Title: The Effects of Iron Complexing Ligands on the Long Term Ecosystem Response to Iron Enrichment of HNLC waters

DOE Grant: *DE-FG02-02ER63431*

Principle Investigators: Charles G. Trick (UWO)
Mark L. Wells (U. Maine), Mary-Jane Perry (U. Maine),
William P. Cochlan (San Francisco State University)

Substantial increases in the concentrations of the stronger of two Fe(III) complexing organic ligand classes measured during the mesoscale Fe enrichment studies IronEx II and SOIREE appeared to sharply curtailed Fe availability to diatoms and thus limited the efficiency of carbon sequestration to the deep. Detailed observations during IronEx II (equatorial Pacific Ocean) and SOIREE (Southern Ocean –Pacific sector) indicate that the diatoms began re-experiencing Fe stress even though dissolved Fe concentrations remained elevated in the patch. This surprising outcome likely is related to the observed increased concentrations of strong Fe(III)-complexing ligands in seawater. Preliminary findings from other studies indicate that diatoms may not readily obtain Fe from these chemical species whereas Fe bound by strong ligands appears to support growth of cyanobacteria and nanoflagellates. The difficulty in assessing the likelihood of these changes with *in-situ* mesoscale experiments is the extended monitoring period needed to capture the long-term trajectory of the carbon cycle. A more detailed understanding of Fe complexing ligand effects on long-term ecosystem structure and carbon cycling is essential to ascertain not only the effect of Fe enrichment on short-term carbon sequestration in the oceans, but also the potential effect of Fe enrichment in modifying ecosystem structure and trajectory.

The project addressed the following central hypothesis:

The complexation of Fe by stronger ligand classes in seawater will sharply curtail Fe availability to diatoms, result in a change in phytoplankton speciation, and thus limit the efficiency of carbon sequestration to deep ocean waters.

The specific goals of the proposed work were to employ novel manipulation experiments to:

1) determine how different natural and synthetic Fe chelators affect Fe availability to phytoplankton species that are representative of offshore HNLC waters,

2) elucidate how the changes in absolute concentrations of these chelators (such as observed during IronEx II and SOIREE) will affect the ecosystem response beyond the normal (1-4 week) period of observations, and

3) ascertain how changes in the ligand composition affect cell sinking and aggregation rates; measures of the efficiency of carbon sequestration to the deep.

Experimental Approach: Our primary emphasis was to use laboratory and field-based, semi-continuous and batch cultures, as well as continuous cultures to measure how a suite of natural ligand analogs and Fe-complexing ligands isolated from seawater affect the availability of Fe to phytoplankton. Growth rates, macronutrient utilization

rates, and physiological parameters (variable fluorescence, cell size, Fe use efficiencies, and light dependent rates of carbon and Fe uptake) were used to ascertain the organism-specific responses to Fe supplied in these different chemical forms with and without elevated UV treatment. The relationship between ligand types and individual cell sinking rates and the kinetics of cell aggregation was determined to better assess the linkage between Fe ligands and export of carbon and macronutrients to the deep. The project combined laboratory experiments with field experiments on two separate extended research cruises in the North Pacific Ocean and nine coastal cruises as part of ECOHAB-PNW off Washington and British Columbia. During most cruises, our novel sea-going continuous culture system was used to evaluate for the first time the effect that different Fe complexing ligands (strong and weak) had on community structure of the phytoplankton and bacterial assemblage.

Central Finding: The experiments and field studies clearly supported the central hypothesis. The addition of strong Fe-complexing ligands at low (nanomolar) concentrations sharply curtailed the growth of eukaryotic phytoplankton and negatively affected the photo-physiological parameters of the cell. During the second Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS II), conducted during a 2-month, 2-ship cruise in the western subarctic Pacific, eukaryotic phytoplankton (diatoms in particular) increased their biomass slightly upon enrichment of surface waters with iron, but the growth response of nanoplankton was very muted. Despite the presence of significantly elevated dissolved Fe concentrations within the patch waters (~0.5-1 nM), further iron amendments in deckboard incubation studies resulted in markedly increased growth rates, demonstrating that the nanoplankton remained Fe limited. This lack of growth response was attributed mainly to a persistent excess of strong Fe(III) complexing ligands (Takeda et al., unpublished data) regulating the chemical speciation, and thus biological availability, of dissolved iron in the patch. We also showed that this limitation could be partly reversed by small amendments of copper, which has been implicated as a key constituent for the high affinity iron uptake systems of yeast, which can access strongly bound Fe.

