Journal of Nematology 44(2):107–114. 2012.

The Society of Nematologists at 50, and Where to from Here?

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Abstract: Nathan Cobb, as the father figure of the Society of Nematologists, set an example to later generations of nematologists in his studies of nematode biology. In the 50 years of the Society's existence nematological research has greatly expanded that knowledge base. Opportunities over the next 50 years are boundless in view of advancing technologies and emerging challenges, and this leads to speculation as to what future nematological research advances will enhance peoples' quality of life.
Key words: behavior, biocontrol, chemosensory, ecology, entomopathogenic nematodes, genomics, marine nematology, molecular technology, nematicides, non-tariff barriers, plant resistance, taxonomy, transgenic plants.

On the occasion of the Society's Golden Anniversary this paper is written as a personal reflection on some of the Society's challenges and achievements of the past, and a speculative look at where we might be going or may have to go, in the next half century.

At this point in time let us reflect first on what drew us into the microcosm of nematodal worms. There is beauty in our science, in the study of these microscopic worms! We are fascinated by them and we seek to understand them better, just as the Society's father-figure, Nathan Cobb, did. His drawings (Cobb, 1932), such as those in Fig.1, exemplify his powers of observation and extraordinary skill that reveals his understanding of these organisms. He crafted dozens of similar drawings, but there are few, if any of us, today that can produce drawings of such quality (with all due respect to the fine work of many of our esteemed colleagues). Why is this?

"We don't have the time," is a frequent response. However, I don't think that lack of time is the fundamental reason. The reason that we don't do this anymore is that times have changed, values have changed and we have new ways of providing most of the essential, discriminatory information necessary for nematode diagnosis. The techniques available to us, themselves based on innovation and experimentation, have changed. The value of that earlier, artistic form of discriminatory information in science has diminished in favour of other forms that are perceived to be less subjective, less labour intensive, and serve the same purpose more rapidly, as well or better than previously. Thus nematology, like every other science, changes its techniques and vision with time. Though, for me personally, bar codes and neighbour-joining phylogenetic trees do not convey quite the same elan, despite their elegance, as do those early drawings from Cobb.

As well as manifesting the excellence of his scientific endeavour Cobb's drawings demonstrate other facets of his character and *modus operandi*. In particular, his commitment to the science (as demonstrated by the quality and quantity of his work), his focus (he fully utilized his skills to give clarity and precision to aspects of nematode biology) and he had an objective (to communicate his scientific observations and to teach others about nematology). All of this was nearly 100 years ago. What have nematologists done since then, and in what way has the Society of Nematologists (SON) contributed in the past 50 years?

There have been many contributors to our nematological lore and we met many of them at the Golden Anniversary Meeting of SON in Corvallis in July, 2011. The quality of the science and the enthusiasm of our members at that meeting amply demonstrated our continued support of the Society. As we look back over the past half century of SON we are reminded of the proverb, "we stand on the shoulders of giants", and our Society's early Newsletters remind us of some of those giants (Figs 2a and b).

For 56 years, the Nematology Newsletter (it commenced publication before the Society itself was created) has been a tangible and valuable expression of the changing scientific interests and of the mood of the time among nematologists. The production of such a regular epistle that is informative, interesting and a pleasure to read is not an easy task to achieve, but the Editors (and there have been 19 of them to date) have each left their stamp of ideas and personality in the Newsletter, be it the hard copy or electronic version.

The Journal of Nematology (JON) came later, after long and tortuous debate among nematologists of the day. Finally, in 1969, eight years after founding of the Society, Seymour Van Gundy took the bull by the horns, as the first Editor-in-Chief, and ensured that the Society had its own journal, one that was distinctive within plant pathology, but distinct from the journal of the American Phytopathological Society. Over the intervening years its 14 Editors-in-Chief have aimed to produce a high quality, much-cited journal. This is a tough task for any journal editor, as we all know, but JON has been successful over the years. However, if measured by the size of the annual volumes, then its success has been "a roller coaster". This reflects many factors, both internal and external to the Society, not least of which has been the general angst of the time due to the vicissitudes of

Received for publication: October 1, 2011.
Department of Biological Sciences, Simon Fraser University, Burnaby, Vancouver, Canada V5A 1S6.
The author gratefully acknowledges discussions with and suggestions from colleagues and students and appreciates the financial support of the Natural Sciences and Engineering Research Council of Canada. Based on an invited paper presented at the Golden Anniversary Meeting of the Society of Nematologists.
This manuscript was edited by Nancy Kokalis-Burelle.

