A Decade of Starry Stonewort in Michigan

G. Douglas Pullman and Gary Crawford

Observations and Operational Management Considerations – 1999 to 2009

Introduction

Starry stonewort (*Nitellopsis obtusa* [Desv.] J.Grove) is considered an exotic charoid species in North America. It has reportedly been present in Lake St. Clair since 1986 (Schloesser 1986). In stark contrast to other invasive species such as the zebra mussel, starry stonewort has apparently taken nearly 30 years to become conspicuous in Michigan inland lakes. Anecdotal observations suggest that it may have been present in several southeastern Michigan lakes as early as 1999, but was thought to be a "super weedy chara." Reflection also suggests that it may have been present in some lakes where fluridone had been used to manage milfoil populations and where successful milfoil control resulted in a "chara" bloom. Unfortunately, samples were not preserved from any of these lakes. Starry stonewort was first positively identified on February 6, 2006 by G. Douglas Pullman in Lobdell Lake, Genesee County, Michigan. Since that time it has been found in Michigan lakes in the Lower Peninsula, ranging from Mason County to Wayne County. It is probably present in nearly every county in the Michigan Lower Peninsula, although this is still conjecture. The invasion and growth of stonewort has been observed in the Michigan lakes listed in Table 1.

Identification

The starry rhizoids are definitive for identification of starry stonewort (Figure 1). They have been observed on all parts of the plant at all times of the year in Michigan Lakes, but are particularly common on the plant parts that are closest to the sediments in the late fall and early spring (Figure 2). It also produces conspicuous, orange-colored oocytes that are easily detected by the naked eye (Figure 3). Starry stonewort is a light green color when it is actively growing, compared to other charoid species in Michigan. It is like Nitella where the stem-like thallus is comprised of a single cell. If the thallus is broken, the cellular contents can be easily expressed from the cell and leave a translucent "tube-like" cell wall. Compared to other charoid algae in Michigan, the branching pattern of starry stonewort is more irregular giving the plant a characteristic "disheveled" look.

Unlike other Michigan charoid algae, starry stonewort can grow to remarkable heights and depths. This characteristic can also aid in identification. It has been observed growing 2 meters (7') tall at 9 m (29') water depth in Williams Lake, Oakland County. Starry stonewort forms dense mats of vegetation that completely cover the lake bottom. When it becomes dense and overcomes most of the other vegetation in an area, it is said to "pillow" or form irregularly spaced "pillows" of dense vegetation of various heights rather than a mat of uniform height. When the growth slows or the plants decline (usually in the summer) circular openings may appear in the dense pillowed mats imparting a "Swiss cheese" pattern in the pillowed mats.

Most charoid algae have a musky or garlic odor. This odor is not nearly as pronounced in starry stonewort. However, caution must be taken here because some chara species appear to be capable of co-mingling in the dense starry stonewort mats and may contribute more odors to samples that contain both plants.

Starry Stonewort Terminology

A new terminology has been developed and used by investigators and herbicide applicators in Michigan to describe the growth and development of starry stonewort communities. These terms have been useful to facilitate better communications between observers and aquatic plant control practitioners and may be found useful by others. "Pillowed" is a term used to describe the stage where starry stonewort covers nearly all of the sediments in an area and forms irregular, undulating "pillows" of biomass (Figure 4). This stage forms and persists into ultimate stage of starry stonewort invasion, which is referred to as "packing."

The term "packing" refers to a starry stonewort population that has filled all available habitats and has moved upslope and downslope into areas that do not appear to be ideal but still adequate for its growth. The term "cheesy" is used to describe starry stonewort when it appears to be dormant or is in decline. Holes open in the starry stonewort mats that resemble the hole pattern in Swiss cheese. "Hair cut treatments" is a term used to refer to algaecide treatments that reduce the height of the starry stonewort mats without eliminating all starry stonewort biomass in a treatment area. The reasons that this is used are described below.

