Journal of Marine Science and Technology

Volume 21 | Issue 6 Article 12

MORTALITY IN THE OCEAN - WITH LESSONS FROM HYDROTHERMAL VENTS OFF KUEISHAN TAO, NE-TAIWAN

Hans-Uwe Dahms
Department of Biology, College of Natural Science, Sangmyung University, Seoul, South Korea.

Jiang-Shiou Hwang
Institute of Marine Biology, National Taiwan Ocean University, Keelung, Taiwan, R.O.C., Jshwang@mail.ntou.edu.tw

Recommended Citation
Dahms, Hans-Uwe and Hwang, Jiang-Shiou (2013) "MORTALITY IN THE OCEAN - WITH LESSONS FROM HYDROTHERMAL VENTS OFF KUEISHAN TAO, NE-TAIWAN," *Journal of Marine Science and Technology*: Vol. 21: Iss. 6, Article 12.
DOI: 10.6119/JMST-012-1128-1
Available at: https://jmstt.ntou.edu.tw/journal/vol21/iss6/12

MORTALITY IN THE OCEAN - WITH LESSONS FROM HYDROTHERMAL VENTS OFF KUEISHAN TAO, NE-TAIWAN

Acknowledgements

We appreciate financial support from the Center of Excellence for the Oceans, National Taiwan Ocean University to J.S. Hwang. We are grateful to the National Science Council ofTaiwan, ROC, grant Nos. NSC 94-2611-M-019-010, NSC95-2923-B-019-001-MY 2, NSC 96-2611-M-019-006, NSC97-2611-M-019-004, NSC 99-2611-M-019-009, NSC 100-2611-M-019-010 and NSC 101-2611-M-019-011, and NSC 102-2611-M-019-003 for financial support to J.-S. Hwang.The research was supported by KRF to H.-U. Dahms (Projectnumber 2010-0025412). The authors acknowledge long termassistance from the captain and crew of Ocean ResearchVessel II, Taiwan and all the samplings from the laboratorymembers of J. S. Hwang's technicians and graduate students.We thank the technicians from J.-S. Hwang's laboratory fortheir contribution to the field sampling program.

Journal of Marine Science and Technology, Vol. 21, No. 6, pp. 711-715 (2013)
DOI: 10.6119/JMST-012-1128-1

MORTALITY IN THE OCEAN - WITH LESSONS FROM HYDROTHERMAL VENTS OFF KUEISHAN TAO, NE-TAIWAN

Hans-Uwe Dahms[1] and Jiang-Shiou Hwang[2]

Key words: plankton, mass mortality, hydrothermal vents.

ABSTRACT

There is evidence of plankton mortality and extinction at various temporal and spatial scales induced by man-made pollution, or by natural causes (ageing, competition, predation, diseases, natural pollution). If mortalities take place at large scale they might become of environmental concern and may impact other biotic compartments including fisheries substantially. Such mortalities are a consistent phenomenon at time scales from geological mass extinctions to regularly occurring HABs, that appear to be increasing on a global basis. Several mass mortalities might have escaped our notice for their patchy and erratic occurrences. This also holds for mortalities caused by hydrothermal vents (HVs) that cover possibly more than 1.5% of the ocean floor. We studied zooplankton diversity, abundance and distribution patterns above shallow water hydrothermal vents at Kueishan Tao (Turtle Island), off the northeast coast of Taiwan (West Pacific). The HVs at this side provide an opportunity for the study of mortality, community and population effects of HV effluents with ecophysiological investigations that are otherwise difficult to perform at the more common HV environment, the deep sea. We found evidence for a bottle-neck situation for plankton above vent sites since holoplankton was generally deadly affected when immersed directly in vent plumes. Here we used copepods from HV sites for ecotoxicological testing in mesocosm field experiments.

I. INTRODUCTION

The causes of episodic mortality events such as mass mortalities in the oceans remain poorly understood [5]. Predation, starvation, and diseases are traditionally assumed to be the most important biological causes of death. However, little attention has been given to the identification of other sources of natural mortality [25]. Here we report on effluents of a shallow hydrothermal vent site that cause mass mortality of plankton. Hydrothermal vent (HV) sites provide a habitat for a number of organisms [19, 28, 51, 52] that show particular physiological and biochemical adaptations [12, 41]. Whereas those of benthic organisms at HV sites are better studied [27, 53], is plankton widely neglected as yet [22, 42].

