Debris Technical Brief: Bryozoans and Hydroids

Technical Update — *Debris Management Interest Group*

Fouling of a trash rack (left) at Ft. Myers Plant (photo courtesy of Florida Power & Light) and (right) a large sample of bryozoans taken from the forebay of a nuclear power plant (photo courtesy of Bryo Technologies).

Bryozoans and Hydroids as Debris—Bryozoans and hydroids can pose a significant threat to power plant cooling water intake structures (CWIS). In sufficient quantities, these organisms can foul intake screening equipment (for example, bar racks and traveling water screens), leading to reduced cooling water flow or, in extreme cases, structural failure of the screening equipment. Furthermore, the establishment of these organisms on components of the CWIS or their passage into the circulating water system can result in condenser tube plugging. Cooling water blockage is a concern as it negatively affects facility reliability and results in a loss of revenue. This technical brief provides background on bryozoans and hydroids as debris agents at power plant CWIS. It includes information on the organisms' biology, their spread mechanisms, control strategies for them, and lists of external resources such as key literature, websites, and contact information for technical experts on bryozoans and hydroids.

Issue

Bryozoans and hydroids are aquatic invertebrates that colonize and foul submerged structures. As such, they have potential to negatively impact the operation and maintenance of CWIS. Bryozoans and hydroids have many similarities, even though these animals are distantly and anatomically very different. It is these similarities between bryozoans and hydroids (rapidly spreading colonies, permanent attachment, and feeding on drifting particles) that make them successful biofouling organisms. Both bryozoans and hydroids are found in fresh and saltwater environments; however, the species that cause the majority of biofouling issues at power plants are primarily freshwater species. For this reason, this technical brief is focused on freshwater bryozoans and hydroids as biofouling agents at CWIS.

Bryozoan Biology

Bryozoans are aquatic invertebrates that can be found in both fresh and saltwater. The freshwater biofouling species are commonly referred to as "moss animals", due to their resemblance to roots or moss. Bryozoans are sessile, colonial organisms with each individual organism (zooid) surrounded by a hardened protective calcareous exoskeleton. **Figure 1** depicts the range of morphologies that exist.

Bryozoans are typically grouped with other phyla as the "lophophorates". Lophophorates are so named because they share a common filter feeding structure called a lophophore. The lophophore organ houses multiple ciliated tentacles and can be extended and retracted to capture planktonic organisms. The cilia on the tentacles are used to induce a current which draws water through the lophophore to collect planktonic food (Ruppert et al. 2004). Bryozoans are commonly divided into two taxa (one marine and one freshwater); it is the freshwater taxon that contains the major biofouling species.

Bryozoans permanently attach to submerged surfaces, such as rocks, plants, logs, or the inside of pipelines. Common fouling bryozoans are composed of branching tubes resembling plant roots that sometimes fuse into a solid mass (**Figure 1** a-c). These species are often brown, green, or grey in color, and can grow more than 10 cm (3.9 in.) thick. Another fouling species *Pectinatella* (**Figure 1**d) grows as a gelatinous blob that can exceed the size of a football.

Sexual reproduction occurs in all freshwater species, although the details of fertilization are not well understood. Eggs develop into unique larva-like structures that swim freely for several hours before finding an anchoring substrate to begin a colony. Reproduction also occurs when freshwater bryozoans produce large numbers of microscopic seed-like capsules called statoblasts (Figure **1**c) which can remain dormant for months. Statoblasts can be buoyant or adhere firmly to substrate. Upon germination, the statoblast projects a sticky pad that aids in substrate adhesion. Statoblasts are more easily mechanically removed from smooth substrates than rough ones. If not removed, colony formation is immediate.

Bryozoans can also reproduce when branches of a colony are torn free during storms or other means. These living fragments can be transported passively within the water column, adhere to a new surface, and resume colony growth.