Biology

Starry stonewort is thought to be native to Europe and is classified as endangered in the U.K. The U.K. Biodiversity Action Plan (available at www.ukbap.org.uk/UKPlans.aspx?ID=474) describes starry stonewort

Table 1. A List of Michigan Lakes Where the Authors Have Observed Starry Stonewort.						
			*Occurrence as Observed in the Maximum Number of BOS**			
Lake Name	*County*	*Date of First Observation*	*2006*	*2007*	*2008*	*2009*
Lobdell Lake	Genesee and Livingston	February, 2006	88%	97%	92%	
Indianwood	Oakland	July, 2006		93%	100%	100%
Sears	Oakland	July, 2006	n/a	n/a	n/a	n/a
Softwater	Oakland	July, 2006	n/a	n/a	n/a	n/a
Lower Straits	Oakland	June, 2006	n/d	n/d	11%	
Pleiness	Mason	June, 2006	n/a	n/a	n/a	n/a
Sears	Oakland	June, 2006	n/a	n/a	n/a	n/a
Whitmore	Livingston and Washtenaw	June, 2006	7%	40%	26%	18%
Williams	Oakland	June, 2006	70%	68%	78%	
Cedar	Alcona and Oscoda	June, 2007	n/d	65%	33%	0%
Iron	Washtenaw	June, 2007	n/a	n/a	n/a	n/a
Joslin	Washtenaw	June, 2007		n/a	n/a	27%
Kent	Oakland	June, 2007	n/d	4%	35%	50%
North	Washtenaw	June, 2007	n/a	n/a	n/a	n/a
Ogemaw	Ogemaw	June, 2007	n/d	74%	10%	3%
Sanford	Midland	June, 2007	n/a	n/a	11%	0%
Waumegah	Oakland	June, 2007	n/a	n/a	n/a	n/a
Millecoquin	Mackinac	August, 2007	n/a	n/a	n/a	n/a
Bass	Mason	June, 2008	n/d	n/d	6%	0%
Stony	Macomb	June, 2008	n/d	n/d	23%	5%
Tipsico	Oakland	June, 2008	n/d	n/d	53%	
Wamplers	Lenawee	June, 2008	n/a	n/a	n/a	n/a
Big	Oakland	May, 2006	n/d	n/d	47%	
Tamarack	Montcalm	October, 2006	n/a	65%	72%	1%
Townline	Montcalm	October, 2007	n/d	n/d	87%	
White	Oakland	September, 2007		n/a	75%	67%

*Maximum number of biological observation sites (BOS) is represented as a percentage of the total number of biological observations sites at each lake where starry stonewort was observed.

Figure 1. Starry stonewort – Nitellopsis Obtusa.

Figure 2. Star-shaped rhizoids are definitive for identification.

Figure 3. Orange-colored oocytes are female gametocytes from which an egg develops.

Figure 4. Dense pillow of starry stonewort.

as a plant that prefers deeper, less turbulent water, and as becoming increasingly rare. The starry stonewort observed in Michigan lakes also appears to thrive in deeper water, but will also thrive in shallow water where it will grow at the water surface. It does not appear to grow well in boat lanes and high-energy shorelines. It will; however, grow in boat lanes when it has colonized or filled virtually all of the habitable area of the lake. It grows well in a wide range of Michigan Lake types including clearwater and dark water systems. It will colonize highly organic, unconsolidated sediments and sands and gravel. It seemingly shows no preference for shade or full sun. The lakes from which these observations were made are not routinely monitored for water hardness, but are typical hard-water Michigan lakes where calcium carbonate alkalinity ranges from 110 to 190 mg/L as $CaCO_3$. Total phosphorus concentrations in infested lakes run from below 10 ppb to 80 ppb (Tipsico Lake, Oakland County).

The U.K. Biodiversity Action Plan (www.ukbap.org.uk/UKPlans.aspx?ID=474) describes starry stonewort as an annual plant that may overwinter in mild winters. Contrastingly, the starry stonewort in Michigan appears to thrive in the cooler waters of fall, winter, and spring, and becomes dormant or less active during the hottest part of the summer. However, extremely active, nuisance-level production and growth has been observed in Indianwood (2007 and 2008), Lower Straits (2008), Sears (2008), and Williams (2006, 2007, and 2008) lakes during the hot summer months.