Kueishan Tao (or Turtle Island) is a holocene volcanic island close at the NE Taiwan coast, with HVs that are located 60 miles from those of the Okinawa Trough [32]. The HVs of Kueishan Tao are located at a tectonic junction of the fault system extension of Taiwan and the southern rifting end of the Okinawa Trough [32, 54]. A cluster of more than 50 HVs, detectable by side scan sonar and echo sounder sensors, at water depths between 10 m and 80 m off the southeastern tip of Kueishan Tao, emits hydrothermal fluids and volcanic gases. The gases of a mantle source region without significant crust contamination show a similar composition of low temperature fumaroles worldwide, with high CO_2 and H_2S but low SO_2 and HCl contents [11, 55]. We know that plankton is deadly affected by the HV site [35]. How and to what extend HV effluents and gases affect the pelagic biota above HV sites, particularly the plankton [31, 33], has never been investigated.

In this study, we exposed planktonic copepods collected from the field in cages that were exposed to the effluents of HVs in the field and were compared with those exposed to unaffected waters off-shore as a control. This study aimed to estimate the extend of mortality events caused by toxic effluents from HVs in shallow waters.

II. MATERIAL AND METHODS

Planktonic assemblages used in field mesocosms were collected on the 13th August 2008 from surface waters about 1 km away to the south from the main vent area of Kueishan Tao (Fig. 1). The plankton comprised predominantly of copepods and was transferred into 5 L polyacryl bottles that had 20 cm^2 meshed (meshsize 100 μm) openings on opposite

Paper submitted 08/19/11; revised 03/28/12; accepted 11/28/12. Author for correspondence: Jiang-Shiou Hwang (e-mail: Jshwang@mail.ntou.edu.tw).
[1] Department of Biology, College of Natural Science, Sangmyung University, Seoul, South Korea.
[2] Institute of Marine Biology, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

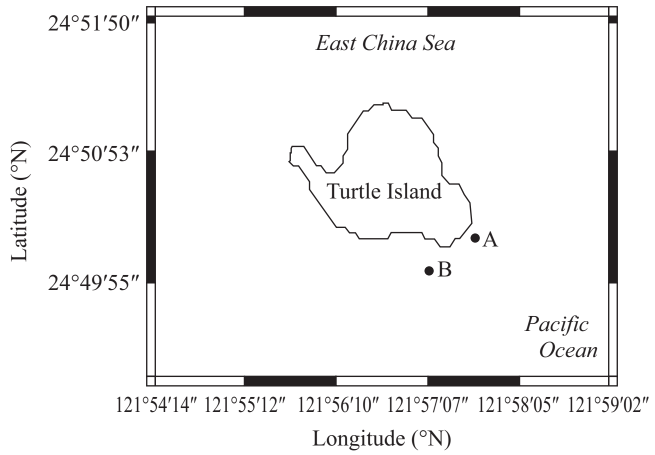

Fig. 1. Experimental hydrothermal vent side "A" at Kueishan Tao.

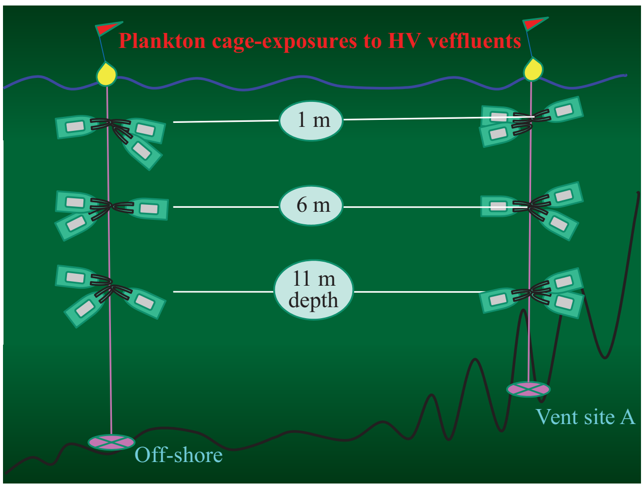

Fig. 2. Experimental set-up of exposure-cages in the field.