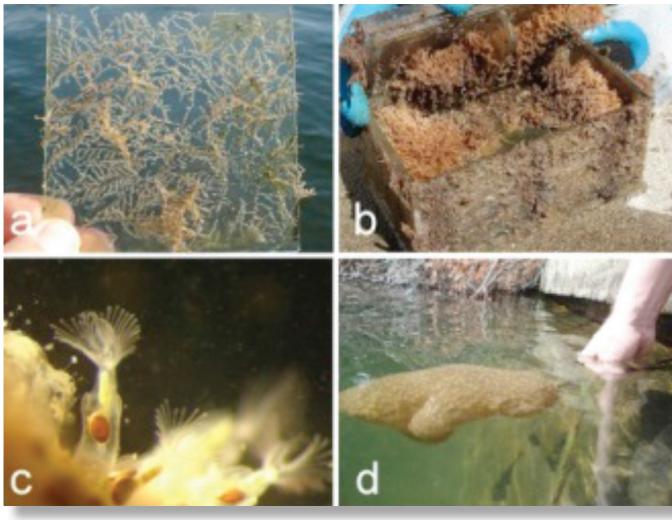

Figure 1. Common freshwater biofouling bryozoan species. Plumatella growing on a monitoring plate (a) and a plastic biobox (b); Close-up of a bryozoan zooid with its seed-like statoblast (c); Pectinatella bryozoan colony (d) (Images courtesy Bryo Technologies).

Hydrozoan Biology

Hydrozoans (Class Hydrozoa) are members of the Phylum Cnidaria along with jellyfish, sea anemones, and corals. The majority of hydrozoans are marine, though some are found in freshwater. Hydrozoans have both free-floating (medusa) and sessile (polyp) stages; however, in some cases, the free-floating medusa stage can be greatly reduced or completely eliminated (Ruppert et al. 2004). The sessile polyp stage that attaches to substrates poses the greatest fouling risk to intake structures; Figure **2** depicts the polyp stage.

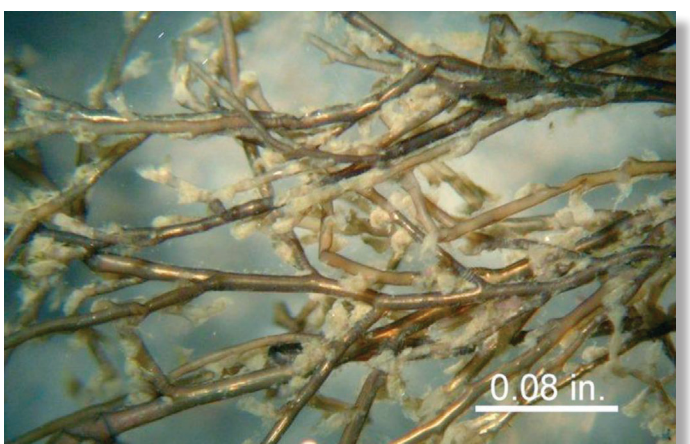

Figure 2. Morphology of a hydrozoan colony (hydroid) (Image courtesy Bryo Technologies).

Polyps are generally tube-shaped and attach to substrate with the mouth oriented upwards. Marine hydrozoans are typically colonial (colonies are commonly referred to as hydroids) and the most visible structure of the colony is the plant-like exoskeleton that houses individual polyps. For hydroids possessing an exoskeleton, it is composed primarily of chitin (Ruppert et al. 2004).

Hydroid species that are a fouling concern reproduce sexually by releasing sperm into the water column. The sperm are attracted to and retained by the female hydroids and the fertilized eggs develop into swimming larvae. Without a mouth or gut, larvae must quickly locate a settlement area before expending their internal energy stores.

Distribution and Dispersal

Bryozoans and hydroids are widely distributed and may withstand unfavorable conditions for hours or even days while being exposed to low levels of heavy metals or other toxins by withdrawing deeper into the colony interior. It is not uncommon for an apparently dead colony to "revive" when it returns to cleaner water (Wood 2005). In addition, a dormant statoblast can be unresponsive to conditions that would normally kill a living colony, allowing these dormant structures to create fouling problems even after the colony is treated or removed (Wood 2005). Produced in large numbers by most species, buoyant statoblasts are responsible for much of bryozoans' dispersal while the larvae are responsible for hydroid dispersal as these stages are easily transported by flowing water. Those species which produce anchoring statoblasts (bryozoans) or polyps (hydroids) may spread as fragments of colonies or by attaching to floating vegetation or other debris. Migrating waterfowl have also been found to aid in the distribution both through external transport on body parts and internal transport through their digestive tract (Wood 2005).

The microscopic size of statoblasts and larvae allows them to be easily entrained into a CWIS where they can colonize the piping system. Fouling within these systems can cause flow degradation and blockage (see Figure 3 for example of a serious blockage that would degrade flow capacity). Environmental factors like heavy rain storms and floods can loosen fouling organisms increasing interactions with CWIS. Sudden increases in flow velocity can have the same effect within a plant, sweeping organisms through the piping system (Satpathy et al. 2010).

Figure 3. Fouling of a trash rack at Florida Power and Light Ft. Myers Plant (Image courtesy FP&L).

