THE BRODIE CLUB

Established 1921

Website: http://thebrodieclub.eeb.utoronto.ca

THE 1,098th MEETING OF THE BRODIE CLUB

The 1,098th meeting of the Brodie Club was held on Tuesday, 17 January, 2017 in Room 432 of the Ramsay Wright Laboratories of the University of Toronto.

Chair: Glenn Coady
Secretary: Ed Addison

The meeting was called to order at 7:37 pm and was attended by 29; 18 members and 11 guests.

Roll Call:

Present: E. Addison, Bertin, Bryant, Carley, Coady, Daniels, Dengler, Dunn, Eadie, A. Falls, B. Falls, Hussell, Iron, Martyn, Peck, Pittaway, T. Rising, Thorpe.

Guests: Ron Dengler (guest of Nancy Dengler), Bev Thorpe (Ron Thorpe), Dominic Stone and Bob Kortright (Bryant), and guests of the club: Rowan Sage, Tammy Sage, Emma Walker, Patrick Moldowan, Roxana Khoshravesh, Stefanie Sultmanis, Vanessa Nielsen.

Regrets: Abraham, R. Addison, Crins, Curry, King, Lindsay, Machin, McAndrews, Obbard, Peter, Rapley, Reading, Riley, J. Rising, Seymour, Slessor, Speakman, Sutherland.

Minutes: Minutes of the 1097th meeting were approved as presented (T. Rising-E. Dunn).

Committee Reports:

<u>1100th Meeting</u>

George Bryant reported that the committee met to fine-tune the agenda. The evening promises to be memorable. The cut-off for registration will be March 1. Additional guests are more than welcome. Members will be sent a final email one week prior to confirm their registrations and meal choices.

<u>Program Committee</u>

The speaker at the February meeting will be Dr. Becky Raboy, a professor in the Department of Ecology and Evolutionary Biology at University of Toronto. Becky's topic will be "Lion tamarins, small-bodied primates of South America".

Announcements:

Ricky Dunn announced that Bruce Falls recently had been appointed a member of the Order of Canada. On behalf of the Club, Ricky congratulated Bruce and presented him with a copy of "Fifty Years of Honouring Canadians: The Order of Canada, 1967-2017" written by Christopher McCreery. Ricky noted that Club members John Speakman and Harry Lumsden were also Members of the Order of Canada and that Ron Tasker is an Officer of the Order of Canada.

SPEAKER: Bruce Falls introduced Club member Nancy Dengler. Nancy completed her university education at the University of California in Santa Barbara (B.SC.) and Davis (M.Sc. and Ph.D). Nancy joined the faculty of the Department of Botany at University of Toronto in 1968, retired in 2005 and is now Professor Emeritus in Ecology & Evolutionary Biology and Cell & Systems Biology). Nancy's presentation was entitled "**Inside C4 Photosyntheis: Leaf Evolution and Development**".

Photosynthesis is a building block of all terrestrial life, the source of all oxygen (O_2) we breathe. The photosynthetic biochemical process itself has evolved over time.
Not all photosynthetic processes present today are the same. The most common form of photosynthesis which fixes 3 carbon atoms at a time is referred to as C3 photosynthesis. Another form, C4, can fix 4 carbon atoms at a time. The talk was centred around differences in the biochemistry between the forms of photosynthesis, why, when and where did C4 photosynthesis evolve and what differences in leaf internal anatomy are there between the types of photosynthesis.

Enzymes are required for all of these processes and the most common enzyme involved and indeed the most common protein on the planet has the acronym RuBisCO. RuBisCO binds a molecule of carbon dioxide (CO_2) to a molecule with 5 atoms of carbon with the product being two stable molecules each with 3 carbon atoms. This fixation is what leads to atmospheric CO_2 being converted to energy-rich molecules such as sugars. RuBisCO functions differently under differing conditions. At low temperatures and with a high CO_2: O_2 ratio RuBisCO facilitates the production of the two stable molecules each with three carbons (photosynthesis). However, at high temperatures and low CO_2: O_2 RuBisCO combines with O_2 instead of CO_2 and results in fixation of less carbon (photorespiration, or C_2 photosynthesis).

