

REPORT OF ADVISORY PANEL ON IRON FERTILIZATION EXPERIMENT IN THE SUBARCTIC PACIFIC OCEAN

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The final meeting of the Advisory Panel on *Iron Fertilization Experiment in the Subarctic Pacific Ocean* (hereafter IFEP-AP) was held from 19:00–21:00 hours on October 30, 2007. The Panel Co-Chairmen, Drs. Shigenobu Takeda and C.S. Wong called the meeting to order and welcomed the participants (*IFEP-AP Endnote 1*). The draft agenda was reviewed and adopted (*IFEP-AP Endnote 2*). As the Advisory Panel has completed its terms of reference and will be disbanded in 2007, the Co-Chairmen expressed appreciation to the IFEP-AP members and to all scientists involved in international collaborative meso-scale iron enrichment field experiments developed, through the Advisory Panel, under the umbrella of PICES. SERIES (Subarctic Ecosystem Response to Iron Enrichment Study) was performed in the eastern subarctic Pacific in summer of 2002, and SEEDS-I and SEEDS-II (Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study) were conducted in the western subarctic Pacific in the summers of 2001 and 2004, respectively.

Publications (Agenda Item 3)

Important new findings from the first two iron enrichment field experiments were published in *Science* (SEEDS-I: Tsuda *et al.*, 2003, 300: 958–961) and *Nature* (SERIES: Boyd *et al.*, 2004, 428: 549–553). More detailed results from these experiments were communicated in special issues of *Progress in Oceanography*, 2005, Vol. 64, Nos. 2-4, pp. 91–324 (SEEDS-I) and *Deep-Sea Research II*, 2006, Vol. 53, Nos. 20-22, pp. 2005–2454 (SERIES).

A synthesis paper on SEEDS-II entitled “*Evidence for the grazing hypothesis: Grazing*

reduces phytoplankton responses of the HNLC ecosystem to iron enrichment in the western subarctic Pacific” by Tsuda *et al.* will be published in the *Journal of Oceanography* in December 2007 (Vol. 63, pp. 983–994).

A special issue of *Deep-Sea Research II* on SEEDS-II is under preparation and is expected to be published in 2009 (Guest Editors: Atsushi Tsuda, Mark L. Wells, Mitsuo Uematsu and Hiroaki Saito). Sixteen papers have been submitted for this volume and 2 more papers will be submitted soon.

Papers related to SEEDS and SERIES that have been published in, or are being submitted to, peer-reviewed journals are listed in *IFEP-AP Endnote 3*.

Proposal of a new Working Group (Agenda Item 4)

IFEP-AP discussed and finalized the title, terms of reference and potential membership of a new PICES Working Group on *Iron Supply and its Impact on Biogeochemistry and Ecosystems in the North Pacific Ocean* (*IFEP-AP Endnote 4*). The new Working Group should include experimentalists and modelers working on iron biogeochemistry and its impact on biological productivity and marine ecosystems. Atmospheric scientists have to be part of the group because atmospheric dust deposition is one of the key iron supply processes to the North Pacific Ocean. Iron could be a potential regulator of harmful algal blooms (HABs) in coastal ecosystems, and relevant experts should be included. The new Working Group will be proposed at the BIO Committee meeting.

IFEP-AP Endnote 1

Participation list

Members

Paul J. Harrison (Canada)
Jun Nishioka (Japan)
Hiroaki Saito (Japan)
Shigenobu Takeda (Japan, Co-Chairman)
Atsushi Tsuda (Japan)
C.S. Wong (Canada, Co-Chairman)

Observers

Fei Chai (U.S.A.)
James Christian (Canada)
Masa Fujii (Japan)
Tsuneo Ono (Japan)
Vera Trainer (U.S.A.)
Emmy Wong (Canada)

IFEP-AP Endnote 2

IFEP-AP meeting agenda

1. Welcome and opening remarks
2. Adoption of agenda
3. Recent publications
4. Proposal of a new working group

IFEP-AP Endnote 3

IFEP-AP Publications

Special issue: “*Results from the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS-I)*”
Progress in Oceanography, 2005, Vol. 64, Nos. 2–4, pp. 91–324 (Guest Editor: A. Tsuda).

P.J. Harrison. Editorial. pp. 91–93.

S. Takeda and A. Tsuda. An *in situ* iron-enrichment experiment in the western subarctic Pacific (SEEDS): Introduction and summary. pp. 95–109.

D. Tsumune, J. Nishioka, A. Shimamoto, S. Takeda and A. Tsuda. Physical behavior of the SEEDS iron-fertilized patch by sulphur hexafluoride tracer release. pp. 111–127.