It is common to observe the collapse or regression of opportunistic, non-endemic aquatic macrophyte species in Michigan Lakes. Collapse and regression also appear to be part of the production patterns observed in starry stonewort. For unknown reasons, starry stonewort was observed growing aggressively in many Michigan inland lakes in the early summer of 2009 (e.g., Indianwood, parts of Lobdell Lake); however, it appeared to be dormant in others (e.g., Whitmore). Conditions were cool all summer in 2009 and rapid growth was anticipated; but, highly invasive growth did not occur in many lakes until October. Starry stonewort appears to be so sensitive to aquatic pesticides that some of the lower production levels observed in 2009 may have related to plant control efforts that were specifically focused on herbicide tolerant nuisance plant populations where potent mixtures of herbicides were necessary to achieve adequate control.

Starry stonewort spreads rapidly from lake to lake. It produces oocytes, as do other charoid algae, and these structures are transported easily on bird feathers or the fur of aquatic animals. They could also be easily transported in aquatic plant debris caught on boat trailers. Often, the presence of public launch sites is associated with the early invasion of alien aquatic plants; however, starry stonewort has quickly become established in many lakes that have no public access. The role of waterfowl in the dissemination of starry stonewort could be very significant.

Starry stonewort is also easily fragmented and these fragments could seemingly act as disseminules that could be important in the spread of the plant within a lake and from lake to lake. Boat traffic can cause significant fragmentation of starry stonewort that can float on the water surface and create nuisance conditions on leeward shorelines. This type of fragmentation has been implicated in the dissemination of other alien species in Michigan such as the invasive milfoils (Eurasian and hybrids).

Plant Community Interactions

Starry stonewort invaded the nearshore areas of Michigan lakes at water depths ranging from approximately 0.5m to 1.5m (2' to 4') deep and then spread downslope and upslope from that point in the lake. This seems to be the typical invasion pattern, but it may have colonized deeper areas of lakes and not been observed. It is the most aggressive aquatic plant ever observed in Michigan and is able to out-compete all other Michigan plant species, including all invasive species and current alien species such as Eurasian watermilfoil, fanwort, and curly leaf pondweed. A precipitous decline in biodiversity index values was expected in lakes where presence and absence data, density, and distribution patterns were subjected to the LakeScan™ lake analysis tools developed by the authors, but this has not always been observed. It is not uncommon to see a single errant plant of competing species, growing in the depressions between the pillowed patches of starry stonewort biomass. It is obvious in all of the infested lakes that the biomass of competing species has declined significantly where starry stonewort has spread and come to dominate the lake flora. This would certainly have been reflected in biomass estimates, however, these values were not compiled for any of the lakes upon which these observations have been made.

It appears that starry stonewort can act like a commercial benthic barrier that contributes to the accumulation of phytotoxins, such as volatile fatty acids (VFAs), and render the sediments inhospitable for plant growth until the conditions change, redox potentials increase, and VFAs are oxidized or diffuse from the sediments. There would be certain obvious benefits to the rootless starry stonewort when redox potentials are suppressed and nutrients are released from the sediments.

Interestingly, certain plant species seem to thrive in the presence of starry stonewort. The apparent benthic barrier impacts on sediment chemistry may be the reason that the rootless bladderworts and coontail can thrive in starry stonewort infested lakes. These plants would not have to cope with low redox concentrations and associated bio-geochemical factors that would sour the rhizosphere; but they may still benefit from the release of nutrients from the sediments. Common bladderwort (*Utricularia vulgaris*), reached near nuisance levels in Indianwood Lake in 2008 and 2009 in the presence of starry stonewort. Water lilies seem to be able to compete effectively or are not apparently diminished by starry stonewort until the starry stonewort occupies the water surface The visual impact of starry stonewort and the influence on the submersed flora of Michigan lakes cannot be understated. But these impacts are not confined to the macroflora. Starry stonewort also appears to have a direct and indirect impact on water clarity. The water clarity in lakes infested with starry stonewort appears to increase with increasing domination of the benthic community. Indirectly, starry stonewort can be a favored substrate for zebra mussels, and the filtering impact of zebra mussels and their affect on water clarity is well known. It is also possible that the upper parts of the dense plant mats compete effectively with phytoplankton for nutrient resources. And, there is speculation that charoid algae are capable of producing allelopathic compounds (Mulderij et al. 2007).

Critical Fish Habitat Impacts

Starry stonewort directly impacts fish spawning habitat by the formation of a thick mat that serves as a physical barrier effectively impeding access to substrates for nest creation resulting in (1) reduction in nesting area and density of nests and (2) complete elimination of spawning activity in the area of infestation. In lakes supporting a mature and/or expanding infestation of starry stonewort, spawning fish must compete for remaining spawning habitat in areas that are suboptimal for spawning.