Our studies show that marine planktonic ecosystems can respond to large inputs of iron by restricting the availability of dissolved Fe to large eukaryotic phytoplankton. In other words, the planktonic ecosystem during SEEDS-II worked towards greatly restricting diatom growth. Aside from the grand unknowns about the effects of sustained Fe enrichment on surface and deep ocean environments, our study indicates that the efficiency of carbon sequestration by iron enrichment of High-Nitrate, Low-Chlorophyll surface waters of the oceans can be <u>very</u> low. Another significant and unexpected finding related to Fe-enrichment of HNLC regions included the stimulation of neurotoxin (domoic acid) production by Fe (and Cu) additions both in natural HNLC assemblages, as well as during laboratory manipulations of pennate diatoms of the genus *Pseudo-nitzschia*; a genus that consistently responds strongly to Fe enrichments in all HNLC regions tested to date.

Project Accomplishments:

<u>Equipment Fabrication and Methods Development</u>: A significant portion of the work was directed to the fabrication (at UWO) of a novel, sea-going continuous culture system (Ecostat) for use in deckboard incubation experiments. To our knowledge, only one other system with this capability exists in the world, and our system has significant improvements over the original system. Our Ecostat culturing system has been used successfully in field experiments in the coastal waters of the Pacific Northwest, and the offshore oceanic waters of the subarctic Pacific (Ocean Station Papa). Additional fabrication and method developments included:

1. Several Plexiglas® settling columns were fabricated, successfully field-tested and used experimentally in the Bering Sea and other environments above. Experiments both in the laboratory and on research cruises have generated valid results.
2. A couette device was designed and fabricated for used for measuring aggregation rates of phytoplankton under both laboratory and field conditions.
3. Image analysis software protocols were developed for automated microscopic analysis of particle numbers and sizes for use with the settling columns and Couette devices.
4. The Alcian blue method for analysis of transparent extracellular polymers (TEP) in seawater was validated on laboratory and field samples from the settling column and Couette device experiments.
5. A custom, trace-metal clean ultra-violet (UV) pretreatment system was acquired for use in photodegradation experiments of natural Fe-binding ligands in seawater. This device was used during incubation experiments in the spring/summer of 2004 and 2006.

Research Accomplishments and Summary of Findings:

1. We participated in nine (9) cruises of opportunity to test the central and offshoot hypotheses developed during the project. These include cruises to the Bering Sea (1), the subarctic Pacific (2) and the coastal waters off the Washington/British Columbia coasts (6). In each case, continuous cultures, standard large-volume (10-L) batch cultures, and small bottle (1-2 L) batch culture experiments were conducted.
2. Combined with laboratory culture experiments, these monoclonal and natural population cultures tested the effects of different organic ligand structures, concentrations, and photochemical susceptibility on the comparative availability of Fe to large eukaryotic phytoplankton over picoplankton populations. The ligands chosen in these experiments were expected analogs of strong and weak Fe-binding ligand classes in seawater. Parameters measured to assess these effects included the growth response (Chlorophyll *a* accumulation as a measure of phytoplankton production, phytoplankton species identification and enumeration, photosynthetic productivity efficiency, macro-nutrient acquisition rates, Fe uptake of eukaryotic and prokaryotic plankton, and heterotrophic bacteria biomass and productivity.
3. We tested and utilized a range of cytoprobes for measuring cell specific intracellular Fe (Phen Green SK, Phen Green FL), photosynthetic efficiency (DCMU-induced oxidative stress measure with Rhodamine 123 and DCMU-induced cellular NO accumulation measured with DAF-FM,(4-amino-5-methylamino-2′,7′-difluroscein)). The method for measuring cell-specific growth rates using the ratio of probe-detected DNA (SYBR Green) to cellular protein (Sytox) have been tested and finalized for a suite of organisms. Our experiments showed that measuring cell-specific Fe uptake by flow cytometry with Phen Green FL was unsuccessful due to lack the needed sensitivity.
4. The availability of Fe to eukarytotic phytoplankton decreases in the presence of strong Fe-binding ligands (siderophores), while Fe bound to the weaker type ligand (protoporhyin IX) appears to be readily available.