M. Kinugasa, T. Ishita, Y. Sohrin, K. Okamura, S. Takeda, J. Nishioka and A. Tsuda. Dynamics of trace metals during the subarctic Pacific iron experiment for ecosystem dynamics study (SEEDS2001). pp. 129–147.

Y. Noiri, I. Kudo, H. Kiyosawa, J. Nishioka and A. Tsuda. Influence of iron and temperature on growth, nutrient utilization ratios and phytoplankton species composition in the western subarctic Pacific Ocean during the SEEDS experiment. pp. 149–166.

K. Suzuki, A. Hinuma, H. Saito, H. Kiyosawa, H. Liu, T. Saino and A. Tsuda. Responses of phytoplankton and heterotrophic bacteria in the northwest subarctic Pacific to *in situ* iron fertilization as estimated by HPLC pigment analysis and flow cytometry. pp. 167–187.

A. Tsuda, H. Kiyosawa, A. Kuwata, M. Mochizuki, N. Shiga, H. Saito, S. Chiba, K. Imai, J. Nishioka and T. Ono. Responses of diatoms to iron-enrichment (SEEDS) in the western subarctic Pacific, temporal and spatial comparisons. pp. 189–205.

I. Kudo, Y. Noiri, K. Imai, Y. Nojiri, J. Nishioka and A. Tsuda. Primary productivity and nitrogenous nutrient assimilation dynamics during the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study. pp. 207–221.

H. Saito, K. Suzuki, A. Hinuma, T. Ota, K. Fukami, H. Kiyosawa, T. Saino and A. Tsuda. Responses of microzooplankton to *in situ* iron fertilization in the western subarctic Pacific (SEEDS). pp. 223–236.

A. Tsuda, H. Saito, J. Nishioka and T. Ono. Mesozooplankton responses to iron-fertilization in the western subarctic Pacific (SEEDS2001). pp. 237–251.

- N. Ramaiah, S. Takeda, K. Furuya, T. Yoshimura, J. Nishioka, T. Aono, Y. Nojiri, K. Imai, I. Kudo, H. Saito and A. Tsuda. Effect of iron enrichment on the dynamics of transparent exopolymer particles in the western subarctic Pacific. pp. 253–261.
- T. Aono, M. Yamada, I. Kudo, K. Imai, Y. Nojiri and A. Tsuda. Export fluxes of particulate organic carbon estimated from $^{234}\text{Th}/^{238}\text{U}$ disequilibrium during the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS 2001). pp. 263–282.
- N. Yoshie, M. Fujii and Y. Yamanaka. Ecosystem changes after the SEEDS iron fertilization in the western North Pacific simulated by a one-dimensional ecosystem model. pp. 283–306.
- M. Fujii, N. Yoshie, Y. Yamanaka and F. Chai. Simulated biogeochemical responses to iron enrichments in three high nutrient, low chlorophyll (HNLC) regions. pp. 307–324.
- Special issue:** “*Canadian SOLAS: Subarctic Ecosystem Response to Iron Enrichment (SERIES)*”
Deep-Sea Research II, 2006, Vol. 53, Nos. 20–22, pp. 2005–2454 (Guest Editors: P.J. Harrison, P.W. Boyd, M. Lavoie, A. Tsuda, R.B. Rivkin, S.O. Roy and W.L. Miller).
- Dedication to Dr. Moire Wadleigh. p. 2005.
- P.J. Harrison. SERIES (subarctic ecosystem response to iron enrichment study): A Canadian–Japanese contribution to our understanding of the iron–ocean–climate connection. pp. 2006–2011.
- C.S. Law, W.R. Crawford, M.J. Smith, P.W. Boyd, C.S. Wong, Y. Nojiri, M. Robert, E.R. Abraham, W.K. Johnson, V. Forsland and M. Arychuk. Patch evolution and the biogeochemical impact of entrainment during an iron fertilisation experiment in the sub-Arctic Pacific. pp. 2012–2033.
- D.A. Timothy, C.S. Wong, Y. Nojiri, D.C. Ianson and F.A. Whitney. The effects of patch expansion on budgets of C, N and Si for the Subarctic Ecosystem Response to Iron Enrichment Study (SERIES). pp. 2034–2052.
- C.S. Wong, D.A. Timothy, C.S. Law, Y. Nojiri, L. Xie, S.K. Emmy Wong and J.S. Page. Carbon distribution and fluxes during the SERIES iron fertilization experiment with special reference to the fugacity of carbon dioxide ($f\text{CO}_2$). pp. 2053–2074.
- C.S. Wong, W.K. Johnson, N. Sutherland, J. Nishioka, D.A. Timothy, M. Robert and S. Takeda. Iron speciation and dynamics during SERIES, a mesoscale iron enrichment experiment in the NE Pacific. pp. 2075–2094.
- A. Marchetti, N.D. Sherry, H. Kiyosawa, A. Tsuda and P.J. Harrison. Phytoplankton processes during a mesoscale iron enrichment in the NE subarctic Pacific: Part I—Biomass and assemblage. pp. 2095–2113.
- A. Marchetti, P. Juneau, F.A. Whitney, C.S. Wong and P.J. Harrison. Phytoplankton processes during a mesoscale iron enrichment in the NE subarctic Pacific: Part II—Nutrient utilization. pp. 2114–2130.
- A. Marchetti, N.D. Sherry, P. Juneau, R.F. Strzepek and P.J. Harrison. Phytoplankton processes during a mesoscale iron enrichment in the NE subarctic Pacific: Part III—Primary productivity. pp. 2131–2151.
- C.S. Wong and D.W. Crawford. Evolution of phytoplankton pigments in an *in-situ* iron enrichment experiment in the subarctic NE Pacific. pp. 2152–2167.
- H. Saito, A. Tsuda, Y. Nojiri, J. Nishioka, S. Takeda, H. Kiyosawa, I. Kudo, Y. Noiri, T. Ono, Y. Taira, K. Suzuki, T. Yoshimura and P.W. Boyd. Nutrient and phytoplankton dynamics during the stationary and declining phases of a phytoplankton bloom induced by iron-enrichment in the eastern subarctic Pacific. pp. 2168–2181.
- M.G. Scarratt, A. Marchetti, M.S. Hale, R.B. Rivkin, S. Michaud, P. Matthews, M. Lavoie, N.D. Sherry, A. Merzouk, W.K.W. Li and H. Kiyosawa. Assessing microbial responses to iron enrichment in the Subarctic Northeast Pacific: Do microcosms reproduce the in situ condition? pp. 2182–2200.
- I. Kudo, Y. Noiri, J. Nishioka, Y. Taira, H. Kiyosawa and A. Tsuda. Phytoplankton

