit with the 'driving' environmental conditions, as well as examine seed-bank and field-seedling dynamics.

In 1967, I made a chance, serendipitous, observation that would cause an eventual shift in orientation from uplands to wetlands. On an early spring day, while visiting my parents, I noticed *Impatiens capensis* seedlings at the bottom of a small woodland stream, stimulating questions about germination oxygen requirements. My *Impatiens* research was slow to take off, but finally, in autumn 1970, I collected seeds, and in spring 1971 started a fairly extensive germination study. Of hundreds of seeds only three or four germinated. However, seeds I had left with my mother, who kept them in the refrigerator and watered when she remembered, germinated well. This was a wake-up call to the world of recalcitrant seeds! This result significantly influenced my thinking about seeds and, consequently, that unless seeds are to be aged, germination tests need to be set up as soon after collection as possible and seeds stored under conditions that reduce deterioration.

Impatiens capensis has provided an interesting model species with which to explore dormancy and seed adaptations to wetlands. Its seeds require prolonged low temperature to break dormancy (3–4 months) and then germination is complete (>90%), light is not required, seeds do not tolerate drying nor can they survive prolonged anaerobiosis, and gibberellin promotes germination, but does not replace cold after-ripening (Leck, 1979). The large seedlings that appear in early spring can grow quickly, out-competing other species (Winsor, 1983). Knowing the low temperature requirement allowed us to time germination and subsequent seedling development for a field experiment involving six of eight study populations that were transplanted to five sites (Simpson *et al*., 1985). Height and production of chasmogamous flowers were plastic responses, but flowering times were population specific. Across eight populations, seed production ranged from 35 to 17,076 m^{-2} yr^{-1} and seed weight from 6.4 ± 0.3 to 26.9 ± 0.3 mg $seed^{-1}$, and following spring germination the soil was virtually devoid of viable seeds.

Once I knew that I could manipulate *Impatiens capensis* germination in the lab, I wondered how it would behave in the field. Initially, I buried seeds in a floodplain site where germination was complete. In 1976 Kevin Graveline, an undergraduate student, was searching for an independent study project. At that same time Dennis Whigham and Robert Simpson were engaged in ecosystem-level studies of a local tidal freshwater wetland. I suggested an *Impatiens* seed-bank study to Kevin, and Dennis suggested the local tidal freshwater marsh as a site having a sizeable population of *Impatiens*.

After that first marsh seed-bank study (Leck and Graveline, 1979), the *Impatiens capensis* population study, and as we spent increasing amounts of time in that marsh habitat, we used community seed banks to address a number of questions, including: the relationship between seed banks, field seedlings and vegetation (cover); the relationship between seed production and seed banks; seed-bank and vegetation composition over 10 years; and seed dispersal and survivorship of seedlings along a hydrological gradient. We also examined seed longevity/persistence and seed-bank turnover. In the greenhouse, we manipulated samples to examine the influence of flooding on recruitment, response to tidal water movement, and even the impact of crude oil on germination and recruitment. These studies have begun to provide an understanding of the relationship between the seed bank and vegetation dynamics. It is not surprising that seedlings have differing tolerances, but it is remarkable to me how precise the tolerances appear to be, as zonation patterns can be quite abrupt. Species such as *Impatiens capensis*, with large seeds and large seedlings, are able to tolerate biotic stress such as competition on the high marsh, where seedling densities can exceed 4000 m^{-2}. In contrast, *Polygonum punctatum* seedlings can survive the physical stresses associated with inundation at the channel edge.

The marsh is dominated by a mix of more than a dozen annual and perennial herbaceous species. In

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large part because of the importance of annuals, seed-bank studies demonstrated considerable depletion during springtime. This mix of species possessed a range of seed-bank strategies: some were transient with complete turnover in the spring; others, present in both surface and subsurface layers, were considered to be short-term persistent; and still others, present only in subsurface layers, had long-term persistent seeds. Interestingly, the largest seeded species had transient seed banks (Leck, 1989; Leck and Simpson, 1993). A set of deep samples (30–32 cm depth) from a shrub forest site fairly close to the marsh edge yielded a number of *Cyperaceae* species, including *Dulicium arundinaceum* and several *Carex* species, which occurred only at the lowest level and were absent from the vegetation at the site. Based on Orson *et al*. (1992), we estimated those seeds to be >70 years old. For several years those samples remained a mystery, but about 3 years ago we discovered a small remnant patch of sedge swamp, and, while perusing books by C.C. Abbott, a well-known local 19th-century naturalist and archaeologist, we found a photograph, published in the late 1800s, of a local sedge swamp essentially contemporaneous with the 30–32 cm depth seeds.