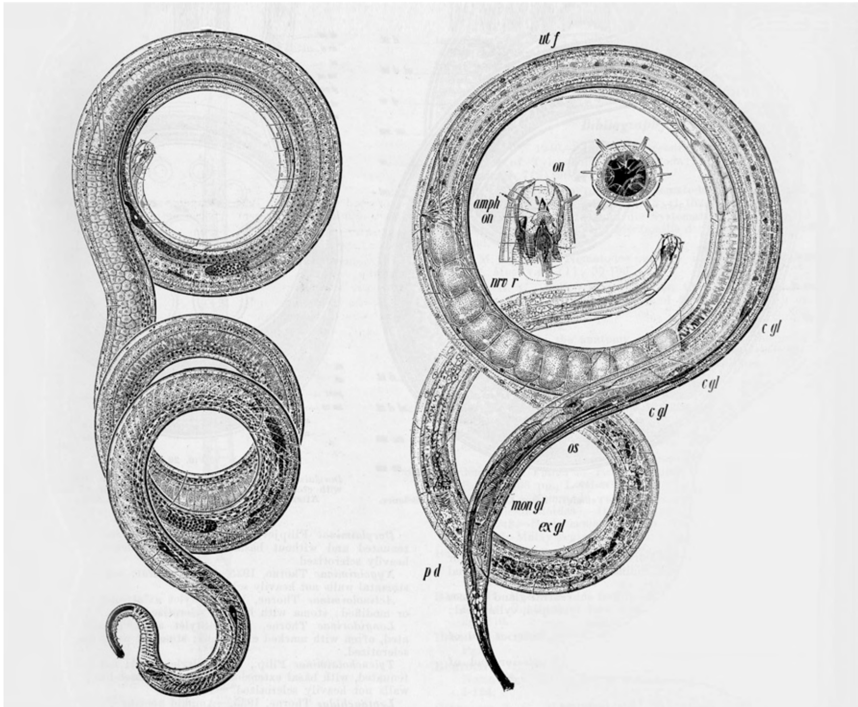


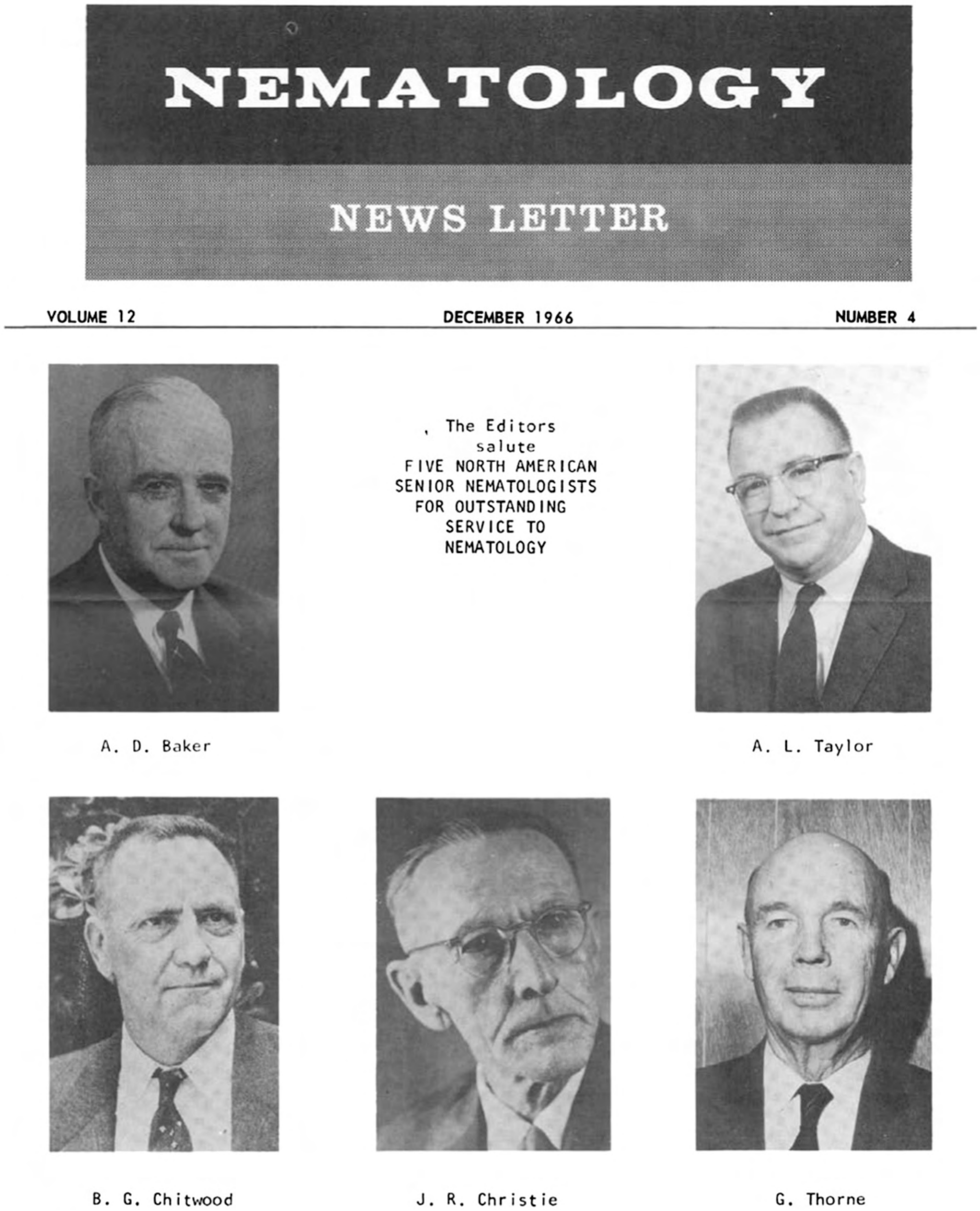
FIG. 1. *Metoncholaimus pristiurus*; male and female (after Cobb, 1932).

research funding and to the associated outcomes of socio-political gyrations.

The Society's other major form of communication between its members has been its Annual Meeting, held in cities across the USA and Canada and, since 1984, held every six years in cities around the world as part of a meeting of the International Federation of Nematological Societies. All have been fun, scientifically rewarding, a forum for information exchange and, as necessary, morale boosting.

The Society's membership, through its Executive Board, has worked hard to operate and achieve the role expected of a scientific society, which is, primarily, professional branding and communication. The prime aim of SON is to help give a distinct professional identity to those with the same collective purpose, namely that of studying the biology of nematodes and their impact. A professional society also plays a key role in communication among its members and between its members and the wider community. The Society has achieved its primary role through targeted communication via the Nematology Newsletter, Journal of Nematology and the Society's Annual Meetings. Nevertheless, there is a disturbing downside that can manifest itself, and Van Gundy alluded to this in his JON article (Van Gundy, 1980) entitled "Let's take off our blinders and broaden our horizons". In it, he describes the Society as being members of a friendly club that spends much of its time talking to itself. There is benefit in being able to discuss within and receive support from such a familial comfort zone as our own professional society. Nevertheless, the potential downside, especially during times of financial constraint, is an associated tendency of progressively diminishing interaction with scientists from other disciplines. Such a tunnel vision approach to scientific communication and research inhibits progress, and in the long run is crippling to the science and to the scientists' careers. Furthermore, these negative effects are visible to the wider community. In order to keep nematology strong and contemporary in both practice and outlook it is vital for nematologists to communicate with scientists in related disciplines, to broaden our horizons and to proactively seek out soil microbiologists and ecologists, plant physiologists and those in the *Caenorhabditis elegans* cohort. Bridging such areas of science stimulates and engenders ideas that help to provide solutions to problems.