C_4 evolved to overcome inefficiencies arising, particularly in hot dry environments, when C3 may fix only 2 carbons. Plants with C_4 photosynthesis have higher productivity (growth rates up to 50% higher), greater efficiency in use of water, and more efficient use of nitrogen. RuBisCO is involved in both C3 photosynthesis and C4 photosynthesis, the difference being that in C3 plants RuBisCO occurs in all photosynthetic cells (two types of photosynthetic cells- mesophyll cells and bundle sheath cells) whereas in C4 plants RuBisCO occurs only in bundle sheath cells.

The higher water use efficiency in C4 plants is accomplished because CO_2 is absorbed when the stomata of the leaves are open (just as with C3 plants), is converted into and stored as an acid and from which the carbon can be retrieved and photosynthesis can continue during the hotter drier parts of the day when the stomata are closed. When the stomata close in C3 plants, the CO_2 concentration drops and there is less C3 photosynthesis and RuBisCO instead enters into C2 fixing photorespiration.

Of the approximate 250,000 species of flowering plants, about 8,000 (3%) are established as employing C_4 photosynthesis. C_4 plants dominate all grassland and savannah plant communities in the tropics, sub-tropics and warm weather temperate zones for reasons outlined above. However, through the use of genetic phylogeny techniques what is most fascinating is that evolution of C_4 photosynthesis did not evolve in a single line of plants and then radiate out from there but instead has been estimated to have more than 60 independent evolutionary origins. This area has been studied by Rowan Sage, EEB professor, colleague of Nancy's and present at the meeting. Rowan has referred to this as one of the best known examples of evolutionary convergence yet documented! Some of the C4 species are: productive crops such as sugar cane, sorghum, pearl millet and maize but include some of the worst weeds such as crab grass, barnyard grass, purple nut sedge, Russian thistle and pigweed!

What anatomical features differentiate C4 species from species lacking C4 photosynthesis? Nancy and her students and colleagues have done much research addressing this question. C4 species have specialization of the mesophyll (M) cells and bundle sheath (BS) photosynthesizing cells, have closer contact between the M and BS cells within the leaf and the leaves have closer spacing of veins. At a more specific level, they have been able to establish predictable differences in the cell anatomy and position within the leaves of grasses depending on which of three different enzymes are involved in the decarboxylation steps of the biochemical processes. In other words, the evolution of the leaf anatomy and the chemistry of photosynthesis have presumably occurred in association with one another. Reduction in proximity of intercellular air spaces (which allow for escape of concentrated CO_2) to the BS cells are also a predictable characteristic of leaf microanatomy in C4 plants. Later more detailed studies with species of *Flaveria* (see below) were suggestive that anatomical changes conducive to C4 photosynthesis preceded full C4 photosynthetic biochemistry.

When did C4 photosynthesis begin? RuBisCO which facilitates both C3 and C4 photosynthesis appeared more than 3 billion years ago. Forty million years ago the atmosphere was warm, moist and high in CO_2 concentration . As more arid environments and lower CO_2 concentration appeared, selection led to evolution of processes whereby photosynthesis could continue when stomata were closed. Grasslands rapidly expanded 10-15 million years ago. Evidence of evolution of C4 plants is derived using a variety of techniques from plant fossils and the estimate is that C4 photosynthesis in plants started evolving 10-15 million years ago.

However, as might be expected in evolution, there would be intermediate steps. These have been elucidated by studying species of *Flaveria,* a genus of the aster family. Focus of the work was on establishing if both C4 leaf anatomy and C4 biochemistry evolved in a stepwise manner and secondly, if there had been some 'pre-adaptation' of C3 species, facilitating the added acquisition of C4 photosynthesis.

DNA sequencing and leaf anatomical studies were conducted on 21 species of *Flaveria*. There were phyologenetic affinities among species of *Flaveria* that were clearly ancestral in having C3 photosynthesis, there were two phylogeneic groups with clear evidence of C3 and C4 origins, and others reflecting only C4-like and C4 characteristics. Thus, within the one genus there was a spectrum of states of evolution of the photosynthetic process. Anatomically there was evidence of thinner leaves, decreased M cells, increased BS cells, differences in BS cell shape and increased vein density along the continuum from C3 to C4 *Flaveria* species.

It was definitely exciting to learn of these interrelated anatomical and biochemical evolutionary results as influenced by the evolution of climates and ecosystems on Earth.

Questions following the presentation:

Dunn: There are advantages to being C4 plants, including higher productivity, but C4 hasn't taken over the world. That suggests there are downsides. What might they be?