5. We find that some eukaryotic phytoplankton can adapt to utilized strongly bound Fe over longer times scales (days).
6. The addition of Cu enhances the kinetics of this adaptation, signifying that Cu is involved in Fe acquisition from strong Fe-complexing ligands.
7. As predicted, there are taxon-specific differences in cell sinking rates (diatoms sink faster in general than other microplankton).
8. Nutrient stress generally increases net sinking rates for all phytoplankton, but Fe-limited cells sinking faster than N-limited cells.
9. Cells grown under Fe-stress conditions exhibit greater cell stickiness, and generate large aggregated particles faster under constant shear conditions than Fe-replete cells. This Fe-enhanced increase in particle formation may be the mechanism behind the higher sinking rates measured under Fe-stress than under N-stress.
10. The project has financially supported 2 PhD graduate students at U Maine, 1 MS graduate student at SFSU, and partial support for 2 graduate students at UWO to conduct research as part of their thesis research projects. In addition undergraduate students from SFSU (2), U Maine (2), and UWO (3) participated in the major oceanic cruises of 2004 and 2006 in the North Pacific Ocean.
11. As part of our outreach efforts, two in-service high school teachers from California [North High School in Torrance, California (Los Angeles County) and Woodside Priory School in Portola Valley, California (San Mateo County)} were financially supported during the summer to participate in research cruises in open-ocean and coastal studies.

Research Products:

Peer-reviewed publications resulting completely or partially (designated by an asterisk *) from this project, in which TRICK is an author.

*Trick,C.G, W.P. Cochlan, M.L. Wells, V.L. Trainer and L. Pickell. Iron enrichment stimulates toxic diatom production in High Nitrate Low Chlorophyll areas. Proc. National Acad. Sci. USA.

*Pickell, L.D., M.L. Wells, C.G. Trick and W.P. Cochlan. A sea-going continuous culture system for investigating phytoplankton community response to macronutrient and trace metal manipulations. Limnol. Oceanogr. Methods

*Trainer, V.L., B.M. Hickey, E.J. Lessard, W.P. Cochlan, C.G. Trick, M.L. Wells, A. MacFadyen, and S. Moore. Variability of *Pseudo-nitzschia* and domoic acid in the Juan de Fuca Eddy region and its adjacent shelves. Limnol. Oceanogr. (In revision).

Wells, M.L., C.G. Trick, and W.P. Cochlan. Iron inputs and the persistence of iron limitation in the western subarctic Pacific SEEDS II mesoscale fertilization experiment. J. Oceanography. (In revision).

*Wells, M.L., C.G. Trick, W.P. Cochlan, M.P. Hughes, and V.L. Trainer. 2005. The synergy of iron, copper and the toxicity of diatoms. Limnol. Oceanogr. *50*: 1908-1917.

*Hickey, B., A. MacFadyen, W.P. Cochlan, R.M. Kudela, K. Bruland, and C.G. Trick. 2006. Evolution of water column physical, chemical and biological properties in the Pacific Northwest following the delayed onset of local upwelling. Geophys. Res Lett. *33*: L22S02.

*Kudela, R.M., W.P. Cochlan, T.D. Peterson, and C.G. Trick. 2006. Impacts on Phytoplankton biomass and productivity in the Pacific Northwest during the warm ocean conditions of 2005. Geophys. Res Lett. *33*: L22S06.

