1 Background

NOWPAP CEARAC developed Procedures for the assessment of eutrophication status including evaluation of land-based sources of nutrients for the NOWPAP region (the NOWPAP Common Procedure) in June 2009 with the help of nominated experts in the NOWPAP member states. Then, the Procedure was used to assess the eutrophication status in the selected sea areas in the member states (Yangtze River Estuary and adjacent area in China, Northwest Kyushu sea area and Toyama Bay in Japan, Jinhae Bay in Korea, and Peter the Great Bay in Russia) in 2010-2011. Then, in 2011, the results of the assessments were combined and published as the Integrated Report on Eutrophication Assessment in Selected Sea Areas in the NOWPAP Region: Evaluation of the NOWPAP Common Procedure.

2 Objective

Objective of this activity is to improve the suitability of the NOWPAP Common Procedure by the refinement work and to apply the refined procedure to the existing or newly selected sea areas. Literature review will also be conducted to evaluate the methodology of the revised NOWPAP Common Procedure and to develop a regional overview of the eutrophication status in the NOWPAP region.

3. Progress of tasks

3.1 Refinement of the Common Procedures

Based on the lessons learned from the case studies on the eutrophication assessment in the selected sea areas of the NOWPAP member states in the 2010-2011 biennium, CEARAC has prepared the refined NOWPAP Common Procedure (UNEP/NOWPAP/CEARAC/FPM 11/Ref4) together with the experts nominated from each member state (table 1).

In the refined NOWPAP Common Procedure, there are two steps in assessing the eutrophication status: Screening Procedure (initial diagnosis) to detect symptoms of eutrophication with the minimum required parameters; and Comprehensive Procedure (second diagnosis) to assess status and possible causes of eutrophication using the existing four categories (Degree of nutrient enrichment, Direct effects of nutrient enrichment, indirect effects of nutrient enrichment, and other possible effects of nutrient enrichment). As all of the currently selected sea areas have shown symptoms of eutrophication in the past and/or at present, Comprehensive Procedure is being applied to each selected sea area.

.

Table 1. Case study areas and experts in each NOWPAP member state

Country	Selected sea areas	Nominated experts
China	Jiazhou Bay	Dr. Zhiming YU, Chinese Academy of Science, Institute of Oceanology
Japan	Northwest Kyushu Sea Areas Toyama Bay	Northwest Pacific Region Environmental Cooperation Center (NPEC)
Korea	Jinhae Bay	Dr. Changkyu Lee South-east Sea fisheries Research Institute, National Fisheries Research and Development Institute
Russia	The Peter the Great Bay	Dr. Pavel Tishchenko, Hydrochmistry Laboratory, Department of the Ocean Geochemistry and Ecology, V. I. Il'ichev Pacific Oceanological Institue, Far Easter Brach of Russian Academy of Sciences

3.2 Literature review on eutrophication assessment and ecological modeling

In order to prepare an overview on the assessment of the eutrophication status of the whole NOWPAP region, the nominated experts has collected literatures on negative impact of eutrophication, ecological modeling and availability of monitoring data, which have been published and/or released in each NOWPAP member state (Annex 1).

Obtained eutrophication assessment results with the refined NOWPAP Common Procedure will be reviewed by the collected literatures.

3.3 Preparation of the regional overview of the eutrophication assessment for the NOWPAP region

Based on the case study reports in each selected sea prepared by the nominated experts (Annex 2), CEARAC Secretariat is developing the regional overview of the eutrophication status for the NOWPAP region with the help of a hired consultant. Provisional table of contents the regional overview (Annex 3) were presented at the Expert Meeting on Marine Biodiversity and Eutrophication in the Northwest Pacific Region held on 5-6 August 2013 for consideration by national experts. The regional overview and the refined NOWPAP Common Procedure will be finalized and published by the end of 2013.

4. Expected outcomes

The obtained assessment results by the refined NOWPAP Common Procedure and the results of literature reviews in each NOWPAP member state will be harmonized and integrated in the regional overview of the eutrophication assessment for the NOWPAP region. The developed Regional Overview of the Eutrophication Assessment for the NOWPAP region will be shared among coastal managers in the NOWPAP member states and expected to foster a common understanding on the status of eutrophication in the NOWPAP region.

The eutrophication status of each case study area will also be summarized and posted on the CEARAC website to be available for the public.