An attempt was made to clear known traditional nesting sites with chemical controls during the spawning season in Big Lake, Oakland County, Michigan in 2008. The chosen area was successfully cleared and spawning activities began; however, starry stonewort re-colonization of the cleared area occurred so rapidly that a successful spawn was not completed.

Michigan riparians inadvertently maintained traditional nesting sites, free of starry stonewort, in both Williams Lake and Lake Waumegah, Oakland County, using labor intensive mechanical methods or weed rollers. Although the removal of starry stonewort was done to support swimming and boating activities, a high degree of utilization by spawning sunfish was observed. Spawning was minimal or absent in areas immediately adjacent to the clearings. Both bass and sunfish will spawn readily in areas containing dense growths of native chara. By comparison, areas in close proximity but dominated by starry stonewort of relatively equal density did not exhibit spawning activity. We are unsure why this occurs.

Though concern for gamefish has been voiced by riparians on infested lakes there is also concern for biodiversity of lake fauna such as native fish species including logperch, darters and various minnow species, native clams, and invertebrates whose intimate association with the lake bottom is absolutely necessary for survival.

In 2009, a LakeScan™ critical fishery habitat survey was conducted in Whitmore Lake, Washtenaw County, Michigan. During the survey, redear sunfish (*Lepomis microlophus*) were observed nesting on a newly developing mat of starry stonewort that had covered a traditional nesting site. This species is not native to Michigan but has become naturalized through public and private stocking efforts. A closer inspection revealed that the nests were absent of sand and gravel and starry stonewort had been pressed down within the spawning depressions. The sunfish demonstrated the territoriality and nest guarding behavior associated with active reproduction. Redear sunfish were observed utilizing both sand gravel habitats in other traditional spawning sites within the lake. Rock bass, smallmouth bass, largemouth bass, bluegill, and pumpkinseed sunfish nests were observed during the survey but these species completely avoided starry stonewort, preferring sand gravel complexes as spawning substrate. It appears that redear sunfish will not be greatly impacted in by starry stonewort during early stages of infestation.

Critical nursery habitat consists of areas that provide optimum conditions for growth and safety for fry and juveniles of a myriad of fish species. These areas exhibit a high degree of vertical structural complexity in the form of vegetation and/or drowned timber that provide niche habitat for feeding and refuge from larger predators. In temperate lakes shallow areas provide warmer temperatures for increased metabolic rates and rapid growth. Starry stonewort's mat forming growth habit reduces structural complexity by physically and possibly chemically preventing the growth of aquatic macrophytes. Observations in nursery habitat areas over time show a gradual decrease in stem density and number of plants as starry stonewort prohibits growth of pondweeds, milfoils, and water lilies. Elimination and reduction of niche habitat may result in increased mortality of young-of-the-year and juvenile fish species of both native and non-native species. Rare and imperiled fish species such as the pugnose shiner (*Notropis anogenus*) and starhead topminnow (*Fundulus dispar*) are at particular risk due to the fact that robust stands of aquatic vegetation are critical to their survival.

Loss of woody habitat complexity beneath mats of starry stonewort conceals fish structure from anglers and results in a change in distribution and decrease in condition of largemouth bass as a result of a change in predatory strategy from the more efficient sit and ambush strategy to the less efficient chase strategy within the pelagic zone (Sass et al. 2006). Critical woody habitat is often rare in developed lakes and primarily consists of sunken snags or stumps. The rate of natural addition of new woody structure is also low because of fewer trees along the shoreline of a developed lake. Loss of this critical habitat to starry stonewort encroachment represents a serious threat to a valuable form habitat already in short supply.