Debate is the soul of a healthy society, so at this time of celebration let us reflect on where our science has taken us. Over the 50 year history of our Society there has been a huge expansion in our knowledge of nematode biology and, in SON, that is especially so for nematode parasites of plants and insects. We have tried to accomplish in 50 years what entomologists and other plant pathologists achieved in 100 years or more. The main thrust in each decade has, of course, been moulded by the application of new scientific breakthroughs and techniques, and by responding to growers and others in the wider community. Recognizing the lag phase between stimulus and response over the 50 years, one can summarize some of the prime changes in research direction as follows:


NEMATOLOGY

NEWS LETTER

VOLUME 12 DECEMBER 1966 NUMBER 4

The Editors salute FIVE NORTH AMERICAN SENIOR NEMATOLOGISTS FOR OUTSTANDING SERVICE TO NEMATOLOGY

A. D. Baker

A. L. Taylor

B. G. Chitwood

J. R. Christie

G. Thorne

FIG. 2A. Early "giants" of nematology in North America; as illustrated in the Nematology Newsletter of December, 1966.

1960-69: New nematicides; EM and SEM
1970-79: "Silent Spring" effect; breeding for resistance; IPM
1980-89: *C. elegans* projects; molecular technology; EPNs
1990-99: Transgenic plant technology; biocontrol
2000-09: Genome sequencing; rhizosphere interactions

The success of nematology in the 1950's and 1960's was manifest in the large increase in research personnel, the acquisition of new, well-equipped facilities and the development of many departments of nematology by governments and universities. This major expansion was driven by the knock-on effect of private sector investment into the development of nematicides during a period of relative food shortage and high prices. The significant, rapid increases in crop yields that resulted from nematicide applications spawned good public relations for nematology. Virtually all aspects of nematology benefitted from this momentum. Nematicides, in parallel with other chemical pesticides at that time, were the prime driver of nematology's multi-pronged, research momentum.

The publication of "Silent Spring" (Carson, 1962) was life-changing for the life sciences, even though Rachael Carson's statements were initially ridiculed by many scientists as being inaccurate sensationalism. Nevertheless, the seed of transmutation of environmental awareness

FIG. 2B. Further "giants" of nematology in the Nematology Newsletter of March, 1967.

had been sown, and a decade later the search for alternatives to chemical nematicides was well entrenched. Nematologists turned to plant breeding for nematode resistance and to various forms of crop rotation as their main response to the dilemma of controlling plant parasitic nematodes in soils that had been partially sterilized by the long-term, excess use of chemical nematicides. There were some significant successes in developing nematode resistant varieties of crops (Starr and Roberts, 2004). Unfortunately, the failure to develop resistant varieties for many of the major crops resulted in fewer significant yield successes and lower overall economic returns than was characteristic of the era of chemical nematicides (Roberts, 1992). Moreover, the ban on the use of chemical nematicides became increasingly pervasive with the passage of time. In turn, this resulted in diminished PR value for nematology with the growers, the public and the politicians. Not surprisingly, therefore, for many nematologists, the exuberance of a young and thriving discipline changed to one of frustration and concern.

A potential life-saver came from science itself as the life sciences received a shot-in-the-arm from the development of molecular biology. The availability of molecular techniques that emerged from the decades of research following the 1953 discovery of DNA promised to provide a vast array of research opportunities. A few nematologists studying the fine structure and developmental genetics of the free-living, soil nematode, *Caenorhabditis elegans*, rapidly incorporated the advantages provided by these molecular approaches and subsequently helped to advance the technology. This reminds us of the old adage;

"For an event, discovery or process to have value it has to blend into, respond to or advance the context in which it is happening."