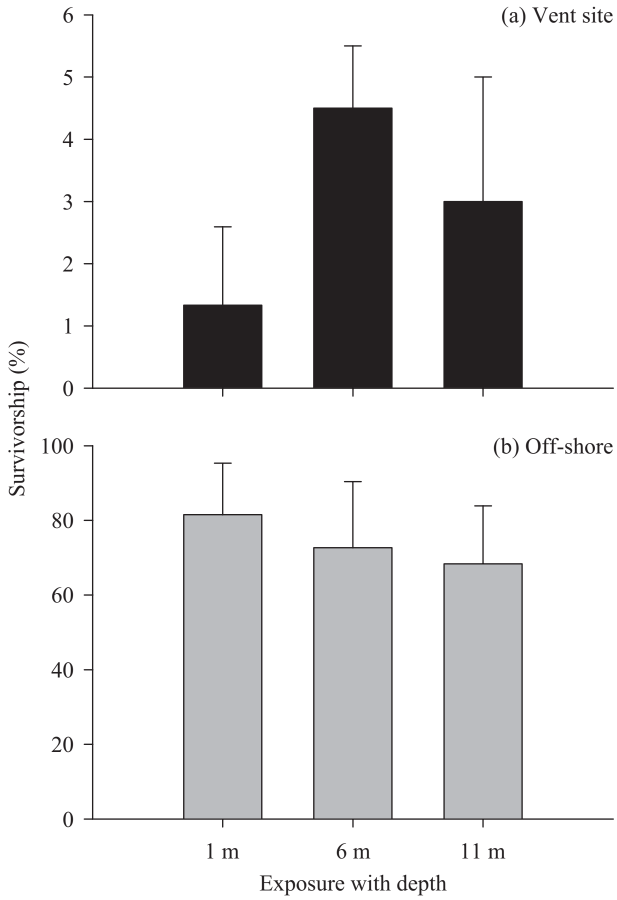

Fig. 3. Survivorship percentage of planktonic copepods caged at different depths above a hydrothermal vent site and in unaffected waters offshore.

lateral sides (Fig. 2). Always 3 bottles were grouped and tied to ropes that were anchored at 1, 6, and 11 m depth and exposed for 3 hours to the following situations: 1). off-shore outside the HV site and 2). in the area of HV site A (see Fig. 1). Lethally affected copepods belonging to different taxa were recognized by their upwardly flexed abdomina.

Statistical Analysis

Data of survivorship were assessed for normality with the Shapiro & Wilk Test [56]. Since none of the data met the normality assumption for parametric analysis, they were analyzed using non-parametric statistics [56]. Data are presented as the means ± standard deviation (S.D.). All statistical analyses were conducted using SPSS version 12.0 (SPSS Inc., Michigan Avenue, Chicago, Illinois, USA).

III. RESULTS AND DISCUSSION

In the present study we explored the sensitivity of a given plankton assemblage taken from the field outside but adjacent to an area of HV activities and exposed to different depths outside the HV site and to HV effluents in cages in the field for 3 hours. The survivorship was significantly reduced next to the hydrothermal vent site compared to unaffected waters offshore within the short period of 3 hours tested (Fig. 3). At the vent site we found highest survivorship at midwaters (6 m depth) of 4.5%, whereas it was lower at the bottom with 3.1% (11 m depth) and lowest at the surface (1 m depth) with 1.2%. Although the mortality endpoint was easy to measure (indicated by upwardly flexed abdomina) it might not be sufficient for a thorough ecological evaluation. The same holds for a systematic account that would have provided information about species-specific sensitivity and to what extend HV stress would have affected the biodiversity of plankton assemblages differentially. Entire plankton assemblages in field mesocosms have not been employed as yet for ecotoxicological testing, but several copepod species were used in marine ecotoxicity testing and biomonitoring since the 1960s [13, 44, 47]. A standardized, full life cycle bioassay with the estuarine copepod *A. tenuiremis* [2] has been used in several studies [1, 14, 50]. Sensitivity to pollutants also depends on the type of organisms and the stage of development used [10]. His *et al*. [29] conducted a comprehensive review of the assessment of marine pollution using bivalve embryos and larvae as testing organisms. Copepods have many attributes [6, 15, 16, 18] that make them an attractive group of organisms for toxicity testing of marine as well as freshwater chemical pollutants [3, 26, 47]. These include their small size, rapid reproduction, and cultiviability as well as their remarkable biodiversity in benthic as well as pelagic environments. There is a need to develop and standardize toxicity tests for meeting the regional environmental and regulatory requirements. Four species of marine copepods, namely, the planktonic calanoid *Acartia tonsa* (the genus *Acartia* was also present at our experimental HV site at Kueishan Tao) and the three harpacticoids, *Nitocra spinipes*, *Tisbe battagliai*, and *Amphiascus tenuiremis* have been identified as potential model species for EDCs [37]. DiPinto and co workers [21] studied lethal and sublethal effects of sediment associated PCB Aroclor 1254 on a meiobenthic copepod. In a recent overview, the OECD has highlighted *Tigriopus japonicus* as another species for toxicity testing risk assessment of EDCs [44].