Control

Removal and temporary control of bryozoan and hydrozoan colonies within a CWIS requires the consideration of many factors including the source water type, access to fouled surfaces, the species, and its source (originating from within or outside of the system). Once the key factors are identified, a treatment program will likely include a combination of two or more control techniques as a single control treatment has yet to prove successful. Even those treatments below, which are found to be promising, will require additional research and development on a site-by-site basis in order to determine the most cost effective methods of control.

Physical Exclusion

Various screening technologies equipped with smaller mesh sizes can act as the first line of defense against entry of macrorganisms into a CWIS. Although a screening technology may successfully exclude a macro-organism, not many can prevent entry of tiny larvae which can settle and grow within the cooling system (Satpathy et al. 2010). Filtering systems (Orival, Inc. Englewood, New Jersey) claim to remove bryozoan statoblasts and other particles larger than 200 microns; however. this technology has been designed typically for smaller piping systems of 11 cm (4 in) with flow rates up to 1500 liters/min (396 gal/min) (Wood 2005). Jet style filters, like those designed by Dango & Dienenthal Inc. for use in cooling water operations, take in raw water (up to 25,000 m^3/h) through stainless steel screening cartridges (≥ 50 μm) contained within a piped filter housing. These cartridges filter raw water from the inside out and utilize a backwashing process which does not interrupt filtration operations (www.dds-filter.com).

Velocity

The velocity of the withdrawn water and the characteristics of the substrate over which it flows can determine the type and extent of organism settlement. At high velocities, the shear stress of the water often exceeds the strength of fouling organism to anchor to substrate (Satpathy et al. 2010). Higher velocities can reduce larval contact time with substrates and lead to lower settling rates. Evaluations of larval settlement found that the bryozoan *Bugula neritina* exhibited a decrease in settling rate with increased flow, but settled over a broader range of flows tested (Qian et al. 2000). Analysis of operational and experimental data from power plants shows that velocities of 3.5 to 4.0 m/sec (11.5 to 13 ft/sec) are required to prevent settlement of macrofoulants (Venkatesan and Murthy 2008). These velocities are likely not feasible within most power plant circulating water systems, making high flow rates a difficult treatment option.

Heat Treatment

Heat treatments have been found to be an effective method for controlling biofouling, wherein the cooling water is raised above the thermal tolerance of the fouling organism (Venkatesan and Murthy 2008). Effective heat treatments are dependent on the water temperature selected, duration and frequency of exposures, and a clear understanding of the thermal tolerance of the fouling species. Disadvantages of heat treatments within a cooling water system include: 1) meeting the environmental regulations governing heated water discharges, 2) the operational capacity of a facility to perform a thermal backwash, and 3) losses incurred during plant shutdowns during the backwash period (Venkatesan and Murthy 2008).

Chemical Treatment

Oxidizing biocides are widely used in cooling water treatment, with chlorine being the most extensively used and cost-effective (Venkatesan and Murthy 2008). Laboratory test results showed a decrease of 23% growth of *Cordylophora caspia* exposed to 0.1 mg/L residual chlorine over seven days, demonstrating that chlorine is effective on hydroids at relatively low concentrations (Rajagopal et al. 2002). Common chlorination practices adopted by power plant facilities include: 1) low level continuous chlorination, 2) intermittent treatments, and 3) end of season chlorination. However, chlorine use at power facilities has been subject to increasing environmental regulations and concern (Venkatesan and Murthy 2008).

A cost effective alternative to chlorination is bromine, a chemical halogen similar to chlorine (Satpathy et al. 2010). Benefits of bromine treatments include: rapid residual decay, lower condenser corrosion rates, high solubility, high density (allowing larger amounts of liquid BrCl to be supplied in smaller containers), and viability in broad temperature and pH ranges (Satpathy et al. 2010). Several forms of bromine are available, which include activated bromine, sodium bromide, bromine chloride, and proprietary mixtures of bromine and chlorine (Venkatesan and Murthy 2008). Regardless of biocide control, chemical treatments programs must be designed and implemented on a site-specific basis taking into consideration facility operation and environmental regulations.

Mechanical Cleaning

Mechanical cleaning techniques typically consist of online and offline methods; however, cleaning methods conducted during normal plant operations are often economically non-viable or operationally impractical. Some online automatic cleaning systems that have been employed at power plant cooling water systems include the Amertrap system and the American M.A.N. brushes system (Venkatesan and Murthy 2008). The Amertrap system is designed to clean shell and tube heat exchangers using sponge rubber balls operated on an intermittent or continuous basis to rub the surface clean. The American M.A.N. system uses flow-driven brushes that pass through the condenser tubes intermittently by reversing the flow and abrasively removing fouling organisms (Venkatesan and Murthy 2008).