The advantage of the C4 adaptation is its efficiency in hot dry climates. That disadvantage is lost compared to C3 plants in the cooler climates of high elevations and climates in the north and south of the planet. C4 plants do not tolerate shade at all well and they cannot become trees, therefore cannot compete for canopy sunlight with species that are trees. Rowan Sage noted that some researchers think with enough time C4 might indeed have become dominant, but with increased CO_2 induced by humans, that window of opportunity may be closing.

Daniels: Are succulent plants with thick leaves in the tropics all C3 plants due to the leaf thickness?
There are some C4 tropical succulent plants. They open their stomata at night, absorb and capture the CO_2 and use the carbon during the day. Some ferns have this daylight adaptation to carry on some C4 photosynthesis during the day.

Coady: Are taxonomists looking for another form of photosynthesis, e.g. C5?
C3 appeared 3-4 billion years ago and now we have C4. Photosynthesis offers a bridge from C3 for C4 being able to capture an additional carbon. There is some evidence of structural possibilities but the physiological opportunities do not seem to be there.

Daniels: Is creosote bush a C4 plant?
No, a C3.

T. Rising: Are there places so hot that if C4 plants did not evolve, there would be no vegetation?
Yes, probably (Rowan Sage). Some places no plants can live because there is no water.

B. Falls: How do C3 vs. C4 plants contribute to bioenergy fuels.
C4 plants make the best bioenergy plants.

Ron Thorpe thanked the speaker.

OBSERVATIONS

Dunn: Canada Geese are already setting up territories in her yard in Simcoe.

Bryant: Red-tailed Hawks are also pairing off.

Patrick Moldowan: There is a posting on the Ontario Environmental Registry relating to harvest of snapping turtles and bullfrogs. Comments to the posting are encouraged since snapping turtles cannot sustain high mortality.

Iron: Ontario Nature has also profiled this posting.

NEXT MEETING

The next meeting will be on 21 February 2017. Dr. Becky Raboy will speak on “Lion tamarins, small-bodied primates of South America”.

The meeting was adjourned at 9:14 pm.

CORRESPONDENCE

The Membership Committee received an application for membership from Patrick Moldowan. His application has been welcomed and approved by the committee, and they have forwarded Patrick's biography for inclusion in these minutes.

PROPOSED NEW MEMBERS

Patrick David Moldowan

Born: St. Catharines, Ontario, 1990.
Brodie Club Membership: 2017 (pending approval).
Interests: natural history, herpetology, evolutionary ecology, biogeography, and conservation science.

Education and work history:
Doctoral student, Department of Ecology and Evolutionary Biology and School of the Environment, University of Toronto (2016-present)
Thesis: Population ecology and sensitivity to environmental change of the Spotted Salamander, *Ambystoma maculatum* (Supervisor: Njal Rollinson)

Durrell Post-Graduate Diploma in Endangered Species Recovery, with distinction, University of Kent, Canterbury, England (2015)
Pilot Project: Population monitoring and putative biocontrol of the invasive Giant African Land Snail (*Achatina* spp.) on Île aux Aigrettes, Mauritius (Supervisor: Nik Cole)

Master of Science, Biology, Laurentian University, Sudbury, Canada (2012-2014)
Thesis: Sexual dimorphism and alternative reproductive tactics in the Midland Painted Turtle, *Chrysemys picta marginata* (Supervisor: Jacqueline D Litzgus)

Bachelor of Science, Honours with distinction, Wildlife Biology, University of Guelph, Guelph, Canada (2008-2012)
Thesis: Influence of genome size on call structure of anurans (Supervisors: T. Ryan Gregory and Thomas D. Nudds)

From 2009-present, I have been involved with long-term studies on turtles and salamanders in Algonquin Park.

Key influences:
Mentors: Ronald J. Brooks (Professor Emeritus, University of Guelph) for sharing his passion for evolution, chelonian biology, conservation, and Algonquin Wildlife Research Station history; Jacqueline D. Litzgus (Professor, Laurentian University) for open-minded academic and life advising and encouragement; Glenn J. Tattersall (Professor, Brock University) for introducing me to field biology.

Formative experiences: The Algonquin Wildlife Research Station (2009-present) has provided inspiration, research questions, and countless opportunities that have formed my life's direction. Volunteer research experience in Peru (2009) was instrumental in cementing my love for biological field research. Being awarded Wildlife Preservation Canada's "New Noah" scholarship (2015) to study abroad and conduct applied conservation research in Mauritius provided an influential educational experience.