- community response to Fe and temperature gradients in the NE (SERIES) and NW (SEEDS) subarctic Pacific Ocean. pp. 2201–2213.
- J.A. Needoba, A. Marchetti, M.F. Henry, P.J. Harrison, C.S. Wong, W.K. Johnson and T.F. Pedersen. Stable nitrogen isotope dynamics of a mesoscale iron enrichment experiment in the NE Subarctic Pacific. pp. 2214–2230.
- M.S. Hale, R.B. Rivkin, P. Matthews, N.S.R. Agawin and W.K.W. Li. Microbial response to a mesoscale iron enrichment in the NE subarctic Pacific: Heterotrophic bacterial processes. pp. 2231–2247.
- N.S.R. Agawin, M.S. Hale, R.B. Rivkin, P. Matthews and W.K.W. Li. Microbial response to a mesoscale iron enrichment in the NE Subarctic Pacific: Bacterial community composition. pp. 2248–2267.
- A.R. Sastri and J.F. Dower. Meso-zooplankton community response during the SERIES iron enrichment experiment in the subarctic NE Pacific. pp. 2268–2280.
- A. Tsuda, H. Saito, J. Nishioka, T. Ono, Y. Noiri and I. Kudo. Mesozooplankton response to iron enrichment during the diatom bloom and bloom decline in SERIES (NE Pacific). pp. 2281–2296.
- S. Takeda, N. Yoshie, P.W. Boyd and Y. Yamanaka. Modeling studies investigating the causes of preferential depletion of silicic acid relative to nitrate during SERIES, a mesoscale iron enrichment in the NE subarctic Pacific. pp. 2297–2326.
- K.L. Denman, C. Voelker, M.A. Peña and R.B. Rivkin. Modelling the ecosystem response to iron fertilization in the subarctic NE Pacific: The influence of grazing, and Si and N cycling on CO₂ drawdown. pp. 2327–2352.
- M. Levasseur, M.G. Scarratt, S. Michaud, A. Merzouk, C.S. Wong, M. Arychuk, W. Richardson, R.B. Rivkin, M. Hale, E. Wong, A. Marchetti and H. Kiyosawa. DMSP and DMS dynamics during a mesoscale iron fertilization experiment in the Northeast Pacific—Part I: Temporal and vertical distributions. pp. 2353–2369.
- A. Merzouk, M. Levasseur, M.G. Scarratt, S. Michaud, R.B. Rivkin, M.S. Hale, R.P. Kiene, N.M. Price and W.K.W. Li. DMSP and DMS dynamics during a mesoscale iron fertilization experiment in the Northeast Pacific—Part II: Biological cycling. pp. 2370–2383.
- R.-C. Bouillon, W.L. Miller, M. Levasseur, M. Scarratt, A. Merzouk, S. Michaud and L. Ziolkowski. The effect of mesoscale iron enrichment on the marine photochemistry of dimethylsulfide in the NE subarctic Pacific. pp. 2384–2397.
- R.M. Moore and L. Wang. The influence of iron fertilization on the fluxes of methyl halides and isoprene from ocean to atmosphere in the SERIES experiment. pp. 2398–2409.
- L. Phinney, W.R. Leitch, U. Lohmann, H. Boudries, D.R. Worsnop, J.T. Jayne, D. Toom-Saunty, M. Wadleigh, S. Sharma and N. Shantz. Characterization of the aerosol over the sub-arctic north east Pacific Ocean. pp. 2410–2433.
- N. Steiner, K.L. Denman, N. McFarlane and L. Solheim. Simulating the coupling between atmosphere–ocean processes and the planktonic ecosystem during SERIES. pp. 2434–2454.
- Special issue on SEEDS-II:** (under preparation) *Deep-Sea Research II* (Guest Editors: A. Tsuda, M. Wells, M. Uematsu and H. Saito).
- Other SEEDS-I publications**
- Tsuda, A., Takeda, S., Saito, H., Nishioka, J., Nojiri, Y., Kudo, I., Kiyosawa, H., Shiimoto, A., Imai, I., Ono, T., Shimamoto, A., Tsumune, D., Yoshimura, T., Aono, T., Hinuma, A., Kinugasa, M., Suzuki, K., Sohrin, Y., Noiri, Y., Tani, H., Deguchi, Y., Tsurushima, N., Ogawa, H., Fukami, K., Kuma, K., Saino, T. A mesoscale iron enrichment in the western Subarctic Pacific induces a large centric diatom bloom. 2003. *Science*, 300(5621), 958–961.
- Saito, H., T. Ota, K. Suzuki, J. Nishioka and A. Tsuda 2006. Role of heterotrophic dinoflagellate *Gyrodinium* sp. in the fate of an iron-enrichment induced diatom bloom. *Geophys. Res. Lett.*, 33, L09602, 10.1029/2005GL025366