Because this tidal freshwater wetland habitat has a large annual species component, community dynamics are tied to the seed bank. A 10-year study (Leck and Simpson, 1995) documented species fluctuations. Notably, although seeds of a species were present in the seed bank and seedlings were present in the field, establishment of some species, such as *Bidens laevis*, with a short-term persistent seed bank, might not occur. However, *Bidens laevis* was observed in other areas of the 500 ha marsh. Such variation in population densities did not lead to extirpation because there was sufficient habitat in other parts of the marsh. Such results suggest that decreasing acreage and isolation of wetlands could lead to decline in regional species richness as local extirpations occur. They also raise the question of what happens to seedlings.

The long-term studies have provided insights that single or 2-year studies could not. The reference marsh study mentioned above (Leck and Simpson, 1995) showed tremendous year-to-year variation in three life-history stages [seed, field seedling and vegetation (cover)]. Two other studies, 10 years for an old field (Leck and Leck, 1998) and 5 years for a created wetland (Leck, 2003), showed the sequential displacement of species from the vegetation, as well as from the seed bank. The lack of persistence of certain (most?) species indicates the considerable and continuing importance of dispersal.

In the two successional studies, small-seeded species initially predominated. The created wetland had staggering numbers of seeds [with some samples having >4000 per sample (initial size 10 × 10 × 3 cm deep) and one having >6000, values much greater than the entire seedling record for many published studies]. Many of the species, even with tiny seeds, did not necessarily have very persistent seeds, raising the question of what happens to the myriad seeds that are produced. Although granivores of various kinds occur in wetlands, something else likely accounts for seed loss, especially of small-seeded species, perhaps microbial decay (Greenfield, 1999) as earthworms do not occur in this habitat. The decline in species richness and numbers of seeds of many early successional species suggest the continuing importance of both dispersal and *in situ* seed production for regional species maintenance. Therefore, it is a concern that, with increasing habitat fragmentation, dispersal may not occur often enough or be of suitable density for species maintenance, especially of rare species. Also, as dispersal agents are adversely affected, community composition and species richness will be altered. As a corollary, controlling the disturbance agents, e.g. fire but also water level, reduces habitat diversity. Tide level has increased by >1 m compared to 1930s, and construction of a canal and railroad in the 1830s at the west edge restricted water flow to the area under a single railroad bridge, causing a longer impoundment period. Even a persistent seed bank may not provide a suitable buffer in such changing times. It is possible that the marsh is still in a state of flux, with dominant high marsh communities dominated by mixed annuals and perennials rather than sedge swamp communities.

The accumulating evidence indicates that some taxa have great capacity to produce large and persistent seed banks. *Juncus effusus* seems to be such a species (Thompson *et al*., 1997) as are certain *Cyperaceae* (Leck and Schütz, submitted), but mysteries remain. I am unable to explain why *Juncus effusus* did not form a large and persistent seed bank in two of three created tidal wetland locations, despite large, dense, albeit temporary, stands occurring in several areas (Leck, 2003). Certainly, not all seeds would have floated away.

These observations suggest that studies are needed that monitor interactions of dispersal and availability of habitat (disturbance), and of the relative importance of long-distance dispersal, *in situ* production/dispersal, and loss agents (decay, herbivory, etc.). A variety of habitat types should be explored. There is also a lack of information on how the various components of a seed-bank model relate to the evolution of seed characteristics. What are the trade-offs between seed characteristics and enhancement of seedling establishment? How are the mechanisms of seed and seedling tolerances related? Seedling establishment appears to me to be a bottleneck in community development. For example, in deserts, seeds of gypsophiles and halophytes must

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tolerate high soil salt concentrations. However, germination may occur with higher water potentials following rain, and seedlings must then tolerate returning low potentials as sediments dry.