The more popular method of offline cleaning of heat exchanger tubes is done by hydrolazing methods, a specialized high pressure (10,000–20,000 psi.) water jet. Other mechanical offline techniques involve molded plastic cleaners (pigs), brushes (spirally formed, indented, or finned), and compressed air driven devices (Venkatesan and Murthy 2008).

Coatings

Virtually all known plastics, rubber, stone, glass and even corroding iron surfaces are known to support bryozoan and hydroid growth. Various paints, coatings, and chemicals have been applied to the surface of components within cooling water systems to prevent such fouling. Antifouling paints have so far proven ineffective against freshwater bryozoans (Satpathy et al. 2010), but surfactants or surface active agents are effective at altering the surface tension and reducing adhesion of organisms to a substrate (Venkatesan and Murthy 2008). Surfactants also enhance the penetration of biocide molecules and allow for more effective removal of those organisms which successfully settle on treated surfaces. The more effective surfactants include: ethylene oxide/propylene oxide block copolymer, dimethlyamide, dinonylsulfosuccinate, a combination of peracetic acid with ethylene oxide/propylene oxide, sodium dodecyl sulfate in combination with urea, and Tween20 (Venkatesan and Murthy 2008).

Other Control

Additional treatment techniques have been shown to be effective; however, they may not be feasible at some power plants. These alternative control approaches include osmotic control (varying salinity), bioactive compounds (i.e., treatment with chemical compounds extracted from other organisms), or complete desiccation of fouled components (Satpathy et al. 2010). Other treatment methods such as ozone have more potential at a power facility and have been tried at Public Service Electric & Gas plants (Satpathy et al. 2010) and recently during an EPRI funded pilot study at Entergy Sabine Plant (see EPRI R&D section). Ozone is an extremely strong oxidant compared to chlorine, however it far less toxic and persistent than chlorine. Some disadvantages include: difficulty in uniform distribution, high ozone demand needed in polluted water with the presence of bromide, large equipment footprint, unknown corrosion effects on condenser tubes, and overall high cost (Satpathy et al. 2010).

EPRI Research and Development

Bryozoan and hydroid fouling at CWIS is an increasing issue across the U.S. and around the world. Identifying a successful control program has been an ongoing challenge requiring the need for continued research and development.

Recently, EPRI funded a pilot study to evaluate the use of ozone and ultraviolet (UV) treatments to control the growth of hydroids (*Garveia franciscana*) at the Entergy Sabine Plant. Sabine Plant is a 2000-MW, 4-unit natural gas fueled facility, with a pumping capacity of 886,000 GPM. Sabine Plant is located near Bridge City, TX on a brackish water embayment off the Gulf of Mexico. Manual cleaning of trash racks, pits, and major CWIS piping is required twice per year in order to remove colony growth and reduce operational issues.

In 2013 a mobile laboratory was installed at the Sabine Plant in order to run the pilot ozone and UV trials. The ozone trials focused on effects of continuous vs. intermittent exposures in a range of ozone concentrations on *Garveia* hydroids naturally occurring within the brackish water. Polycarbonate panels were used to monitor ambient and treated water for hydroid settling and growth rates on a weekly basis.

Preliminary results indicated that it is more practical to interfere with growth or feeding of hydroids rather than killing the colonies outright. Intermittent ozone doses were as effective as continuous exposure and lower concentrations appeared practical over short terms (several days). During UV trials, monitoring panels in treated water showed no settlement, while control panels (no UV treatment) showed settlement of hydroids, bryozoans, and other aquatic organisms. Due to the size of the UV system (pipes up to 30 inches in diameter) it is limited in its application at power facilities to service water and other smaller piped systems.

EPRI plans to expand to a full scale evaluation of an ozonation system at the Entergy Sabine Plant (two full-sized bays) in 2014. The focus will be on lowering future operational costs of the ozonation system by determining the least amount of ozone needed in order to keep the Sabine Plant hydroids at a level where additional O&M is not needed.