Toxicity results of chemicals are significantly affected by environmental variables [40, 45, 46]. Toxicities of certain chemicals have been reported to be affected by these variables [39]. For instance, Kwok and Leung [38] observed that toxicities of Cu and TBT are significantly increased in *T. japonicus* when culture temperature was increased by 10°C. At higher temperatures, animals can also undergo dormancy [17]. Therefore, environmental variables and confounding factors have to be considered in the laboratory as well as in field-based bioassays.

Naturally occurring chemical stressors such as HV effluents have not been a research object for testing as yet. This is likely so since their impact on human and environmental health has not been questioned. There is a need, however, in basic and applied ecology to develop new methods and test new model species for such purpose [36]. Concerted efforts should be made to develop and standardize for both, acute and chronic tests for the evaluation of the impacts of environmental pollutants, also if they are naturally occurring and not fostered by man [8].

1. Mass Mortalities in Geological Times

Mass mortalities occurred throughout the history of the earth. Hsü *et al*. [30] postulate catastrophic geologically instantaneous mass mortalities near the end of the Cretaceous, and much reduced productivity to cause immediate changes of the pH of oceanic surface waters. The more acidic surface waters caused a catastrophic rise of CCD, which led to a widespread deposition of clays at the C-T boundary. A reduction of productivity in the oceans led to an increase of CO_2 in the atmosphere, and a greenhouse effect resulted in a temperature increase in ocean waters. Hsü *et al*. [30] postulate that such catastrophic environmental changes at the beginning of the Tertiary were the consequences of mass mortalities in the oceans, not their causes. The assumed cause was the impact of a large meteorite.

Berner [4] assumed that mass mortality at the Permian-Triassic boundary would also have affected marine plankton. The killing of marine plankton would stop the "biological pump" whereby photosynthetically fixed and isotopically light carbon was transferred to the deep ocean by settling of dead plankton and its oxidation back to CO_2 in deep waters. This situation has been referred to as a "strangelove" ocean. The drop in $\delta^{13}C$ of dissolved inorganic carbon in oceanic surface waters as a result of oceanic overturn following cessation of the biological pump has been shown to be about 1-1.5‰ by D'Hondt *et al.* [20] for the Cretaceous-Tertiary mass extinction. Also, cessation of the present-day biological pump has been shown by Sarmiento and Orr [48] to result, after exchange with the atmosphere, in a rise in atmospheric CO_2 from 280 ppm to about 500 ppm.

2. Diseases

There are various causes of diseases that in turn are responsible for mass mortalities. Viruses are evidently the most abundant entities in the sea and the question may arise whether they are widespread regulators of oceanic populations. However, there is very little known about marine viruses and their role in aquatic ecosystems and the species that they infect (for a review, see [23]). There is some evidence that viral infection might accelerate the termination of phytoplankton blooms [24, 34]. Viruses are held responsible for the collapse of *Emiliania huxleyi* blooms in mesocosms [7] and in the North Sea [9] and are shown to induce lysis of *Chrysochromulina* [49]. Because most viruses are strain-specific, they can increase the genetic diversity of their hosts [43].