Despite the inherent problems in some habitats, especially of obtaining adequate numbers of viable, ripe seeds and the difficulties in working with very small seeds, laboratory germination studies provide data that complement those from seed-bank studies and allow greater understanding of seed-bank ecology. For example, our marsh seed-bank data showed substantial turnover during spring germination in *I. capensis, Peltandra virginica* and *Polygonum arifolium*, which were transient (lasting <1 year). However, dormancy mechanisms differed. For germination, *I. capensis* and *P. arifolium* needed stratification (5°C for >2 months) and then germination could occur at 5°C in the dark. In contrast, *P. virginica* seeds were not dormant and could germinate at suitable temperatures (>10°C), provided the fruit coat was removed. Thus, the timing of field germination differed. Of 14 marsh species studied, only *Phalaris arundinacea* seeds are produced in summer; germination requires alternating temperatures (10–20°C) and light, and seeds can germinate in the field in late summer/autumn (Leck, 1996). Evaluation of the seed bank dynamics of each species or community requires an understanding of germination requirements as well as field germination patterns. Despite a common habitat, wetland species varied in their dormancy mechanisms, seed-bank strategies, and evolutionary histories. It appears that there is considerable sensitivity in responses to the germination environment.

Moreover, the challenges of using seed banks to answer particular questions necessitate understanding the major environmental factors driving seed-bank response and determining how to elicit optimal germination of the majority of species. Some species require very specific conditions and, to my knowledge, have not been recovered from seed banks (e.g. orchids and hemiparasites such as *Agallinis* spp.; Nicholson and Keddy, 1983; Thompson *et al*., 1997). Spending considerable time with (and in) a particular habitat results in the appreciation of its germination and seed-bank nuances.

Seeds of wetland species generally must be able to tolerate inundation (hypoxia or anoxia) to a greater degree than upland species, but wetlands may experience drawdowns of varying lengths. In contrast to 'my' tidal freshwater marsh, which has a predictable inundation regime, the temporary wetlands of the New England Tablelands of New South Wales, Australia have unpredictable dry periods (Leck and Brock, 2000). There, selection (drying regime and secondarily climate) has resulted in seeds that can persist for a decade or more in soil samples that have been wetted and dried multiple times (Leck and Brock, 2000; M. Brock, personal communication). The differences between Brock's wetlands and mine raise questions about the seed characteristics that control germination, resulting in such temporal dispersion.

Seed-bank selection studies, such as the rapidity with which seed-bank persistence can occur, might be easy to design. *I. capensis*, for example, could be a suitable species. New Jersey populations are transient, except for only an occasional seed that persists to a second year (Simpson *et al*., 1985); in contrast, in Nebraska, populations have some persistent seeds (Antlfinger, 1989). Other possibilities of species with both transient and persistent reports may be found in Thompson *et al*. (1997). Also, selection for seed size might also be possible. For example, the size of *I. capensis* seeds varies considerably. They are four times larger in a tidal freshwater marsh than in upland wooded locations (Simpson *et al*., 1985). Is this a phenological response? What are the trade-offs between seed size and seedling size? In the tidal freshwater marsh, large seed size (and rapid growth) would appear to confer advantage in a community where seedling densities (Leck and Simpson, 1995) and biomass accumulation are high (Simpson *et al*., 1983).

Changes in conditions that affect germination behaviour may be linked to human activities including, directly or indirectly, urban sprawl. Global warming and associated sea-level rise (and tide rise), as well as nutrient enrichment (Bedford *et al*., 1999), may act alone or interact synergistically to affect the seed bank, germination, recruitment, and, thus, composition and diversity, as well as the spatial and temporal distribution, of tidal wetland plant communities. There are also intriguing questions involving the interrelationships between dispersal, frugivory, dormancy, seed-bank mechanisms and seedling survival.