Case Study - Controlling Biofouling Caused by the Colonial Hydroid *Cordylophora caspia* (Folino-Rorem & Indelicato 2005)

A laboratory study was conducted to evaluate the use of thermal and chlorine treatments to curtail the growth of *Cordylophora caspia* in the CWIS of the Collins Power Station (owned by Midwest Generation, an Edison International Company) located in Morris, IL. *Cordylophora caspia* is a colonial hydroid which tolerates a wide range of salinity (0 to 30 ppt) allowing it to inhabit brackish and freshwater environments. Rapid growth occurs via asexual budding at optimal conditions (16 ppt and 20°C) usually during spring and summer.

Thermal and chlorine experiments were conducted independently using colonies of *Cordylophor*a collected from the Des Plaines River in Joliet, IL due to the inaccessibility of colonies at the Collins Station. Two thermal experiments were conducted: 1) assessing the effects of colony exposure to 35 and 36.1(±0.5)°C for durations of 1 to 8 hrs and 2) assessing the effects of colony exposure to 37.7 and 40.5 (±0.5) °C for durations of 1 and 2 hrs. Test colonies were placed in trays with ambient (19.4°C) water which was increased by 2°C every 15 min until the test temperature was reached. Once the exposure duration was completed, the colonies were placed in ambient water and individual hydranth numbers were assessed for immediate survival and again at 7 and 12 days for experiment one and after 7 days only for experiment two. Control colonies kept in ambient water were also counted after exposure times to control for handling effects.

The chlorine concentrations and exposure times evaluated were selected based on communications with the Collins Station chemical engineers on the concentrations that would be feasible and cost effective for the plant. The first chlorine experiment exposed colonies to concentration of 0 (control), 0.5, 1.0, and 2.0 (±0.1) mgl^{-1} for 105 min. The second chlorine experiment exposed colonies to concentration levels of 0.2 (±0.01), 3.0, 4.0, and 5.0 (±0.1) mgl^{-1} for 105 min. Hydranths were counted before and after exposure and then placed in non-chlorinated water (19.4°C) and counted again at 10 and 20 (first experiment) or 28 days (second experiment) after exposure. A third chlorine experiment was conducted to evaluate the effect of intermittent exposure on colonies. Colonies were exposed to chlorine concentrations of 1.0, 2.0, 3.0, and 4.0 mgl^{-1} during three 20-min doses over a 24–hr period, with placement in non-chlorinated water (19.4°C) between doses. Hydranth numbers were counted before and after each 20-min dose and again after 7 and 14 days.

The results of thermal treatments demonstrated that colonies exposed to 35°C exhibited a significant decrease in hydranth numbers for 6 and 8-hr exposures after 12 days of observation, with the 8-hr exposure demonstrating extreme degeneration. The control and 2-hr treatment colonies increased significantly in hydranth numbers after 12 days. All colonies exposed to 36.1°C for 1 hr had re-grown after 12 days; however, those exposed for 3, 5, and 7 hrs exhibited deteriorations and a decrease in hydranth numbers with no regeneration. Colonies exposed to 37.7 and 40.5°C treatments decreased significantly in hydranth numbers, deteriorated, and did not regenerate. Control colonies showed significant increases in hydranth numbers.

Results of chlorine treatment trials demonstrated adverse affects during trials with increased concentrations. In the first trials, hydranth numbers decreased significantly after 10 days at concentrations of 1.0 and 2.0 mgl^{-1}; however, significant regeneration occurred at all concentrations after 20 days. In the second trials, significant decreases were observed with 4.0 and 5.0 mgl^{-1} concentrations and a significant increase in number was observed with the 0.2 mgl^{-1} concentration. All concentration treatments had some level of regeneration. During the third trials looking at intermittent exposure, the lower concentrations (1.0 and 2.0 mgl^{-1}) and control demonstrated a significant increase after 7 and 14 days, while higher concentrations (3.0 and 4.0 mgl^{-1}) demonstrated a significant decrease in hydranth numbers after the third 20-min exposure. Only colonies exposed to 4.0 mgl^{-1} concentration showed no significant increase in hydranth after 14 days.

Overall, colonies exposed to 37.7 and 40.5°C did not survive, while those exposed to 35.0 and 36.1°C and all chlorine concentration treatments exhibited varying degrees of survival and regeneration relative to exposure time. Thermal treatments appear to be the more effective and ecologically sound approach to addressing the biofouling problem at Collins Station.

Key Resources

Literature

Durr, S. and J.C. Thomason. 2010. Biofouling. Blackwell Publishing Ltd. United Kingdom.

Smith, D.G. 2001. Pennak's Freshwater Invertebrates of the United States. Wiley.

Thorp, J.H. and A.P. Covich, eds. 2009. Ecology and Classification of North American Freshwater Invertebrates. Academic Press.