*Tsuda, A., Takeda, S., Saito, H., Nishioka J., Kudo, I., Nojiri, Y., Suzuki, K., Uematsu, M., Wells, M.L., Tsumune, D., Yoshimura T., Aono, T., Aramaki, T., Cochlan, W.P., Hayakawa, M., Imai, K., Isada, T., Iwamoto, Y., Johnson, W.K., Kameyama, S., Kato, S., Kiyosawa, H., Kondo, Y., Levasseur, M., Machida, R., Nagao, I., Nakagawa, F., Nakanishi, T., Nakatsuka, S., Narita, A., Noiri, Y., Obata, H., Ogawa, H., Oguma, K., Ono, T., Sakuragi, T., Sasakawa, M., Sato, M., Shimamoto, A., Takata, H., Trick, C.G., Watanabe, Y.Y., Wong, C.S., and N. Yoshie. 2007. Evidence for the grazing hypothesis: Grazing reduces phytoplankton responses of the HNLC ecosystem to iron enrichment in the western subarctic Pacific (SEEDS II). J. Oceanography *63*: 983-994.

*MacFadyen, A, B.M. Hickey, and W.P. Cochlan. 2008. Influences of the Juan de Fuca Eddy on circulation, nutrients and phytoplankton production in the northern California Current System. J. Geophys. Res – Oceans.

*Olson, M.B., E.J. Lessard, W.P. Cochlan, and V.L. Trainer. 2008. Intrinsic growth and microzooplankton grazing on toxigenic *Pseudo-nitzschia* spp. diatoms from the coastal North Pacific. Limnol. Oceanogr. *53*: 1352-1368.

Presentations at international/national conferences resulting completely or partially (designated by an asterisk *) from this project, in which Trick is an author, include:

*Wells, M.L., W.P. Cochlan, and C.G. Trick. 2003. Iron limitation of natural phytoplankton assemblages associated with the Pacific Northwest ECOHAB *Pseudo-nitzschia* blooms. Second Symposium on Harmful Marine Algae in the U.S., Woods Hole, MA, December 2003.

*Trick, C.G., M.L Wells, W.P. Cochlan, L. Pickell, L. McClintock, and N.C. Ladizinsky. 2004. Iron limitation and copper effects in the Juan de Fuca Eddy. ASLO/TOS Ocean Research Conference. Honolulu, HI, February 2004.

*Trainer, V.L., B.M. Hickey, and W.P. Cochlan. 2004. Ecological linkages between physical and oceanographic conditions and the seasonal growth and distribution of toxic algae blooms. Western Juan de Fuca Ecosystem Symposium. Sydney BC, May 2004.

*Trainer, V.L., B.M. Hickey, M.L Wells, and W.P. Cochlan. 2004. Ecological linkages between physical and oceanographic conditions and the seasonal growth and

distribution of *Pseudo-nitzschia* blooms on the U.S. west coast. PISCES 13th Annual Meeting, Honolulu, HI, October 2004.

*Hickey, B., S. Geier, R. Thomson, W.P. Cochlan, A. MacFadyen, and V.L. Trainer. 2004. Comparison of two sites with respect to HABs viability: a topographic eddy and a coastal upwelling region. 11th International Conference on Harmful Algae, Cape Town, South Africa, November 2004.

Cochlan, W.P., J. Herndon, J.N. Betts, D.R. Costello, C.G. Trick, and M.L. Wells. 2005. Ammonium inhibition of nitrate uptake during mesoscale iron-enrichment experiments: A comparison of the planktonic response during SOFeX and SEEDS II. SEEDS II Workshop: Second Iron Enrichment Experiment in the western subarctic Pacific. Tokyo, Japan, October 2005.

Cochlan, W.P., C.G. Trick, and M.L. Wells. 2005. Complexity of grow-out experiments: further iron stimulation of communities from iron fertilized patch. SEEDS II Workshop: Second Iron Enrichment Experiment in the western subarctic Pacific. Tokyo, Japan, October 2005.

*Hickey, B.M., W.P. Cochlan, V.L. Trainer, E.J. Lessard, and A. MacFadyen, A. 2005. A lagrangian view of the Juan de Fuca Eddy: macronutrients and circulation. Third Symposium on Harmful Algae in the U.S. Monterey, CA, October 2005.