5. Schedule

Time		Actions	Main body
2013	September (11th CEARAC FPM)	• Review of the case study reports and provisional table of contents of the regional overview by CEARAC FPM	CEARAC and FPs
	September	• Complete case study reports in each selected sea area	National Experts
	October	• Develop the draft regional overview on the eutrophication assessment	CEARAC and consultant
	Early to mid November	• Review of the draft regional overview by CEARAC FP and NOWPAP RCU	CEARAC FP and NOWPAP RUC
	Mid to End November	• Review of the draft regional overview by NOWPAP National FP including proofreading	CEARAC Secretariat
	December	• Publishing the regional overview on the eutrophication assessment	CEARAC

#	Title	Country
1	CCIED (2010) Ecosystem Issues and Policy Options Addressing Sustainable Development of China's Ocean and Coast. CCICED Task Force Report.	China
2	Chen, C-T. A. (2000) The Three Gorges Dam: Reducing the upwelling and thus productivity in the East China Sea. Geophysical Research Letters, 27, 381-383.	China
3	Chen, C-C., G-C. Gong and F-K. Shiah (2007) Hypoxia in the East China Sea: One of the largest coastal low-oxygen areas in the world. Marine Environmental Research, 64, 399-408.	China
4	Chen, M.Y., Yu, Z.M., Song, X.X., & Cao, X.H., 2007. Evaluation of fuzzy synthesis to assess the seawater eutrophication in the Changjiang estuary. Marine Sciences, 31(11), 47-54(in Chinese with English abstract).	China
5	Chai C, Yu Z, Song X, Cao X (2006). The Status and Characteristics of Eutrophication in the Yangtze River (Changjiang) Estuary and the Adjacent East China Sea, China. Hydrobiologia 563: 313-328.	China
6	Chen C-TA (2000). The Three Gorges Dam: Reducing the upwelling and thus productivity in the East China Sea. Geophysical Research Letters 27: 381-383.	China
7	Chen-Tung Arthur Chen and Shu-Jun Wang (1999) Carbon, alkalinity and nutrient budgets on the East China Sea continental shelf. JGR. Vol.104, No.C9.	China
8	Dong, Z., D. Liu, J. K. Keesing (2010) Jellyfish blooms in China: Dominant species, causes and consequences. Marine Pollution Bulletin, 60, 954-963.	China
9	Gong, G-C., J. Chang, K-P. Chiang, T-M. Hsiung, C-C. Hung, S-W. Duan and L. A. Codispoti (2006) Reduction of primary production and changing of nutrient ratio in the East China Sea: Effect of the Three Gorges dam? Geophysical Research Letters, 33, L07610, doi: 10.1029/2006GL025800.	China
10	Hu, C., D. Li, C. Chen, J. Ge, F. E. Muller-Karger, J. Liu, F. Yu and M-X. He (2010) On the recurrent Ulva prolifera blooms in the Yellow Sea and East China Sea. Journal of Geophysical Research, 115, 1-8, C05017, doi: 10.1029/2009JC005561.	China
11	Huang X P, Huang L M, Yue W Z. 2003. The characteristics of nutrients and eutrophication in the Pearl River estuary, South China. Mar. Pollut. Bull., 47 (1-6):30-36.	China
12	Hao Wei, Jun Sun, Andreas Moll and Liang Zhao (2004) Phytoplankton dynamics in the Bohai Sea—observations and modeling. JMS.	China
13	Leliaert, F., X. Zhang, N. Ye, E. Malta, A. H. Engelen, F. Mineur, H. Verbruggen and O. D. Clerck (2009) Identity of the Qingdao algal bloom. Phycological Research, 57, 147-151.	China
14	Liu S. M., Zhang J., Chen H. T., Wu Y., Xiong H. and Zhang Z. F. (2003) Nutrients in the Changjiang and its tributaries. Biogeochemistry, 62, 1-18.	China
15	Liu, D., J. K. Keesing, Z. Dong, Y. Zhen, B. Di, Y. Shi, P. Fearns and P. Shi (2010) Recurrence of the world's largest green-tide in 2009 in Yellow Sea, China: Porphyra yezoensis aquaculture rafts confirmed as nursery for macroalgal blooms. Marine Pollution Bulletin, 60, 1423-1432.	China
16	Li, D., Zhang, J., Huang, D., et al., 2002. Oxygen depletion off the Changjiang (Yangtze River) Estuary. Science in China 45:1137–1146.	China
17	Li M, Xu K, Watanabe M, Chen Z (2007). Long-term variations in dissolved silicate, nitrogen, and phosphorus flux from the Yangtze River into the East China Sea and impacts on estuarine ecosystem. Estuarine, Coastal and Shelf Science 71: 3-12.	China
18	Liu S, Zhang J, Chen HT, Wu Y, Xiong H, Zhang ZF (2003). Nutrients in the Changjiang and its tributaries. Biogeochemistry 62: 1-18.	China