Timing and context; crucial commentary also on research progress in nematology! By the 1980s, the biological sciences, including nematology, were once again on a role. Research in my own lab, as an example, resulted in Jon Curran publishing the first paper on the use of molecular diagnostics for nematodes (Curran et al., 1985). The life sciences as a whole are continuing the amazing ride of "molecular discovery" the likes of which we have not seen since the post-Darwinian days of the nineteenth century. Already, the advances in molecular biology and transgenic plant technology (Bird et al., 2005) have "opened the door" to a better understanding of host-parasite relationships (Atkinson et al., 2003) and to the enhanced development of nematode resistant plants (Simon et al., 2000; Niblack et al., 2006; Williamson and Kumar, 2006; Evans and Trudgill, 2008) and nematode diagnostics (Abad and Castagnone-Sereno, 2008). However, this is just the beginning, as through the application of functional genomics we learn of the precise function of genes, collectively and separately, in an array of metabolic pathways and processes. A sure measure that times are changing is that physicists and engineers are themselves proactively linking with researchers in the plant sciences, in evolution and in cell and molecular biology to develop new ideas and create whole new theories as well as practical applications. These collaborations are part of the rapidly changing scene of integration in science that, undoubtedly, will be central also to some of the excitement and solutions of tomorrow in nematology.

Despite the prevailing passion for molecular technology and for how its application can further our understanding in biology, and in nematology in particular, there are storms ahead. Huge challenges are emerging globally from a demographic, socio-political, financial and technological perspective. Concurrent with these are the emerging challenges of global changes in climate patterns, the diminishing availability of productive soils and oceans and of potable water, and serious questioning of the air quality for sustainable life. There is a growing public awareness of the limitations in the environment's ability to accommodate sufficiently rapidly to these changes in view of the increasing imposition of the negative aspects of an expanding human population that seeks an ever-higher quality of life. Some may consider that this is more of the daily, media, super-hype, and that we have nothing to fear because of the resilience of the earth's natural processes and the adaptability of its life forms. Nevertheless, mankind too does not respond rapidly to change, so we ourselves continue to be part of the problem.

Despite the dynamic pulsations of nationalism, democratization, revolution and introspection among the world's peoples, the power of immediate, worldwide communication and of the relative ease of global travel is resulting in progressive cultural mixing, hopefully cultural mutualism and certainly changes in dietary preferences. Agriculture, fisheries and forestry, therefore, will be strongly impacted by these many challenges and, consequently, the research opportunities in plant and insect nematology will be diverse and substantial.

As nematologists, we understand some of the mechanisms of how nematodes survive and thrive in our basic planetary substrates, namely the soils, rivers and oceans. In plant and insect nematology we are beginning to understand the multifaceted interactions of nematodes and their interdependency with and influence on bacteria and fungi and on plants and insects in the soil environment and of how nematode species and populations of species respond to changing environmental factors (Yeates et al., 1993; Yeates, 1999; Ruess et al., 2000). However, we have advanced less rapidly in research on the world's oceans, the other major source of our natural sustenance. Meanwhile, we observe mankind's dilettante approach to ocean pollution that is choking seaweed action in the carbon dioxide cycle, and admire the entrepreneurial, high-tech, hunting skills that over-fish to the point of fish population collapse. The Society of Nematologists has neglected this progressive demise of the vast, hidden depths of the oceans. Should we continue to ignore this major frontier that holds untold thousands of species of nematodes?

Nematodes are a dominant group in the meiobenthos, but their processes and contribution to the planet's environmental equilibrium have been disregarded by all, except for a few specialists. The recent report (Rogers and Laffoley, 2011) by the United Nations International Program on the State of the Oceans has brought into focus the realities of these threats to the marine environment by describing it as a "catastrophe unprecedented in human history." Should the Society of Nematology expand from its almost exclusive focus on plant and insect nematology and nurture the growth of research in marine nematology in this, the last, of our great natural food sources?
Food for thought for the future!

What of the next 50 years in nematology?

Collectively, we may have ideas of what this time capsule will deliver in nematology, though some persons of distinction maintain that speculation and prediction is superfluous.

Take the view of Niccolo Machiavelli; the 15th century Florentine philosopher and politician:

"Whoever wishes to foresee the future must consult the past; for human events ever resemble those of preceding times. This arises from the fact that they are preceded by men who ever have been, and ever shall be, animated by the same passions and thus they necessarily have the same results."