Dense aggregations of plankton organisms may increase the transmission of disease causing agents. Gómez-Gutiérrez *et al*. [25] postulated that dense euphausid aggregations may increase the transmission of parasitoids after an infected animal bursts and sinks through the aggregation, distributing infective stages. This phenomenon may lead to large-scale euphausiid mortalities as have been observed by these authors at the base of Astoria Canyon, Oregon, where they discovered high densities of dead *Euphausia pacifica* on the ocean floor between 550 and 220 m depth. Parasitoids may also modify the behaviour of the infected members of the prey population.

ACKNOWLEDGMENTS

We appreciate financial support from the Center of Excellence for the Oceans, National Taiwan Ocean University to J. S. Hwang. We are grateful to the National Science Council of Taiwan, ROC, grant Nos. NSC 94-2611-M-019-010, NSC 95-2923-B-019-001-MY 2, NSC 96-2611-M-019-006, NSC 97-2611-M-019-004, NSC 99-2611-M-019-009, NSC 100-2611-M-019-010 and NSC 101-2611-M-019-011, and NSC

102-2611-M-019-003 for financial support to J.-S. Hwang. The research was supported by KRF to H.-U. Dahms (Project number 2010-0025412). The authors acknowledge long term assistance from the captain and crew of Ocean Research Vessel II, Taiwan and all the samplings from the laboratory members of J. S. Hwang's technicians and graduate students. We thank the technicians from J.-S. Hwang's laboratory for their contribution to the field sampling program.