Starry Stonewort Management

Starry stonewort appears to be highly sensitive to common copper and endothall based algaecides and appears to be even more susceptible than are most common Michigan charoid species. The application rates recommended for chara control on the U.S. EPA approved pesticide labels appear to be sufficient to control low-growing starry stonewort. Problems can arise when starry stonewort mats become tall. The algaecide application rates that are normally used in chara control operations usually cause impacts on only the upper surface of the starry stonewort mats. It appears that the active ingredients are sequestered in the upper portions of the starry stonewort mats and the lower portions of the mats are not injured. Injury can be caused at greater depths in the starry stonewort mat when chelated agents are used, the amine salt of endothall (Hydrothol 191, United Phosphorus, Inc., King of Prussia, PA) is added as an adjuvant or other adjuvants are added to the algaecide mixture. Challenge testing is being performed in laboratory studies at Clemson University as of this writing, and operational results are being analyzed to develop more effective control strategies. Field data collected in 2009 also suggest that starry stonewort may be susceptible to a broader range of aquatic herbicides than was considered in previous years. There was a significant decline in the percent occurrence of starry stonewort as observed in biological observation sites in any lakes in 2009 as an apparent result of nuisance plant control efforts that were focused on herbicide tolerant aquatic angiosperms (in Bass, Cedar, Lobdell, Sanford, White, and Whitmore lakes). These management efforts included mixtures of herbicides that included a product known as Cutrine Ultra (Applied Biochemists, Germantown, WI). Cutrine Ultra, combined with other herbicides, appeared to be the factor that has resulted in the consistent suppression of starry stonewort.

Mechanical harvesting was used for the control of starry stonewort in Indianwood Lake and has been used for the control of other nuisance plant growth in some of the other lakes that are inhabited by starry stonewort. The amount of biomass produced by starry stonewort in a relatively small area can very quickly fill a mechanical harvesting machine to capacity and cause harvesting operations to be very slow relative to the harvesting of other nuisance vascular plant species. The "sponge"-like mats of starry stonewort are also prone to roll down the forward conveyor of some harvesting machines making it difficult to pick the cut plants off of the surface of the water. Starry stonewort appeared to grow faster than any competing plants in the harvested areas of Indianwood Lake and this shifted the plant community to a mono-culture of starry stonewort in 2007. The resulting outcome was inconsistent with the lake management goals for that lake and harvesting operations were suspended in 2008.

The ability to control only the upper biomass of starry stonewort mats presents some interesting aquatic plant management opportunities. Many of the lakes where starry stonewort has been found have historically been challenged by the spread, proliferation, and domination of milfoil species and hybrids. Starry stonewort is a superior competitor and will eliminate nuisance milfoil growth from the deeper parts of some lakes. And, if the water is clear, starry stonewort will not grow as tall in the water column. Riparian property owners, recreational water users, and some lake managers have been very pleased with this outcome. If starry stonewort grows taller, the height of the starry stonewort can be reduced with low level algaecide treatments. This is referred to as a "hair cut treatment" and is used to suppress plants like milfoil through competition and still keep boat lanes open. The wisdom of such a treatment strategy may be debatable, but the utility of the approach has been very effective.

The timing of starry stonewort treatment is also worthy of consideration. Early treatment may be necessary, to open spawning habitats. However, early treatment may open large areas of the lake bottom to colonization by early growing season species such as milfoil, milfoil hybrids, curly leaf pondweed, fanwort, or other highly undesirable invasive species in Michigan. If treatment is delayed to late June, the adverse impacts on these early-growing invasive species may be exaggerated. Presumably, some of the more desirable pondweed species may benefit from the suppression of these vascular invasive species and the creation of habitat when the starry stonewort is removed late in June. This strategy is only one of several that is being considered and evaluated in Michigan.

Concerns and Questions

Starry stonewort may be the greatest challenge that has ever faced lake management professionals and lake user groups in Michigan. The impact on Michigan fisheries could be profound. Although it is relatively easy to control, management strategies need to be fine tuned to be more effective and useful. There are many questions that need to be answered or investigated to gain a better understanding of the biology and threat to Midwestern and North American lakes that is posed by the spread of the starry stonewort in Michigan. The following points are offered for discussion and to possibly guide researchers.

1. BASIC BIOLOGY: The biology of starry stonewort is very different in Michigan. Curiously, it was known

to inhabit Lake St. Clair for nearly 30 years before it became conspicuous in inland lakes. It is currently spreading rapidly throughout the lower peninsula of Michigan. Is this a novel genotype or even a hybrid?