Other outcomes

My tidal freshwater marsh studies have inevitably led to other things. I incorporated research topics into my teaching. Students in the first-year course collected soil samples for student-designed seed-bank studies, and students in advanced courses used seeds of wetland species to address a variety of questions, including the impact of wetting and drying on membrane permeability and on viability, the effect of anaerobiosis on alcohol dehydrogenase (ADH) activity, leachate of *I. capensis* seeds as an antimicrobial or allelopathic agent, and host preference of *Cuscuta gronovii.*

Getting students into hip boots and into the 'serious' mud of the marsh was, for most, enjoyable.

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For a group of inner-city high school students on a sunny Saturday morning in early June, the marsh was an adventure that challenged them physically and led to an epiphany that changed their thinking about science, and that propelled me to think about the value of the marsh as an educational resource and the need for a nature/interpretive centre with staff. There have been many field trips and canoe trips for school children, VIPs and other groups. There have been numerous meetings that have dealt with developing a management plan (challenging me to think outside the academic box) and developing materials for teachers (a resource manual with site-specific lesson plans), nature trail guides and interpretive signs. Despite the commitment of many concerned individuals, it requires considerable effort to develop the social and governmental will to make such a centre a reality. Among the lessons are: (1) just how invisible an academic can be – my academic world has been so much more collegial; and (2) how unprepared one can be for dealing with the 'not-in-my-backyard' public.

Issues relating to preservation, protection and stewardship become increasingly important in such an urbanizing landscape. The issues are not unique. How can the uses by people – paint-ballers, drivers of all-terrain vehicles (ATVers), jet skiers, hunters, fishermen, paddlers, photographers, hikers and bikers, etc. – be reconciled with ecosystem sustainability? Besides the issues related to education, how can science inform public policy? While these are grand ideas/words, I think rather more simplistically and believe that a marsh interpretive centre would help develop the attitudes needed to guarantee sustainability. The marsh is truly an urban wetland with multiple owners, located in a landscape that is rapidly reaching saturation.

On a (more) personal note

I have been fortunate in many things – advisors, fellow graduate students, colleagues, friends and a wonderfully supportive husband, but there were two events that were not professionally encouraging for me as a young botanist. A post-doctoral position in New Zealand, where I was to study an introduced lake weed, although educational in many ways, was ill-fated, and my decision to return home within 6 months was a difficult one. Similarly, I accepted a position at Rutgers University, Newark in 1967, where I would teach botany and plant physiology. Of the three junior faculty hired about the same time, none of us 'survived', a similar fate to previous young faculty. Controversy swirled, with headlines such as 'Teacher of the Year Fired'. For me the notoriety was nearly as bad as the 'failure'.

In 1970 I accepted a position at Rider College, an undergraduate institution, with supportive colleagues where teaching was the primary interest of the biology department and where, over the years, I could thrive. Interacting and working with students was a pleasure. However, teaching loads were heavy (12 contact hours a semester, which were eventually reduced to 9). Responsibilities included teaching lectures and labs, doing my own lab preps, which for physiological experiments could be time consuming, and serving on various committees. Summers provided time to catch my breath. I worked on research, but at my own pace, and, in part because I did not want the associated obligations, and because seed germination and seed-bank studies were 'low budget', I never applied for extramural funding, although the National Science Foundation (NSF) and other funds provided growth chambers, greenhouse space and reprints. (An exception was a small grant that provided $US2500 summer stipend for a student.) The university provided small competitive grants for supplies and small equipment, as well as sabbaticals and funding to attend meetings. Two summers, when it was necessary to count the thousands of seedlings germinating from created wetland samples, I paid students out of pocket (This lack of extramural funding would not now be permissible, as the department expects faculty to obtain grants and involve students in summer research.)

Over the years, I taught introductory botany, both as a separate course and as part of an 'integrated' first-year sequence, field natural history (non-major), indoor gardening (non-major), life science – ecobotanical emphasis (non-major), marine botany, modern plant biology (mainly plant physiology) and plant physiology. There was also the occasional honours course, including, by odd circumstance, co-teaching a section of honours English. My favourites were botany and marine botany.

It has been a gift that I could do what I loved and be paid for doing it, and as I listen to world news, I am disheartened to think of counterparts in Kosovo, Baghdad and Liberia who are distracted by life-threatening situations and are unable to pursue their life's work.