REFERENCES

1. Andersen, H. R., Wollenberger, L., Halling-Sørensen, B., and Kusk K. O., "Development of copepod nauplii to copepodites - A parameter for chronic toxicity including endocrine disruption," *Environmental Toxicology and Chemical*, Vol. 20, No. 12, pp. 2821-2829 (2001).
2. ASTM E 2317-04, *Standard Guide for Conducting Renewal Microplate-Based Life-Cycle Toxicity Tests with a Marine Meiobenthic Copepod*, ASTM International (2012).
3. Barata, C., Medina, M., Telfer, T., and Baird, D. J., "Determining demographic effects of cypermethrin in the marine copepod *Acartia tonsa*: Stage-specific short tests *versus* life-table tests," *Archives of Environmental Contamination Toxicology*, Vol. 43, pp. 373-378 (2002).
4. Berner, R. A., "Examination of hypotheses for the Permo-Triassic boundary extinction by carbon cycle," *Proceeding of National Academy Sciences of the United States of Amecica*, Vol. 99, No. 7, pp. 4172-4177 (2002).
5. Boero, F., "Episodic events: their relevance to ecology and evolution," P.S.Z.N.I: *Marine Ecology*, Vol. 17, pp. 237-250 (1996).
6. Boxshall, G. A. and Halsey, S. H., *An Introduction to Copepod Diversity*, Vol. 166, The Ray Society, Andover, United Kingdom (2004).
7. Bratbak, G., Levasseur, M., Michaud, S., Cantin, G., Fernández, E., Heimdal, B. R., and Heldal, M., "Viral activity in relation to *Emiliania huxleyi* blooms: a mechanism of DMSP release?" *Marine Ecology Progress Series* Vol. 128, pp. 133-142 (1995).
8. Breitholtz, M., Rudén, C., Hansson, S. O., and Bengtsson, B. E., "Ten challenges for improved ecotoxicological testing in environmental risk assessment," *Ecotoxicology and Environmental Safety*, Vol. 63, pp. 324-335 (2006).
9. Brussard, C. P. D., Gast, G. J., Van Duyl, F. C., and Riegman, R., "Impact of phytoplankton bloom magnitude on a pelagic food web," *Marine Ecology Progress Series*, Vol. 144, pp. 211-221 (1996).
10. Chapman, G. A., Denton, D. L., and Lazorchak, J. M., *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to West Coast Marine and Estuarine Organisms*, First Edition, EPA/600/R-95-136, U.S. Environmental Protection Agency, Washington, D.C. (1995)
11. Chen, C. T. A., Wang, B. J., Huang, J. F., Lou, J. Y., Kuo, F. W., Tu, Y. Y., and Tsai, H. S., 'Investigation into extremely acidic hydrothermal fluids off Kueishantao islet, Taiwan," *Acta Oceanica Sinica*, Vol. 24, pp. 125-133 (2005).
12. Childress, J. J. and Fisher, C. R., "The biology of hydrothermal vent animals: physiology, biochemistry, and autotrophic symbioses," *Oceanography and Marine Biology: An Annual Review*, Vol. 30, pp. 337-441 (1992).
13. Coull, B. C. and Chandler, G. T., "Pollution and Meiofauna: Field, laboratory and mesocosm studies," *Oceanography and Marine Biology: An Annual Review*, Vol. 30, pp. 191-271 (1992).
14. Dahl, U., Gorokhova, E., and Breitholtz, M., "Application of growth-related sublethal endpoints in ecotoxicological assessments using a harpacticoid copepod," *Aquatic Toxicology*, Vol. 77, pp. 433-438 (2006).
15. Dahms, H.-U., Harder, T., and Qian, P.-Y., "Effect of meiofauna on macrofauna recruitment: settlement inhibition of the polychaete *Hydroides elegans* by the harpacticoid copepod *Tisbe japonica*," *Journal of Experimental Marine Biology and Ecology*, Vol. 311, pp. 47-61 (2004).
16. Dahms, H.-U., Harder, T., and Qian, P.-Y., "Selective attraction and reproductive performance of a harpacticoid copepod in a response to biofilms," *Journal of Experimental Marine Biology and Ecology*, Vol. 341, pp. 228-238 (2006).
17. Dahms, H.-U., Li, X., Zhang, G., and Qian, P.-Y., "Resting stages of *Tortanus forcipatus* (Crustacea, Calanoida) in sediments of Victoria Harbor, Hong Kong," *Estuarine, Coastal and Shelf Science*, Vol. 67, pp. 562-568 (2006).