Websites

Bryozoa of the British Isles
http://britishbryozoans.myspecies.info/

Bryo Technologies
http://www.bryotechnologies.com/

Dango & Dienenthal
www.dds-filter.com

University of Massachusetts, Amherst; Department of Biology
http://www.bio.umass.edu/biology/conn.river/bryozoa.html

Encyclopedia of Life
http://eol.org/pages/2160/details

Wright State University; Department of Biological Sciences
http://www.wright.edu/~tim.wood/bryozoans.html

USGS Non-indigenous Aquatic Species Database
http://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=1060

Experts

Table 1 provides a list of experts in the area of hydroid and bryozoan fouling control.

References

Folino-Rorem, N.C. and J. Indelicato, J. 2005. Controlling biofouling caused by the colonial hydroid *Cordylophora caspia*. Water Research. 39: 2731-2737.

Qian, P-Y, D. Rittschoi, and B. Sreedhar. 2000. Macrofouling in unidirectional flow: Miniature pipes as experimental models for studying the interaction of flow and surface characteristics on the attachment of barnacle, bryozoan, and polychaete larvae. Marine Ecology Press Series 207: 109-121.

Ruppert, E.E., R.S. Fox, R.D. Barnes. 2004. Invertebrate Zoology: A Functional Evolutionary Approach. Seventh Edition. Brooks/Cole a division of Thompson Learning, Inc. Belmont, CA.

Satpathy, K.K., A.K. Mohanty, G. Sahu, S. Biswas, M.Z.V.R. Prasad, and M. Selvanayagam. 2010. Biofouling and its control in seawater cooled power plant cooling water system - a review, Nuclear Power, Pavel Tsvetkov (Ed.), ISBN: 978-953-307-110-7, InTech, Available from: http://www.intechopen.com/books/nuclear-power/biofouling-and-its-control-in-seawater-cooled-power-plant-cooling-water-system-a-review-

Venkatesan R., P.S. Murthy. 2008. Macrofouling control at power plants. Marine and Industrial Biofouling. Springer Series on Biofilims. Volume 4: pp 265-291.

Wood, T.S. 2005. The pipeline menace of freshwater bryozoans. Landesmussen Neue Serie 28: 203-208.

Contact Information

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com).

Table 1. Names, affiliation, area of expertise, and contact information for those individuals identified during this technical review to be experts in the field of hydroid and bryozoan biology.

Contact Information

Name	Affiliation	Area of Expertise	Email	Phone
Ferdinando Boero	*University of Salento, Italy*	Marine biodiversity, hydrozoan taxonomy, marine biology, marine ecology, ecosystem functioning, marine protected areas, climate change	boero@unisalento.it	+39 (0)83.229.8619
Clifford Cunningham	*Duke University, North Carolina*	Evolution and biogeography of marine invertebrates, evolution of life cycle, colony morphology of hydrozoa	cliff@duke.edu	919.660.7356
Nadine Folino-Rorem	*Wheaton College, Illinois*	Ecology, taxonomy and physiological adaptability of the colonial hydroid, *Cordylophora* spp.	Nadine.Rorem@wheaton.edu	630.752.7038
Dennis Gordon	*National Institute of Water and Atmospheric Research, Wellington New Zealand*	Biology of bryozoa	d.gordon@niwa.co.nz	+64 (0)4.386.0388
F.G. (Eric) Hochberg	*Santa Barbara Museum of Natural History*	Diversity of marine and terrestrial invertebrate groups including: parasites of marine animals (protozoans, dicyemids, orthonectids and flatworms); cnidarians (hydroids, octocorals and corals); annelids (earthworms); mollusks (land snails and slugs); crustaceans (terrestrial isopods); and brachiopods (lamp shells).	fghochberg@sbnature2.org	805.682.4711 x145
Beth Okamura	*Natural History Museum, London*	Biology of marine and freshwater bryozoans	b.okamura@nhm.ac.uk	+44 (0)207.942.6631
Bernard Picto	*National Museums Northern Ireland*	Hydrozoans and taxonomy of hydrozoa	Bernard.Picton [at] nmni.com	+44 (0)28 9039 5266
John Ryland	University of Wales, *Swansea, United Kingdom*	Biology of bryozoa and hydrozoa	j.s.ryland@swan.ac.uk	+44 (0)17.9229.5440
Timothy Wood	*Bryo Technologies*	Biofouling control technologies	tim.wood@bryotechnologies.com	937.671.1670

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

3002003052 March 2014

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com