Kudo, I., T. Aramaki, W.P. Cochlan, Y. Noiri, T. Ono, and Y. Nojiri. 2005. Primary production, bacterial production and nitrogen assimilation dynamics during SEEDS-II. SEEDS II Workshop: Second Iron Enrichment Experiment in the western subarctic Pacific. Tokyo, Japan, October 2005.

*Lessard, E.J., B. Olson, V.L. Trainer, W.P. Cochlan, and B. Hickey. 2005. Ups and downs in the life of a toxic *Pseudo-nitzschia* bloom in the Juan de Fuca Eddy off the Washington coast. Third Symposium on Harmful Algae in the U.S. Monterey, CA, October 2005.

Roy, E., M.L. Wells, C.G. Trick, W.P. Cochlan, and D.R. Costello. 2005. Iron oxidation state during the SEEDS II mesoscale experiment and its potential biological limitations. SEEDS II Workshop: Second Iron Enrichment Experiment in the western subarctic Pacific. Tokyo, Japan, October 2005.

*Trainer,V.L., B.M. Hickey, W.P. Cochlan, E. Lessard, C.G. Trick, and M.L. Wells. 2005. A seasonal eddy and a coastal upwelling region provide insights to HAB development 2005 International Ocean Research Conference, Paris, France, June 2005.

*Trainer, V.L., B.M. Hickey, E.J. Lessard, M.L. Wells, C.G. Trick, and W.P. Cochlan. 2005. Characteristics of the Juan de Fuca Eddy, a source of Domic Acid to the Washington coast. Third Symposium on Harmful Algae in the U.S. Monterey, CA, October 2005.

Trick, C.G, L. McClintock, W.P. Cochlan, and N.C Ladizinsky. 2005. The role of copper for iron acquisition in the Juan de Fuca Eddy *Pseudo-nitzschia* bloom. 2005 International Ocean Research Conference, Paris, France, June 2005.

Wells, M.L., C.G. Trick, W.P. Cochlan, P. Hughes, and N.C. Ladizinsky. 2005. The synergy of iron, copper and the toxicity of diatoms. GEOHAB Open Science Meeting on HABs and Eutrophication, Baltimore, MD, March 2005.

Wells, M.L., C.G. Trick, W.P. Cochlan, M.P. Hughes, and V.L. Trainer. 2005. Domoic acid: the synergy of iron, copper and the toxicity of diatoms. Presented at: 2005 International Ocean Research Conference, Paris, France, ASLO Summer Meeting, Santiago de Compostela, Spain. June, 2005, and PICES XIV Annual Meeting, Vladivostok, Russia. October 2005

*Auro, M.E., W.P. Cochlan, and V.L. Trainer. 2006. Nitrogen dynamics of *Pseudo-nitzschia cuspidata* from the U.S. Pacific Northwest. Twelfth International Conference on Harmful Algae, Copenhagen, Denmark, September 2006 and PICES 15th Annual Meeting, Yokohama, Japan, October, 2006.

*Cochlan, W.P., M.L. Wells, V.L. Trainer, C.G. Trick, E.J. Lessard, and B.M. Hickey. 2006. Domoic Acid Production is not linked to silicate limitation in natural populations of *Pseudo-nitzschia*. Twelfth International Conference on Harmful Algae, Copenhagen, Denmark, September 2006.

Isao, K., Y. Noiri, T. Aramaki, W.P. Cochlan, K. Suzuki, T. Ono, and Y. Nojiri. 2006. Primary production, bacterial production, and nitrogen assimilation dynamics during the SEEDS II experiment. PICES 15th Annual Meeting, Yokohama, Japan, October, 2006.

*MacFadyen, A, B.M. Hickey, V.L. Trainer, and W.P. Cochlan. 2006. Intra-seasonal and interannual variability in the circulation and biochemical water properties in the Juan de Fuca Eddy region. ASLO/AGU/TOS Ocean Sciences Meeting, Honolulu, HI, February 2006.

Pickell, L.D., M.L. Wells, C.G. Trick, W.P. Cochlan, and J. Herndon. 2006. Determining the effects of Fe(III) complexing ligands on phytoplankton community structure using a sea-going continuous culture incubator. ASLO/AGU/TOS Ocean Sciences Meeting, Honolulu, HI, February 2006.