18. Dahms, H.-U. and Qian, P.-Y., "Exposure of biofilms to meiofaunal copepods affects the larval settlement of *Hydroides elegans* (Polychaeta)," *Marine Ecology Progress Series*, Vol. 297, pp. 203-214 (2005).
19. Desbruyeres, D. M., Segonzac, M., and Bright, M., *Hydrothermal Vent Animals – Identification*, Linz Museum, Austria (2006).
20. D'Hondt, S., Donaghay, P., Zachos, J. C., Luttenberg, D., and Lindinger, M., "Organic carbon fluxes and ecological recovery from the cretaceous-tertiary mass extinction," *Science*, Vol. 282, pp. 276-279 (1998).
21. DiPinto, L. M., Coull, B. C., and Chandler, C. T., "Lethal and sublethal effects of the sediment associated PCB Aroclor 1254 on a meiobenthic copepod," *Environmental Toxicology and Chemical*, Vol. 12, pp. 1909-1918 (1993).
22. Epifanio, C. E., Perovich, G., Dittel, A. I., and Cary, S.C., "Development and behavior megalopa larvae and juveniles of the hydrothermal vent crab *Bythograea thermydron*," *Marine Ecology Progress Series*, Vol. 185, pp. 147-154 (1999).
23. Fuhrman, J. A., "Marine viruses and their biogeochemical and ecological effects," *Nature*, Vol. 399, pp. 541-548 (1999).
24. Gastrich, M. D., Leigh-Bell, J. A., Gobler, C., Anderson, O. R., and Wilhelm, S. W., "Viruses as potential regulators of regional brown tide blooms caused by the alga, *Aureococcus anophagefferens*: a comparison of bloom years 1999-2000 and 2002," *Estuaries*, Vol. 27, pp. 112-119 (2004).
25. Gómez-Gutiérrez, J., Peterson, W. T., De Robertis, A., and Brodeur, R. D., "Mass mortality of krill cause by parasitoid ciliates," *Science*, Vol. 301, p. 339 (2003).
26. Gourmelon, A. and Ahtiainen, J., "Developing Test Guidelines on invertebrate development and reproduction for the assessment of chemicals, including potential endocrine active substances – The OECD perspective," *Ecotoxicology*, Vol. 16, pp. 161-167 (2007).
27. Gramling, C., "Uncharted territory," *Science News*, Vol. 169, pp. 202-204 (2006).
28. Grassle, J. F., "The ecology of deep-sea hydrothermal vent communities," *Advances of Marine Biology*, Vol. 23, pp. 301-362 (1986).
29. His, E., Beiras, R., and Seaman, M. N. L., "The assessment of marine pollution – bioassays with bivalve embryos and larvae," In: Southward, A. J., Tyler, P. A., and Young, C. M. (Eds.), *Advances in Marine Biology*, Academic Press, San Diego (1999).
30. Hsü, K. J., He, Q., McKenzie, J. A., Weissert, H., Perch-Nielsen, K., Oberhänsli, H., Kelts, K., Labrecque, J., Tauxe, L., Krähenbühl, U., Percival, S. F. Jr., Wright, R., Karpoff, A. M., Petersen, N., Tucker, P., Poore, R. Z., Gombos, A. M., Pisciotto, K., Carman, M. F. Jr., and Schreiber, E., "Mass mortality and its environmental and evolutionary consequences," *Science*, Vol. 216, pp. 249-256 (1982).
31. Hwang, J.-S., Dahms, H.-U., Tseng, L.-C., and Chen, Q.-C., "Intrusions of the Kuroshio Current in the northern South China Sea affect copepod assemblages of the Luzon Strait," *Journal of Experimental Marine Biology and Ecology*, Vol. 352, pp. 12-27 (2007).
32. Hwang, J. S. and Lee, C. S., *The Mystery of Underwater World for Tourism of Turtle Island, Taiwan*, Northeast Coast National Scenic Area Administration, Tourism Bureau, The Ministry of Transportation, and Communication, Taiwan (2003). (in Chinese)
33. Hwang, J.-S., Wang, C.-H., and Chan, T.-Y. (Eds.), *Proceedings of the International Symposium on Marine Biology in Taiwan - Crustacean and Zooplankton Taxonomy, Ecology and Living Resources, 26-27 May, 1998, Taiwan*, National Taiwan Museum Special Publication Series, Vol. 10, pp. 1-199 (2000).
34. Jacquet, S., Heldal, M., Iglesias-Rodriguez, D., Larsen, A., Wilson, W., and Bratbak, G., "Flow cytometric analysis of an *Emiliana huxleyi* bloom terminated by viral infection," *Aquaict Microbial Ecology*, Vol. 27, pp.