Or the view of one of our distinguished 21st century nematological colleagues, Ernie Bernard:

"Predicting the course of a science over the next 50 years is a hopelessly risky business, and is more likely to produce laughter at the 2061 meetings of the nematological societies than acknowledgement of a (by then very old) nematologist's gift of prophecy."

Predicting the future may be a fool's game, but based on current trends some clear avenues are apparent as regards diseases caused by plant parasitic nematodes, especially if one considers the demands that will be made on agricultural technology to provide adequate nutrition for the projected 9 billion inhabitants, by 2061. Hence, the new growth driver for nematology will be to provide more food, fiber and energy more efficiently and from less land by mitigating nematode disease losses and by deriving value from nematodes.

Agricultural innovation in diverse ways can be expected as the world's problems and the innovations to overcome them are addressed globally rather than locally. We can expect, over the next 50 years, that there will be an increased emphasis on producing crops that use less fertilizer and chemical pesticides and less acreage of soil (Melakeberhan, 2002, 2004) Concurrent with this, the growing of high yielding, transgenic crops will become progressively more acceptable to the public, and under the guidance of approved, updated regulatory processes, the number of embarrassingly corrupt, international non-tariff barriers will diminish. These changes will require intensive interdisciplinary collaboration among scientists, including nematologists, and extensive discussions with regulators and politicians.

Greater emphasis on the development of nematode resistant crop varieties through the deployment of molecular and transgenic techniques will become a priority for the production of staple food crops (Starr and Roberts, 2004). The ground-breaking advances provided by combining transgenic plant technology and gene silencing through RNA*i* (Fire et al., 1998) has enabled the silencing of parasitism genes that encode some of the key enzymes in the esophageal secretions of root-knot nematodes (Huang et al., 2006b). I refer to the fundamental, or should I say basic, research on nematode spit, no less, by spitologist, Dick Hussey and colleagues (Gao et al., 2003; Huang et al., 2003; Baum et al., 2007; Davis et al., 2008). These discoveries of the precise genes that need to be blocked will speed the development of resistant varieties for root-knot disease control. These discoveries also may have " opened the door" to the modulation of a whole range of plant functions as we now know (Huang et al., 2006a) some of the effector proteins in the esophageal gland cell secretions that trigger particular plant genes to induce rapidly metabolizing giant cells. In and of itself this could lead to a whole new level of synthetic agriculture to help satisfy the burgeoning global food requirements. This discovery, once deployed, has the potential to not only decrease crop losses due to nematodes, but may be the embryo for developing alternative, photosynthetic, plant product through the mass culture of genetically engineered, fast-metabolizing, "monster" giant cells containing chloroplasts. Such *in vitro* agriculture, once developed, for specific nutrients or fiber would have the great advantage of programmed production, being free of ambient diseases, potentially less environmentally harmful and of providing an enhanced, stable, global food supply adjustable to market change.

The rapid diagnosis of nematodes (Powers et al., 2001) to the species and sub-specific level is virtually upon us, and molecular advances will soon enable accurate, on-the-spot identification of single species by quarantine authorities and the determination of single species density in mixed, soil nematode populations. Such developments are becoming increasingly necessary in the face of changing agricultural practices and increasing global travel and trade (Webster, 2004b).

Mycorrhizal and rhizosphere studies of the associated microflora, herbivorous insects and nematodes point to the development of another route of improving plant growth and yield (Hallman and Sikora, 1996; Neipp and Becker, 1999; Borneman and Becker, 2007). Such studies could give rise to the growth of crops from seed strategically coated with bacteria and fungi as pesticides that suppress nematode activity and enhance plant growth. A subsequent generation of seed coated pesticides could be multi-layered and activated by transgenic-plant controlled auxin triggers. Such a development would provide on-site, pin-point pest control of root diseases adjusted to the stage of plant development and to the specific disease or insect/nematode herbivore.