For many of my 31 years at Rider, I was the only botanist. Collaborations with Dennis Whigham and Tom Parker when they were at Rider, as well as afterwards, were fruitful (e.g. Whigham *et al.*, 1979; Parker and Leck, 1985). Bob Simpson, who was at Rider until 1987, was trained as a limnologist, but knew plants well.

Other collaborations were also important. During the summer of 1972, I worked with Larry Tieszen, who had been a fellow graduate student at the University of Colorado, on translocation of ^{14}C-

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labelled photosynthate in *Dupontia fisheri* in the arctic tundra at Barrow, Alaska. While there, I collected soil cores from the tundra using the old golf cup cutter (Leck, 1980). More recently, there were joint ventures with Carol and Jerry Baskin, who provided data from their carefully orchestrated germination protocol (Baskin *et al*., 1994; Leck *et al*., 1994); with Margaret Brock, with whom I explored the evolution of wetland seeds and seed banks in person in Australia and via internet (Leck and Brock, 2000); and with Wolfgang Schütz, whom I met at the seed conference in Merida, Mexico and who added considerably to a discussion of sedge seed banks (Leck and Schütz, submitted). For 10 years Charlie Leck and I followed the revegetation/succession of an agricultural field (Leck and Leck, 1998). Remarkably, the collaboration that involved numerous authors, and resulted in *Ecology of soil seed banks*, which I co-edited with Tom Parker and Bob Simpson (Leck *et al*., 1989), is still being cited. In these and other associations, including many students, I have been truly blessed.

Although Rider did not have graduate students, I had the opportunity to serve as a member of graduate committees for students, for example, at Rutgers University, University of Pennsylvania, University of Maryland, New England University (Armidale, New South Wales, Australia) and Université Claude Bernard (Lyon, France). These, as well as seed symposia and meetings, were fun, provided intellectual stimulation and allowed me to meet similarly minded researchers.

So too, over the years I have had many opportunities to spend time in botanically interesting places – arctic and alpine tundra, tropical rainforests of Central and South America, the deserts of North and South America and Australia (the latter I traversed by train), the grasslands of North America and Africa, and the fragments of natural forests in New Zealand. In an ancient caldera in northern Mexico, isolated by geology and called Quatro Cienegas, I discovered a new-to-science marine isopod, while on a graduate student collecting trip for the University of Colorado Museum. This, of course, is merely a list without the associated memories of the people, including exceptional field botanists, plants, birds, food, archaeological ruins, as well as superb sunrises and sunsets. Initially, a camera helped show my family where I had been, then it became a way to illustrate lecture topics. Now the camera has become something of a frustration as I attempt to make film images and mental images align as I examine textures and patterns in nature and how light plays on water, flowers and, of course, seeds.

My decision to retire 3 years ago was, in large part, due to the need to get the created wetland research, a marsh plant species list and other research written up. I am involved in ongoing research as Rider's Biology Department continues to provide space and other support. 'Leisure' has provided the opportunity to consider an edited seedling ecology book that has been on the back burner for more than 10 years; the challenge of identifying seedlings led to an appreciation of their morphological and physiological diversity.

There are more questions waiting to be studied than can be accomplished in a single lifetime. What would I recommend to someone starting out? Find something that's interesting and worth doing, and have fun! There are opportunities to examine germination and seed-bank characteristics of little-known habitats, and of applying biotech approaches to understanding seed and seed-bank ecology. At another scale, the impact of anthropogenic stresses (e.g. sea-level rise, global warming, desertification, invasive species and nutrient enrichment) on germination, seed banks and thus plant communities would also provide interesting and challenging opportunities.

I admit to moments of doubt as I write this. That I have been asked to write a Personal View for *Seed Science Research*, causes me to shake my head in wonder, to be among those who have provided previous Views, even without a full research program! I am thankful for these splendid opportunities that have come my way.

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For the many satisfactions of my professional life, there are too many to acknowledge by name. I should like to mention, however, Charles F. Leck, whose idea of a Christmas gift is a seed quiz, a piece of cardboard on which are glued seeds of species from near and far, as well as obscure clues as to their identity. Thanks to all!

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