Other SERIES publications

- Boyd P. W., Strzepek R., Takeda S., Jackson G., Wong C. S., McKay R. M., Law C., Kiyosawa H., Saito H., Sherry N., Johnson K., Gower J., and Ramaiah N. 2005. The evolution and termination of an iron-induced mesoscale bloom in the northeast subarctic Pacific. *Limnol. Oceanogr.* 50, 1872–1886.
- Boyd, P.W., Law, C.S., Wong, C.S., Nojiri, Y., Tsuda, A., Levasseur, M., Takeda, S., Rivkin, R., Harrison, P.J., Strzepek, R., Gower, J., McKay, R.M., Abraham, E., Arychuk, M., Barwell-Clarke, J., Crawford, W., Hale, M., Harada, K., Johnson, K., Kiyosawa, H., Kudo, I., Marchetti, A., Miller, W., Needoba, J., Nishioka, J., Ogawa, H., Page, J., Robert, M., Saito, H., Sastri, A., Sherry, N., Soutar, T., Sutherland, N., Taira, Y., Whitney, F., Wong, S.-K.E., Yoshimura, T. 2004. The decline and fate of an iron-induced subarctic phytoplankton bloom. *Nature* 428, 549–553.

Various SEEDS II Publications

- Sasakawa, M., U. Tsunogai, S. Kameyama, F. Nakagawa, Y. Nojiri, and A. Tsuda. In press. Carbon isotopic evidence for the origin of excess methane in subsurface seawater. *J. Geophys. Res.*
- Nishioka, J., T. Ono, H. Saito, T. Nakatsuka, S. Takeda, T. Yoshimura, K. Suzuki, K. Kuma, S. Nakabayashi, A. Tsuda. 2007. Iron supply to the western subarctic Pacific: Importance of iron export from the Sea of Okhotsk. *J. Geophys. Res.* 112, C10012, doi:10.1029/2006JC004055
- Sato, M., S. Takeda and K. Furuya. 2007. Iron regeneration and organic iron(III)-binding ligand production during in situ zooplankton grazing experiment. *Mar. Chem.* 106(3-4), 471–488.
- Tsuda, A., S. Takeda, H. Saito, J. Nishioka, I. Kudo, Y. Nojiri, K. Suzuki, M. Uematsu, M.L. Wells, D. Tsumune, T. Yoshimura, T. Aono, T. Aramaki, W.P. Cochlan, M. Hayakawa, K. Imai, T. Isada, Y. Iwamoto,