19	NSQS (1997) National Seawater Quality Standard of China, GB3097-1997.	China
20	NSQS, 1997. National seawater quality standard. GB 3097-1997 (in Chinese) .	China
21	Qiao, L.L., Wang, Y.Z., Li, G.X., Deng, S.G., Liu, Y., Mu, L., 2011. Distribution of suspended particulate matter in the northern Bohai Bay in summer and its relation with thermocline. Estuar. Coast. Shelf. Sci. 93, 212-219.	China
22	Shen, Z. L., 2001. Historical changes in nutrient structure and its influences on phytoplantkon composition in Jiaozhou Bay. Estuar. Coast. Shelf Sci., 52 (2):211-224.	China
23	State Oceanic Administration, 2006. Bulletin of Marine Environmental Quality of China (in Chinese)	China
24	State Oceanic Administration, 2007. Bulletin of Marine Environmental Quality of China (in Chinese)	China
25	State Oceanic Administration, 2008. Bulletin of Marine Environmental Quality of China (in Chinese)	China
26	State Oceanic Administration, 2009. Bulletin of Marine Environmental Quality of China (in Chinese)	China
27	Su, C., Shen, Z.L., Yao, Y., & Cao, H.R., 2008. Assessment of eutrophication in the Yangtze River estuary and its adjacent waters. Advances in Water Science, 19(1), 99–105(in Chinese with English abstract).	China
28	Sun, S., et al., 2011. Atlas of long-term changes in the Jiaozhou Bay ecosystem. Beijing. Ocean Press. p: 60-179.	China
29	Sun, S., et al., 2011. Lakes, wetland and Bays ecosystem dataset of China: Jiaozhou Bay marine ecosystem. Beijing. Agricultural Press of China. p:80-135.	China
30	Sun, X. X., Sun, S., Zhao, Z. X., et al. 2011. Long term changes in nutrient concentrations and structure in the Jiaozhou Bay. Oceannologia et limnologia sinica. 42 (5): 662-669.	China
31	Song S, Sun J, Luan Q, Shen Z (2008). Size-fractionated phytoplankton biomass in autumn of the Changjiang (Yangtze) River Estuary and its adjacent waters after the Three Gorges Dam construction. Chin J Ocean Limnol 26: 268-275.	China
32	Shin S. Y, C I Lee, S-C. Hwang and K. D. Cho. 2004. Relationship between pollutuion factors and environmental variation in waters around Masan Bay. Journal of the Korean Society of Marine Environment and Safety. 10(2): 69-79 (in Korean).	China
33	Tian, R. C., F. X. Hu and J. M. Martin (1993) Summer nutrient fronts in the Changjiang (Yantze River) Estuary. Estuarine, Coastal and Shelf Science, 37, 27-41.	China
34	Tian Tian, Hao Wei, Jian Su and Changsoo Chung (2005) Simulations of annual cycle of phytoplankton production and the utilization of nitrogen in the Yellow Sea. JO. Vol.61.	China
35	Wang B (2007). Assessment of trophic status in Changjiang (Yangtze) River estuary. Chin J Ocean Limnol 25: 261-269.	China
36	Wang, B. D. (2006) Cultural eutrophication in the Changjiang (Yangtze River) plume: History and perspective. Estuarine, Coastal and Shelf Science, 69, 471-477.	China

37	Wei, H., Y. He, Q. Li, Z. Liu and H. Wang (2007) Summer hypoxia adjacent to the Changjiang Estuary. Journal of Marine Systems, 67, 292-303.	China
38	Wang gang. 2009. Research on the pollutants fluxes from point sources and aquaculture farms. Master thesis (in Chinese).	China
39	Wu, Y. L., Sun, S., Zhang, Y. S., et al. 2005. The impact of long term changes of environment to the structures of phytoplanktons in Jiaozhou Bay. Chinese Journal of Oceanology and Limnology. 36 (6): 487-499.	China
40	Xiao, Y. J., Ferrerira, J. G., Bricker, S. B., et al. 2007. Trophic assessment in Chinese coastal systems: review of methods and application to the Changjiang (Yangtze) estuary and Jiaozhou Bay. Estuaries Coasts, 30 (6):901-918.	China
41	Xinyu Guo and Tetsuo Yanagi (1999) Three dimensional structure of tidal current in the East China Sea and Yellow Sea. JO. Vol.54.	China
42	Zhou, M (2010) Environmental settings and harmful algal blooms in the sea area adjacent to the Changjiang River Estuary. pp. 133-149. Coastal environmental and ecosystem issues of the East China Sea (eds., Ishimatsu, A. and H. -J. Lie) TERRAPUB and Nagasaki University.	China
43	Zhang, X. Q., Sun, Y. L., 2007. Research on the control of total pollutants loads into the Jiaozhou Bay. Marine Environmental Sicence. 26(4): 347-351.	China
44	Zou, J.Z., Dong, L.P., & Qin, B.P., 1983. Preliminary Study of eutrophcaion and algal bloom in Bohai Bay. Marine Environmental Science, 2(2), 41-54 (in Chinese).	China
45	Fukuyo, Y., Imai, I., Kodama, M. and Tamai, K. (2002) Red tides and other harmful algal blooms in Japan. in 'Harmful Algal blooms in the PICES Region of the North Pacific (eds by F. J. R. 'Max' Taylor and V. L. Trainer)', PICES Scientific Report, No.23, North Pacific Marine Science Organization, 7-20.	Japan
46	Fukuoka City (2008) Hakata Bay environmental conservation plan, Clean water plan. pp.77	Japan
47	Fuchigami, S. (2009) Nutrient state and Porphyra (nori) aquaculture in Hakata Bay. Aquabiology, 31, 171-172.	Japan
48	Fujiwara T, Kobayashi S, Kunii M, Uno N (2006) Nitrogen and Phosphorus in Seto Inland Sea: Their Origin, Budget and Variability. Bull Coast Oceanogr 43(2):129-136	Japan
49	Goh Onitsuka and Tetsuo Yanagi (2005) Differences Ecosystem Dynamics between the Northern and Southern Parts of the Japan Sea : Analyses with Two Ecosystem Models. JO. Vol.61.	Japan
50	Goh Onitsuka, Tetsuo Yanagi and John-Hwan Yoon (2007) A numerical study on nutrient sources in the surface layer of the Japan Sea using a coupled physical-ecosystem model. JGR. Vol.112.	Japan
51	Harashima, A. (2007) Evaluating the effects of change in input ratio of N: P: Si to coastal marine ecosystem. Journal of Environmental Science for Sustainable Society, 1, 33-38.	Japan
52	Isobe A, Kamizono M, Tawara S (1993) An Oxgen-Deficient Water Mass in the Southwestern Part of the Suo Sea. Bull Coast Oceanogr 31 (1)	Japan
53	Ishii D, Yanagi T (2009) Generation and Disapperance Mechanisms of Hypoxia in the Head of Hakata Bay. Oceanography in Japan 18(2): 169-176	Japan
54	Japan Fisheries Resource Conservation Association (2005) Fisheries water quality standard.	Japan