*Trainer, V.L., W.P. Cochlan, B.M. Hickey, E.J. Lessard, A. MacFadyen, C.G. Trick, C.G, and M.L. Wells. 2006. The nature of the Juan de Fuca eddy: the rise and fall of domoic acid to the Washington State coast. Twelfth International Conference on Harmful Algae, Copenhagen, Denmark, September 2006.

Trick, C.G., W.P. Cochlan, and M.L. Wells. 2006. Complexity of grow-out experiments: further iron stimulation of communities from iron-fertilized mesoscale patch. ASLO/AGU/TOS Ocean Sciences Meeting, Honolulu, HI, February 2006.

Trick, C.G., W.P. Cochlan, M.L. Wells, and J.N. Betts. 2006. Complexity of grow-out experiments: further iron stimulation of planktonic communities from the iron fertilized mesoscale patch during SEEDS. PICES 15th Annual Meeting, Yokohama, Japan, October 2006.

*Trick, C.G., E.J. Lessard, W.P. Cochlan, B.M. Hickey, V.L. Trainer, and M.L. Wells. 2006. A drifter study of a toxic *Pseudo-nitzschia* bloom from the Juan de Fuca Eddy in the Pacific Northwest. Twelfth International Conference on Harmful Algae, Copenhagen, Denmark, September 2006.

Wells, M.L., C.G. Trick, W.P. Cochlan and J.N. Betts. 2006. Copper-assisted iron acquisition in iron limited regimes. ASLO/AGU/TOS Ocean Sciences Meeting, Honolulu, HI, February 2006.

Wells, M.L., C.G. Trick, W.P. Cochlan, and J. Herndon. 2006. The persistence of iron limitation during the SEEDS II mesoscale iron enrichment experiment. PICES 15th Annual Meeting, Yokohama, Japan, October 2006.

*Auro, M.E., W.P. Cochlan, and V.L. Trainer. 2007. Growth, toxicity and nitrogen uptake capabilities of the toxigenic diatom *Pseudo-nitzschia cuspidata* from the Pacific Northwest. Fourth Symposium on Harmful Algae in the U.S., Woods Hole, MA, October 2007.

*Beall, B., C.G. Trick, W.P. Cochlan, V.L. Trainer, and M.L. Wells. 2007. Low sinking rates of *Pseudo-nitzschia*: A competitive feature contributing to the development and maintenance of toxic blooms. Fourth Symposium on Harmful Algae in the U.S., Woods Hole, MA, October 2007.

*Bill, B.D., W.P. Cochlan, V.L. Trainer, M.L. Wells, C.G. Trick, and B.M. Hickey. 2007. Puget Sound, Washington: An emerging hotspot for *Pseudo-nitzschia* blooms and domoic acid toxic events. Fourth Symposium on Harmful Algae in the U.S., Woods Hole, MA, October 2007.

Cochlan, W.P., M.L. Wells, C.G. Trick, and J. Herndon. 2007. The effect of iron and copper on nutrient utilization and new production in High Nitrate Low Chlorophyll Waters. EGU General Assembly, Vienna, Austria, April 2007.

*Cochlan, W.P., M.L. Wells, C.G. Trick, V.L. Trainer, E.J. Lessard, and B.M. Hickey. 2007. Silicic acid limitation is not a trigger for domoic acid production by *Pseudo-nitzschia* blooms in the Pacific Northwest. Fourth Symposium on Harmful Algae in the U.S., Woods Hole, MA, October 2007.

*Cochlan, W.P., M.E. Auro, J. Herndon, V.L. Trainer, M.L. Wells and C.G. Trick. 2007. The possible role of anthropogenic nutrients in harmful algal bloom development in the Pacific Northwest. Coastal Zone 2007, Portland, OR, July 2007.

Trick, C.G., W.P. Cochlan, M.L. Wells, and J.N. Betts. 2007. Complexity of grow-out experiments: further iron stimulation of planktonic communities from the iron fertilized mesoscale patch during SEEDS. EGU General Assembly, Vienna, Austria, April 2007.