- W.K. Johnson, S. Kameyama, S. Kato, H. Kiyosawa, Y. Kondo, M. Levasseur, R. Machida, I. Nagao, F. Nakagawa, T. Nakanishi, S. Nakatsuka, A. Narita, Y. Noiri, H. Obata, H. Ogawa, K. Oguma, T. Ono, T. Sakuragi, M. Sasakawa, M. Sato, A. Shimamoto, H. Takata, C.G. Trick, Y.Y. Watanabe, C.S. Wong, 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. Oceanogr.* 63, 983–994.
- Nakatsuka S., Sohpjn Y., Norisuye K., Okamura K., Takeda S., Nishioka J. 2007. Physicochemical speciation of trace metals during the mesoscale iron enrichment (SEEDS II) in the western North Pacific. *Geochim. Cosmochim. Acta* 71(15), A704–A704 Suppl. S, 2007.

Synthesis publications

- deBaar, H., P.W. Boyd, K. Coale, M.R. Landry, A. Tsuda, P. Assmy, D.C.E. Bakker, Y. Bozec, R.T. Barber, M.A. Brezinski, K.O. Buesseler, M. Boye, P.L. Croot, F. Gervais, M.Y. Gorbunov, P.J. Harrison, W.T. Hiscock, P. Laan, C. Lancelot, C.S. Law, M. Lavasseur, A. Marchetti, F.J. Milero, J. Nishioka, Y. Nojiri, T. van Oijen, U. Riebesell, M.J.A. Rikenberg, H. Saito, S. Takeda, K.R. Timmermans, M.J.W. Veldhuis, A.M. Waite and C.S. Wong. 2005. Synthesis of iron fertilization experiments: From the iron age in the age of enlightenment. *J. Geophys. Res.*, 110, C09S16, doi:10.1029/2004JC002601.
- Boyd, P.W., T. Jickells, C.S. Law, S. Blain, E.A. Boyle, K.O. Buesseler, K.H. Coale, J.J. Cullen, H.J.W. de Baar, M. Follows, M. Harvey, C. Lancelot, M. Levasseur, R. Pollard, R.B. Rivkin, J. Sarmiento, V. Schoemann, V. Smetacek, S. Takeda, A. Tsuda, S. Turner and A.J. Watson. 2007. Mesoscale iron-enrichment experiments 1993–2005: Synthesis and future directions. *Science*, 315, 612–617.

IFEP-AP Endnote 4

**Proposal for a Working Group on
*Iron Supply and its Impact on Biogeochemistry and Ecosystems in the North Pacific Ocean***

Duration: October 2007 – October 2010

Parent Committee: BIO

The primary goals of the Working Group are:
a) to promote better understanding of natural and anthropogenic iron supplies to the North Pacific and their impact on biogeochemistry and ecosystems; and b) to facilitate closer ties among various research communities (aerosol, physical oceanography, biology, chemistry and modeling) to better integrate new findings and to provide needed feedback to help coordinate research activities.

Terms of reference

1. Compile and synthesize available iron biogeochemistry data in the North Pacific;
2. Review the past and ongoing laboratory, field and modeling studies on iron biogeochemistry and its impact on biological productivity and marine ecosystems in the North Pacific Ocean;
3. Determine the natural supplies of iron to the North Pacific, which includes atmospheric dust transport and movement of iron-enriched waters, and examine linkages between iron supply and ecosystem responses;
4. Identify gaps and issues related to experimental and modeling activities, encourage and plan national and international scientific programs on iron biogeochemistry and its impact on marine ecosystems in the North Pacific;
5. Elucidate the role of iron as a potential regulator of harmful algal bloom (HAB) in coastal ecosystems of the North Pacific.

Proposed members

Canada

James Christian
William R. Crawford
Paul J. Harrison
Maurice Levasseur
Charles Trick
C.S. Wong

Japan

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Mitsuo Uematsu
Yasuhiro Yamanaka

China

Liqi Chen
Xiuren Ning
Guangyu Shi

Korea

Kyung-Ryul Kim
Kitack Lee

Russia

Vladimir M. Shulkin

U.S.A.

Fei Chai (Co-Chairman)
William P. Cochlan
Natalie Mahowald
Suzanne Strom
Mark L. Wells