55	Kawahara, K. S. Uye, K. Ohtsu and H. Iizumi (2006) Unusual population explosion of the giant jellyfish Nemopilema nomurai (Scyphozoa: Rhizostomeae) in East Asian waters. Marine Ecology Progress Series, 307, 161-173.	Japan
56	Kishi et al. 2007. NEMURO—a lower trophic level model for the North Pacific marine ecosystem. Ecological Modelling 202: 12-25.	Japan
57	Kuramoto T, Nakata K (1991) Numerical Simulation of the Formation and Movement of an Oxygen Dificient Water Mass in Tokyo Bay. Bull Coast Oceanogr 28 (2)	Japan
58	Kobayashi S, Fujiwara T, Harashima A (2007) Seasonal and Inter-annual Variation of Dissolved Inorganic Nitrogen in the Seto Inland Sea. Bul Coast Oceanogr 44(2): 165-175	Japan
59	Ministry of the Environment of Japan (1971) Environmental quality standards for water pollution.	Japan
60	Ministry of the Environment of Japan (2011) Guidance for Introducing the Total Pollutant Load Control System 101pp.	Japan
61	Miyahara K, Uji R, Yamada H, Matsui Y, Nishikawa T, Onitsuka G (2005) A harmful algal bloom of Cochlodinium polykrikoides Margalef (Dinophyceae) in the coastal area of San-in, western part of the Japan Sea, in September 2003. Bull Plankton Soc Japan 52: 11–18. (in Japanese with English abstract)	Japan
62	M. Kawamiya et al. (2000a) An ecosystem model for the North Pacific embedded in a general circulation model. Part I: Model descriptions of biological variables, J. Marine Systems, Vol.25, 129-157.	Japan
63	M. Kawamiya et al. (2000b) An ecosystem model for the North Pacific embedded in a general circulation model. Part II:Mechanisms forming seasonal variations of chlorophyll, J. Marine Systems, Vol.25, 159-178.	Japan
64	M. J. Kishi et al. (1981) Sensitivity analysis of a coastal marine ecosystem, J. Oceanog., Vol.37, 102-134.	Japan
65	Magome S, Isobe A, Kamizono M (2002) The Response of the Oxygen-Deficient Water Mass to River Discharge in Suo-Nada. Bull Coast Oceanogr 40 (1): 59-70	Japan
66	Nakamura, T., K. Matsumoto, M. Uematsu (2005) Chemical characteristics of aerosols transported from Asia to the East China Sea: an evaluation of anthropogenic combined nitrogen deposition in autumn. Atmospheric Environment, 39, 1749-1758.	Japan
67	Nakao T, Matsuzaki K (1995) Potential for Eutrophication based on the Topography of Coastal Bays, Oceanographic Society of Japan	Japan
68	Onitsuka, G., I. Uno, T. Yanagi and J. H. Yoon (2009) Modeling the effect of atmospheric nitrogen input on biological production in the Japan Sea. Journal of Oceanography, 65, 433-438.	Japan
69	Onitsuka, G., K. Miyahara, N. Hirose, S. Watanabe, H. Semura, R. Hon, T. Nishikawa, K. Miyagi and M. Yamaguchi (2010) Large-scale transport of Cochlodinium polykrikoides blooms by the Tsushima Warm Current in the southwest Sea of Japan. Harmful Algae, 9, 390-397.	Japan
70	Okunishi et al. 2009. A simulation model for Japanese sardine (Sardinops melanostictus) migrations in the western North Pacific. Ecological Modelling 220: 462-479.	Japan
71	Onitsuka G, Yanagi T, Yoon J-H (2007). A numerical study on nutrient sources in the surface layer of the Japan Sea using a coupled physical-ecosystem model. Journal of Geophysical Research: Oceans 112: C05042.	Japan
72	Toyama Bay Water Quality Preservation Research Committee (2001) Report on water pollution in Toyama Bay.	Japan