111-124 (2002).

35. Jeng, M. S., Ng, N. K., and Ng, P. K. L., "Hydrothermal vent crabs feast on sea 'snow'," *Nature*, Vol. 432, pp. 969 (2004).
36. Jenssen, B. M., "Marine pollution: the future challenge is to link human and wildlife studies," *Environmental Health Perspect*, Vol. 111, pp. A198-A199 (2003).
37. Kusk, K. O. and Wollenberger, L., "Towards an internationally harmonized test method for reproductive and developmental effects of endocrine disrupters in marine copepods," *Ecotoxicology*, Vol. 16, pp. 183-195 (2007).
38. Kwok, K. W. H., and Leung, K. M. Y., "Toxicity of antifouling biocides to the intertidal harpacticoid copepod *Tigriopus japonicus* (Crustacea, Copepoda): effects of temperature and salinity," *Marine Pollution Bulletin*, Vol. 51, pp. 830-837 (2005).
39. Kwok, K. W. H., Leung, K. M. Y., Bao, V. W. W., and Lee, J. S., "Copper toxicity in the marine copepod *Tigriopus japonicus*: Low variability and high reproducibility of repeated acute and life-cycle tests," *Marine Pollution Bulletin*, Vol. 57, pp. 632-636 (2008).
40. Larrain, A., Soto, E., Silva, J., and Bay-Schmith, E., "Sensitivity of the meiofaunal copepod *Tisbe longicornis* to K2Cr2O7 under varying temperature regimes," *Bulletin of Environment Contamation and Toxicology*, Vol. 61, pp. 391-396 (1998).
41. Milius, S., "Into hot water: Lab test shows that worms seek heat," *Science News*, Vol. 169, pp. 228-229 (2006).
42. Mullineaux, L. S., Mills, S. W., Sweetman, A. K., Beaudreau, A. H., Metaxas, A., and Hunt, H. L., "Vertical, lateral and temporal structure in larval distributions at hydrothermal vents," *Marine Ecology Progress Series*, Vol. 293, pp. 1-16 (2005).
43. Nagasaki, K. and Yamaguchi, M., "Isolation of a virus infectious to the harmful blooms causing microalga *Heterosigma akashiwo* (Raphidophyceae)," *Aquatic Microbial Ecology*, Vol. 13, pp. 135-140 (1997).
44. OECD, *Detailed Review Paper on Aquatic Arthropods in Life Cycle Toxicity Tests with an Emphasis on Developmental, Reproductive and Endocrine Disruptive Effects*, OECD Series on Testing and Assessment, No. 55, ENV/JM/ 433 (2006).
45. Pedroso, M. S., Bersano, J. G., and Bianchini, A., "Acute silver toxicity in the euryhaline copepod *Acartia tonsa*: influence of salinity and food," *Environmental Toxicology and Chemical*, Vol. 26, pp. 2158-2165 (2007).
46. Pedroso, M. S., Pinho, G. L., Rodrigues, S. C., and Bianchini, A., "Mechanism of acute silver toxicity in the euryhaline copepod *Acartia tonsa*," *Aquatic Toxicology*, Vol. 82, pp. 173-180 (2007).
47. Raisuddin, S., Kwok, K. W. H., Leung, K. M. Y., Schlenk, D., and Lee, J.-S., "The copepod *Tigriopus*: a promising marine model organism for ecotoxicology and environmental genomics," *Aquatic Toxicology*, Vol. 83, pp. 161-173 (2007).
48. Sarmiento, J. L. and Orr, J. C., "Three-dimensional simulations of the impact of Southern Ocean nutrient depletion on atmospheric CO_2 and ocean chemistry," *Limnology and Oceanography*, Vol. 36, pp. 1928-1950 (1991).
49. Suttle, C. A., Anda, A., and Chan, M., "Marine cyanophages infecting oceanic and coastal strains of *Synechococcus*: Abundance, morphology, cross-infectivity and growth characteristics," *Marine Ecology Progress Series*, Vol. 92, pp. 99-109 (1993).
50. Templeton, R. C., Ferguson, P. L., Washburn, K. M., Scrivens, W. A., and Chandler, G. T., "Life-cycle effects of single-walled carbon nanotubes (SWNTs) on an estuarine meiobenthic copepod," *Environmentsl Science and Technology*, Vol. 40, pp. 7387-7393 (2006).
51. Tunnicliffe, V., "The biology of hydrothermal vents: ecology and evolution," *Oceanography and Marine Biology: An Annual Review*, Vol. 29, pp. 319-407 (1991).
52. VanDover, C. L., *The Ecology of Deep-Sea Hydrothermal Vents*, Princeton University Press, Princeton, N.J. (2000).
53. VanDover, C. L., German, C. R., Speer, K. G., Parson, L. M., and Vrijenhoek, R. C., "Evolution and biogeography of deep-sea vent and seep invertebrates," *Science*, Vol. 295, pp. 1253-1257 (2002).
54. Wang, C., Yang, M. L., Chou, C. P., Chang, Y. T., and Lee, C. S., "Westward extension of the Okinawa Trough at its western end in the northern Taiwan area: Bathymetric and Seismological Evidence," *Terrestrial, Atmospheric and Oceanic Science*, Vol. 11, No. 2, pp. 459-480 (2000).
55. Yang, T. F., Lan, T. F., Lee, H.-F., Fu, C.-C., Chuang, P.-C., Lo, C.-H., Chen, C.-H., Chen, C.-T. A., and Lee, C.-S., "Gas compositions and helium isotopic ratios of fluid samples around Kueishantao, NE offshore Taiwan and its tectonic implications," *Geochemical Journal*, Vol. 39, pp. 469-480 (2005).
56. Zar, J. H., Biostatistical Analysis, 4th Ed., Prentice Hall, Upper Saddle River, NJ (1999).