*Hickey, B.M., A. MacFadyen, V.L. Trainer, E.J. Lessard, W.P. Cochlan, C.G. Trick and M.L. Wells. 2007. Regional oceanography leading to toxic *Pseudo-nitzschia* events on beaches in the northern California Current. Fourth Symposium on Harmful Algae in the U.S., Woods Hole, MA, October 2007.

*Lessard, E.J., V.L. Trainer, B.M. Hickey, W.P. Cochlan, C.G. Trick, M.L. Wells, J. Herndon, A. MacFadyen, and S. Moore. 2007. Seasonal and interannual variability of *Pseudo-nitzschia* and domoic acid in the Juan de Fuca Eddy region and its adjacent shelves. Fourth Symposium on Harmful Algae in the U.S., Woods Hole, MA, October 2007.

*MacFadyen, A., B. Hickey, W.P. Cochlan, J. Herndon, and V.L. Trainer. 2007. The Juan de Fuca Eddy – An initiation site for toxigenic *Pseudo-nitzschia* blooms impacting

the Washington coast. PICES 16th Annual Meeting, Victoria, B.C., Canada, October 2007.

*Radan, R.L., M.E. Auro, J. Herndon, and W.P. Cochlan. 2007. Ammonium surge uptake and inhibition of nitrate uptake by small and large cell-sized *Pseudo-nitzschia* species from the Pacific Northwest. Fourth Symposium on Harmful Algae in the U.S., Woods Hole, MA, October 2007.

*Trainer, V.L., W.P. Cochlan, A. Erickson, B.D. Bill, F.H. Cox, J.A. Borchert and K.A. Lefebvre. 2007. Intrusion of domoic acid into Puget Sound, Washington State. 2007 Georgia Basin Puget Sound Research Conference, Vancouver, BC, Canada, March 2007.

*Trainer, V.L., W.P. Cochlan, M.L. Wells, C.G. Trick, and the ECOHAB education group (L. Kuehne, C. Muir, D. Costello). 2007. ECOHAB Pacific Northwest (ECOHAB PNW) outreach: Opening the scientific journey to the world. Fourth Symposium on Harmful Algae in the U.S. Woods Hole, MA, October 2007.

*Trick, C.G., W.P. Cochlan, M.L. Wells, and V.L. Trainer. 2007. *Pseudo-nitzschia* growth and toxin production in the Juan de Fuca Eddy in the Pacific Northwest – environmental stimulators of a toxic bloom.

Wells, M.L., C.G. Trick, and W.P. Cochlan. 2007. Fe (III) Complexing organic ligands and their regulation of ecosystem response to atmospheric iron enrichment of High Nitrate Low Chlorophyll Waters. EGU General Assembly, Vienna, Austria, April 2007.

Beall, B., C.G. Trick, W.P. Cochlan, V.L. Trainer, and M.L. Wells. 2008. Nutrient supply affects the community structure and spatial distribution of small phytoplankton and bacterioplankton in the coastal subarctic Pacific Ocean. Ocean Sciences Meeting, Orlando, FL, March 2008.

*Bond, N., B. Hickey, W. Peterson, E. Lessard, and W. Cochlan. 2008. The weather during summer of 2006 in the Pacific Northwest and its consequences for the coastal ocean. Ocean Sciences Meeting, Orlando, FL, March 2008.

*Hickey, B.M., V.L. Trainer, W.P. Cochlan, M.J. Foreman, E.J. Lessard, A. Pena, R.E. Thomson, C.G. Trick, M.L. Wells, J. Herndon, A. MacFadyen, and M.B. Olson. 2008. ECOHAB Pacific Northwest: Toxic *Pseudo-nitzchsia* in the northern California Current. Ocean Sciences Meeting, Orlando, FL, March 2008.

Wells, M.L., C. G. Trick, and W.P. Cochlan. 2008. Fe (III) complexing organic ligands strongly restrict ecosystem responses to atmospheric iron enrichment in high nitrate low chlorophyll waters. Ocean Sciences Meeting, Orlando, FL, March 2008.