73	Toyama Prefectural Government (2008) Clean Water Plan. 106pp.	Japan
74	Toyama Prefecture (2008) Water and Environment Plan in Toyama Prefecture, Clean Water Plan, p106, Civic Affairs, Environment and Culture Department, Environmental Conservation Division, Toyama Prefecture.	Japan
75	Toyama Bay Water Quality Preservation Research Committee (2001) Bulletin of the FY2000. Toyama Bay Water Quality Preservation Research Committee – the pollution of water in Toyama Bay. pp. 3-37-3-43, Civic Affairs, Environment and Culture Department, Toyama Prefecture.	Japan
76	Tetsuo Yanagi, Goh Onitsuka, Naoki Hirose and John-Hwan Yoon (2001) A Numerical Simulation on the Mesoscale Dynamics of the Spring Bloom in the Sea of Japan. JO. Vol.57.	Japan
77	Taniguchi A, Nakashima Y, Suzuki T, Hirakawa K, Imamura A, Ikeda T (1997) Seasonal variations in the phytoplankton assembly in Toyama bay, southern Japan sea. Buee. Japan Sea Natl Fish Res Inst (47):33-55	Japan
78	Tsukuda S, Sugiyama M, Harita Y, Nishimura K (2006). Atmospheric Phosphorus Deposition in Ashiu, Central Japan – Source Apportionment for the Estimation of True Input to a Terrestrial Ecosystem. Biogeochemistry 77: 117-138.	Japan
79	Uematsu, M., A. Yoshikawa, H. Muraki, K. Arao, I. Uno (2002) Transport of mineral and anthropogenic aerosols during a Kosa event over East Asia. Journal of Geophysical Research, 107(D7), 4059, doi: 10.1029/2001JD000333.	Japan
80	Uye, S. (2008) Blooms of the giant jellyfish Nemopilema nomurai: a threat to the fisheries sustainability of the East Asian Marginal Seas. Plankton Benthos Research, 3, 125-131.	Japan
81	Uematsu M, Yoshikawa A, Muraki H, Arao K, Uno I (2002). Transport of mineral and anthropogenic aerosols during a Kosa event over East Asia. Journal of Geophysical Research: Atmospheres 107: AAC 3-1-AAC 3-7.	Japan
82	Ueno Y, Miyahara S (2002) Secular Change of the Nutrition Salt and Chlorophyll-a in the Eastern Hakata Bay	Japan
83	Uye, S. (2008) Bloom of the giant jellyfish Nemopilema nomurai: a threat to the fisheries sustainability of the East Asian Marginal Seas. Plankton Benthos Res 3:125-131	Japan
84	Yamamoto, T. (2003) The Seto Inland Sea-eutrophic or oligotrophic? Marine Pollution Bulletin, 47, 37-42.	Japan
85	Yanagi, T. (2007) Sato-umi: A new concept for coastal sea management, Terra Scientific Publishing Company, Tokyo, pp 86.	Japan
86	Yokoyama, H. (2003) Environmental quality criteria for fish farms in Japan. Aquaculture, 226, 45-56.	Japan
87	Yanagi T, Ishii D (2008) Seasonal and Year-to-year Variations in Water Quality at the Head of Hakata Bay. Oceanography in Japan, 17(4): 255-264	Japan
88	Yamamoto H, Yamamoto T, Takada T, Mito Y, Takahashi T (2011) Dynamic Analysis of Oxygen-Dificient Water Mass Formed in the Northern Part of Hiroshima Bay Using a Pelagic-Benthic Coupled Ecosystem Model. Journal of Japan Society on Water Environment 34 (2): 19-28	Japan
89	Yokota M, Marumo K (2012) Review on Hypoxia Formation and its Effects on Aquatic Organisums. Rep Mar Ecol Res Inst 15:1-21	Japan
90	Yanagi (2004) Can a Numerical Ecosystem Model Reproduce the Ecosystem of Ariake Bay? Bull Coast Oceanogr 42 (1): 61-65	Japan