2. EPIPHYTE AND AWFUCH COMMUNITY INTERACTIONS: There is evidence from the Great Lakes that cladophorales algae benefit from being in close proximity to the pseudofeces of zebra mussels which are able to supply necessary plant nutrients. The association of zebra mussels and starry stonewort is also very strong and seems to suggest that these same benefits may be provided to starry stonewort, while starry stonewort provides zebra mussels with suitable attachment substrates.
3. The awfuchs community that colonizes the surface of starry stonewort has not been investigated. This community could also be key to the successful upward growth of starry stonewort, as epiphytic cyanobacteria are known to fix nitrogen on charoid algae in rice paddies. Manipulation of these communities may help to regulate upward growth of starry stonewort pillows and mats.
4. BASIC WATER QUALITY: Starry stonewort appears to have a profound impact on water clarity in Michigan Lakes. The impact of starry stonewort on the inorganic and nutrient chemistry of lakes has not been directly addressed. Starry stonewort phosphorus demand may limit essential and desirable plankton community production in starry stonewort lakes (too little phosphorus). Allelopathy may also play a role in the reduction of phytoplankton production.
5. PLANT COMMUNITY DIVERSITY: Starry stonewort seems to extirpate most submersed plant species; however, long-term studies have not provided any indication of what aquatic plant communities may become after years of cohabitation with starry stonewort. Some plants, such as bladderworts and coontail appear to be benefited by starry stonewort infestations.
6. SEDIMENT IMPACTS: Starry stonewort seems to have a dramatic impact on sediment bio-geochemistry. The impact on redox potentials, the availability of suitable electron acceptors for the terminal stages of sediment diagenesis (breakdown), and the accumulation of phytotoxic volatile fatty acids that certainly accumulate below dense starry stonewort mats would be another area of investigation to understand better the recolonization of areas by rooted vascular plants that previously were dominated by starry stonewort.
7. IMPACTS ON PRIMARY PRODUCTION: There is evidence that charoid algae can serve as a nutrient sink, by a wide variety of mechanisms, and thereby limit primary production though resource deprivation (Blindlow et al. 2004). The production, presence, and function of starry stonewort allelopathic compounds would be difficult to investigate, but needs to be considered for a wide range of reasons.
8. The impact of starry stonewort on the richness and diversity of phytoplankton communities may be profound. Blue-green algae blooms have been observed in some lakes that are dominated by starry stonewort (Williams Lake, Lobdell Lake, Indianwood Lake). The association of starry stonewort with zebra mussel may be significant.
9. IMPACTS ON SECONDARY PRODUCTION: It is reasonable to expect a shift in zooplankton species from those associated with pelagic habitats to species associated with littoral habitats. And, the expected impact on benthic invertebrates may be profound.
10. IMPACTS ON FISHERIES: Some of the questions that we have considered are: Are temperate lakes that support extensive and mature infestations of starry stonewort more vulnerable to winter kill if large amounts of biomass are carried over into times of the year where there is ice cover? How do increases in water clarity and possible reductions in dissolved organic carbon effect the selection of spawning habitat by yellow perch in lakes? Do redear sunfish nests yield the same number of swim up fry in starry stonewort and sand gravel complexes? How much critical spawning and nursery habitat is enough to support viable fish populations in inland lakes? Is angler dissatisfaction in starry stonewort lakes linked to density, condition or distribution of fish?
11. STARRY STONEWORT MANAGEMENT: Although there seem to be a myriad of ways to control starry stonewort, better ways could be developed to control its growth with lower concentrations of active ingredients. The timing of control operations is likely to have a significant impact on the subsequent recolonization of areas where starry stonewort was once the dominant macrophyte due to the impact of dense starry stonewort mats on sediment biogeochemistry. Better estimates of the rate of starry stonewort encroachment on areas that have been cleared for restoration of spawning habitats need to be made to calculate how large an area must be managed to protect these resources.
12. STARRY STONEWORT PRODUCTION: The biology of starry stonewort has been confusing. The populations in some lakes seem to exhibit slow growth or may even decline in the hot summer months while continued growth has occurred in other lakes. The differences in the populations may be genetic or may be determined by other factors. Does the appearance of open pockets (cheesy effect) suggest that starry stonewort mats may collapse soon? When with the exponential growth phase of starry stonewort begin so that management efforts can be better timed? These considerations and the differences observed in different lakes need to be investigated to improve management practices.

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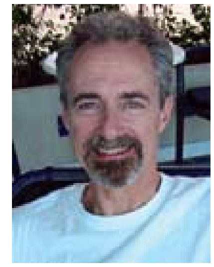

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