Research to date has demonstrated the high level of sensitivity of the nematode's chemosensory system to substances released by a potential host or mate (Riga et al., 1992; Perry and Maule, 2004). Following further behavioral and neurological research it will become possible to introduce into the soil sex pheromones (for amphimictic species) and species-specific pheromones (for hermaphroditic species) to confuse or prevent the mating of nematodes (Riga, 2008). Alternatively, transgenic crop plants will be developed carrying genes that enable the slow release of narrowly-targeted, semiochemicals that confuse or repel the target nematode species or inhibit mate finding, development or reproduction. This development in agriculture will likely parallel the development of a new era of social drug development among human populations based on the controlled use of enhanced, targeted erotic-perfume cosmetics.

Microbivorous nematodes have a significant effect on plant nutrient cycling by regulating the component populations of the microflora in the soil (Yeates et al., 2009). Future research can be expected to result in the number and activity of key soil nematode species being modulated, depending on the prevailing soil conditions, by the in-row planting of gas sensitive, transgenic plant engineered control systems. By integrating the advances (Benjamins and Scheres, 2008) in functional genomics with transgenic plant technology and intelligent control systems it will become possible to optimize the balance of different microbivorous nematode populations so as to increase crop yield through managed optimized nitrate, ammonia and carbon dioxide cycles. Moreover, this could be adjusted for different climates, soils and synthetic substrates according to crop scheduling in successive growing seasons.

The use of entomopathogenic nematodes (EPNs) in the biological control of insect pests will expand its target range of insect pest species as genetic selection to improve nematode search behavior are developed (Kaya and Koppenhoffer, 2004). A much expanded EPN research endeavor (Ehlers and Shapiro-Ilan, 2005) will lead to enhanced nematode host-finding abilities, increased shelf-life and an ability to optimize the conditions for nematode-bacteria mass culture. Innovative production and application technology will result in EPNs becoming the preferred biocontrol agent against a wide range of insect pests in different climatic zones.

As it is already possible to mass culture many tons of EPNs for use in biological control, it should soon be possible, given improved methodologies, to produce even larger quantities of nematodes of differing species and flavors for processing into high value, proteinaceous food supplements or gourmet fast-foods (Webster, 2004a). Perhaps it will not be long before we can purchase a bowl of NemaTofu for a tasty lunch, and then wash it down with a glass of ice-cold NemaCola!

One of the greatest challenges that both nematodes and humans are already facing, and will do so increasingly over the next 50 years, is the availability of adequate water. Greater efficiency in water usage in agriculture will become mandatory in many parts of the world and this will require the integration of different nematode management programs. Many nematode species have ways of modifying their metabolism to accommodate the problem of dry or environmentally unsatisfactory conditions (Wharton 1995; Wharton and Alders, 1999). Fourth stage larvae of *Ditylenchus dipsaci* survive in the anhydrobiotic, "eelworm wool" stage, for over 20 years. Can we benefit from a better understanding of this phenomenon and so utilize some of these nematode attributes? A long-term, decreased metabolic activity, if applicable to humans, could have value in managing life during drought conditions or for the development of low temperature medical procedures, in facilitating more restful, long-distance space travel and in helping to survive the aftermath of cataclysmic meteor strikes of the Earth.

Nematodes can feed and reproduce at zero gravity in outer space (Johnsen and Baillie, 2008), and one can but speculate as to whether further research and development of this phenomenon could benefit mankind during the course of the next 50 years. There may well be opportunities here for the medical enhancement of fertility and for specific, high-sensitive brain surgery or, once protection from space radiation can be assured, for vacationing in space moonshine to enjoy the delights of deep, muscle-relaxing massage spas. Remarkably, *C. elegans* survived the Columbia spaceship disaster with a survival impact of 2,295 times the force of the Earth's gravity (Johnsen and Baillie, 2008); a "very exciting result," stated NASA, in spite of the unfortunate connotations of the day. Will this extraordinary result contribute to yet another intriguing advance and application of mankind's ingenuity?

There is so much to do in nematology, and so much that can now be achieved, with a focus on excellence and commitment.

> "There is a tide in the affairs of men,
> Which taken at the flood, leads on to fortune
> Omitted, all the voyage of their life
> Is bound in shallows and in miseries.
> On such a full sea are we now afloat,
> And we must take the current when it serves,
> Or lose our ventures."
> (from William Shakespeare's Julius Caesar)

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