91	Yanagi T, Hayashi M (2002) Comparison of the Lower Trophic Level Ecosystem with Suo-Nada and the Inner Part of Osaka Bay	Japan
92	Zhang, J. and H. Satake (2003) Chemical characteristics of submarine groundwater seepage in Toyama Bay, Central Japan. Land and Marine Hydrogeology. Ed. by M. Taniguchi, K. Wang and T. Gamo Elsevier, Amsterdam, The Netherlands.	Japan
93	Zhang, J. and H. Satake (2003) Chemical characteristics of submarine groundwater seepage in Toyama Bay, Central Japan. Land and Marine Hydrogeology. Ed. by M. Taniguchi, K. Wang and T. Gamo Elsevier, Amsterdam, The Netherlands.	Japan
94	Cho H. Y. and J. W. Chae. 1998. Analysis of the Characteristics of the pollutant load in Chinhae-Masan Bay. Journal of Korean Society of Coastal and Ocean Engineers. 10(3): 132-140 (in Korean).	Korea
95	Cho C-H (1991). Mariculture and eutrophication in Jinhae Bay, Korea. Marine Pollution Bulletin 23: 275-279.	Korea
96	Chang WK, Ryu J, Yi Y, Lee W-C, Lee C-W, Kang D et al (2012). Improved water quality in response to pollution control measures at Masan Bay, Korea. Marine Pollution Bulletin 64: 427-435.	Korea
97	Han, M-S., J-K. Jeon and Y-O. Kim (1992) Occurrence of dinoflagellate Alexandrium tamarense, a causative organism of oaralytic shellfish poisoning in Chinhae Bay, Korea. Journal of Plankton Research, 14, 1581-1592.	Korea
98	Han M-S, Jeon J-K, Kim Y-O (1992). Occurrence of dinoflagellate Alexandrium tamarense, a causative organism of paralytic shellfish poisoning in Chinhae Bay, Korea. Journal of Plankton Research 14: 1581-1592.	Korea
99	Hyun-cheol Kim, Sinjae Yoo and Im Sang Oh (2007) Relationship between phytoplankton bloom and wind stress in the sub-polar frontal area of the Japan/East Sea. JMS	Korea
100	Kim, T-W., K. Lee, R. G. Najjar, H-D. Jeong and H. J. Jeong (2011) Increasing N abundance in the Northwestern Pacific Ocean due to atmospheric nitrogen deposition. Science, 334, 505-509.	Korea
101	Kim J. H. 1984. Seawater exchange in Chinhae bay Pukyong Nat'l Univ. MS Thesis. 36 pp (in Korean).	Korea
102	Lee C-K. and W. Lim (2006) Variation of harmful algal blooms in Masan-Chinhae Bay. Science Asia, 32, 51-56.	Korea
103	Lee, Y-W., D-W. Hwang, G. Kim, W-C. Lee, Y-T. Oh (2009) Nutrient inputs from submarine groundwater discharge (SGD) in Musan Bay, an embayment surrounded by heavily industrialized cities, Korea. Science of the Total Environment, 407, 3181-3188.	Korea
104	Lee DI, Park CK, Cho HS (2005). Ecological modeling for water quality management of Kwangyang Bay, Korea. Journal of Environmental Management 74: 327-337.	Korea
105	Lee D-I, Choi J-M, Lee Y-G, Lee M-O, Lee W-C, Kim J-K (2008). Coastal environmental assessment and management by ecological simulation in Yeoja Bay, Korea. Estuarine, Coastal and Shelf Science 80: 495-508.	Korea
106	Lim H-S, Diaz RJ, Hong J-S, Schaffner LC (2006). Hypoxia and benthic community recovery in Korean coastal waters. Marine Pollution Bulletin 52: 1517-1526.	Korea
107	Lee J. H. 1998. Policy issues and management framework of Chinhae Bay, Republic of Korea. Ocean & Coastal Management. 38: 161-178.	Korea
108	Lee I. C., Y. J. Oh and H. T. kim. 2008. Annual variation in oxygen-deficient water mass in jinhae bay, Korea. J. of. kor. Fish. soc. 41(2): 134-139 (in Korean).	Korea

109	Lim H-S, Diaz RJ, Hong J-S, Schaffner LC (2006). Hypoxia and benthic community recovery in Korean coastal waters. Marine Pollution Bulletin 52: 1517-1526.	Korea
110	MOMAF. 2002. Improving coastal environment of Coastal Environmental Management Area (CEMA) (In Korean).	Korea
111	Nam, J. H., D. S Kang, J. S. Yoon, A. A. Yoon, J. Y. Choi, H. J. Choi, H. H. Lim and J. D. Kim (2005) Management strategies for the coastal environment of the Masan-Chinhae Bay. Proceedings of the workshop on ecosystem management of interrelated river basins, estuaries and coastal sea. 104-112 pp.	Korea
112	Nam J.H., D. S Kang, J. S. Yoon, A. A. Yoon, J. Y. Choi, H. J. Choi, H. H. Lim and J. D. kim. 2005. Management Strategies for the Coastal Environment of the Masan-Chinhae Bay. Proceeding of the workshop on ecosystem management of interrelated river basins, esturies and coastal sea. 104-112 pp.	Korea
113	Oh, H. T., W. C. Lee. S. E. Park, S. J. Hong, R. H. Jung and J. S. Park (2006) Marine ecosystem response to nutrient input reduction in Jinhae Bay, South Korea. Journal of Environmental Sciences, 9, 819-827.	Korea
114	Oh H. T., W. C. Lee. S. E. Park, S. J. Hong, R. H. Jung and J. S. Park. 2006. Marine ecosystem response to nutrient input reduction in Jinhae Bay, South Korea. Journal of Environmental Sciences. 9: 819-827.	Korea
115	Park K, Jung H-S, Kim H-S, Ahn S-M (2005). Three-dimensional hydrodynamic-eutrophication model (HEM-3D): application to Kwang-Yang Bay, Korea. Marine Environmental Research 60: 171-193.	Korea
116	Park S. C., K. W. Lee and Y. I. Song. 1995. Acoustic characters and distribution pattern of modern fine-grained deposits in a tide-dominated coastal bay: Jinhae bay, Southeast Korea. Geo-Marine Letters. 15: 77-84.	Korea
117	Anikiev V.V. (1987) Short-scale of geochemical processes and pollution of ocean. Moscow. Nauka. 192 p.	Russia
118	Belan T.A. (2003) Benthos abundance pattern and species composition in conditions of pollution in Amursky Bay (Peter the Great Bay, Sea of Japan). Marine Pollution Bulletin, 46, 1111–1119.	Russia
119	Belan, T.A., Tkalin A.V., Lishavskaya T.S. (2003) The present status of bottom ecosystems of Peter the Great Bay (the Sea of Japan). Pacific Oceanography, 1, 158–167.	Russia
120	Belan T.A., Moshchenko A.V. (2005) Polychaete taxocenes variability associated with sediment pollutionloading in the Peter the Great Bay (East Sea/Japan Sea). Ocean Science Journal, 40, 1-10.	Russia
121	Belan T.A., Belan L.S. (2006) Composition and Quantitative Distribution of Macrozoobenthos in Amursky Bay. Okeanology, 46, 685-694. (Rus.).	Russia
122	Boyarova M.D., Lukyanova O.N. (2012) Persistent organochlorine pesticides in bivalve mollusks and fish from Peter the Great Bay, pp 334-345. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).	Russia
123	Dolganova N.T. (2005) Plankton researches in TINRO: history, directions, results. Izv. TINRO, 141, 209 –228.	Russia
124	Ecological normalization and management of coastal aquatic area of Primorye (2000). Report of Pacific Oceanological Institute (POI FEB RAS), No 01.20.00 06073. Vladivostok, pp 28.	Russia
125	Galysheva Yu. A. (2009) Biological Consequences of Organic Pollution of Nearshore Marine Ecosystems in the Russian Waters of the Sea of Japan. Russian Journal of Marine Biology, 35, 521–534.	Russia
126	Gavrilevsky A. V., Gavrilova T. A., Kochergin I. E. (1998) Complex Quantitative Assessment of the Sources Polluting the Sea Adjacent to Vladivostok. pp 102-113. FERHRI Proceedings, Special Issue (Rus.).	Russia

127	Gomoyunov K.A. (1927) Hydrological essay of Amursky Bay and Suyphun River. I conference: Production power of Far East. Vladivostok: 2, 73-91. (Rus.).	Russia
128	Henze M. (2006) Wastwater, Volumes and Composition. pp. 25-59. Wastewater Treatment. Biological and Chemical Processes. Ed. Mogens Henze. Politeknisk Forlag. (Rus. Moscow, “Mir”).	Russia
129	Khen G.V., Moroz I.F. (2005) Oceanographic studies in TINRO-Center. Izv. TINRO, 141, 297-324.	Russia
130	Khristoforova N.K., Shulkin V.M.,Kavun V.I. and Chernova F.M. (1993) Heavy metals in commercial and cultured mollusks of Peter the Great Bay. Vladivostok: Dalnauka, pp 296. (Rus.).	Russia
131	Khristoforova N.K. (2012) Peter the Great Bay: natural environment and biodiversity, 12-30. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).	Russia
132	Klimova V.L. (1971) Quantitative distribution of benthos in Peter the Great Bay (Sea of Japan) in summer of 1970. Proceedings VNIRO, 87, 97-103.	Russia
133	Klimova V.L. (1976) Variation of distribution of benthic trophic zones in Peter the Great Bay from 1930s to the 1970s. Oceanology, 16, 343-345.	Russia
134	Konovalova G.V., Orlova T.Yu., Pautova L.A. (1989) Atlas of phytoplankton of the Japan Sea. Leningrad: Nauka, pp 160. (Rus.).	Russia
135	Korshenko A., Matveichuk I., Plotnikova T., Udovenko A.V., Luchkov V.P. (2008a) Marine Water Pollution. Annual Report, 2005. Moscow. PC “Meteoagency ROSHYDROMET”, pp 160.	Russia
136	Korshenko A., Matveichuk I., Plotnikova T., Udovenko A.V. (2008b) Marine Water Pollution. Annual Report, 2006. Obninsk. PC “Artifex”, pp 146.	Russia
137	Korshenko A., Matveichuk I., Plotnikova T., Panova A., Ivanov D., Kirianov V. (2009a) Marine Water Pollution. Annual Report, 2007. Obninsk. PC “FOP”, pp 199.	Russia
138	Korshenko A., Matveichuk I., Plotnikova T., Panova A., Ivanov D., Kirianov V., Krutov A., Kochetkov V. (2009 b) Marine Water Pollution. Annual Report, 2008. Obninsk. PC “FOP”, pp 192.	Russia
139	Kovekovdova L.T., Kiku D.P., Blokhin M.G. (2012) Metals in bottom sediments of Peter the Great Bay, pp 312-333. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).	Russia
140	Lastovetsky E.I, Veshcheva V.M. (1964) Hydrometeorological essay of Amurskiy and Ussuriiskiy Bays. Ed. Zaokopnaya L.N. Vladivostok: Regional Hydrometeorological agency, pp 264. (Rus.).	Russia
141	Levenets I.R., Skriptsova A.V. (2008) Benthic flora of the inner part of Amursky Bay (Sea of Japan), pp 284 – 301. Ecological Studies and the State of the Ecosystem of Amursky Bay and the Estuarine Zone of the Razdolnaya River (Sea of Japan), 1.	Russia
142	Lishavskaya T.S., Sevastyanov A.V., Chernova A.C., Chatkina T.V. (2010) Monitoring of pollutions of Peter the Great Bay coastal area. Proceedings. FERHRI – 60 year. Vladivostok, 97-112.	Russia
143	Luchin V.A., Tikhomirova E.A., Kruts A.A. (2005) Oceanographic regime of Peter the Great Bay (Japan Sea). Izvestiya TINRO, 140, 130-169. (Rus.).	Russia
144	Luchin V.A., Kislova S.I., Kruts A.A. (2007). Tendencies of long-term changes of temperature in the waters of Peter the Great Bay, pp 33-50. Dynamics of Marine Ecosystems and Modern Problems of Conservation of Biological Resources of the Russian Seas. Vladivostok: Dalnauka. (Rus.).	Russia

145	Lukyanova O.N., Cherkashin S.A., Nigmatulina L.V., Chernyaev A.P., Veideman E.L., Ireykina S.A., Pryazhevskaya T.S. (2009) Integral chemical-ecological assessment of the state of Ussuriysky Bay (the Sea of Japan) 36 (5), 615-622. (Rus.).	Russia
146	Lukyanova O.N., Cherkashin M.V., Simokon M.V. (2012) The review of modern ecological state of Peter the Great Bay (2000-2010). Vestnik FEB RAS, 2, 55-63. (Rus.).	Russia
147	Lutaenko K.A., Vaschenko M.A. (2008) Amursky Bay – an ecosystem under stress, pp 7-29. Ecological studies and the state of ecosystems of Amursky Bay and estuarine zone of Razdolnaya River, 1. Vladivostok: Dalnauka. (Rus.).	Russia
148	Mihailik T.A., Tishchenko P.Ya., Koltunov A.M., et al. (2011) Impact of Razdolnaya River on ecological status of the Amursky Bay (Japan Sea). Water Resources, 38, 474-484. (Rus.).	Russia
149	Moshchenko A.V, Belan T.A. (2008) Ecological state and long–term changes of macrozoobenthos in the northern part of Amursky Bay (Sea of Japan), pp 61-91. Ecological studies and the state of ecosysytems of Amursky Bay and estuarine zone of Razdolnaya River, 1. Vladivostok: Dalnauka. (Rus.).	Russia
150	Nadtochy V.V. (2012) Seasonal dynamics of plankton in the Amursky Bay (Japan Sea). Izv. TINRO, 169, 147-161. (Rus.).	Russia
151	Nadtochy V.A., Budnikova L.L., Besrukov R.G. (2005a) Macrozoobenthos of Peter the Great Bay (Japan Sea): composition, distribution, stocks. Izvestiya TINRO, 140, 170-195. (Rus.).	Russia
152	Nadtochy V.A., Koblikov V.N. (2005b) Studies of benthos of the Far Eastern Seas of Russia in TINRO-Center. Izv. TINRO, 141, 229–236. (Rus.)	Russia
153	Nadtochy V.A., Galysheva Yu.A. (2012) Modern condition of macrobenthos in Peter the Great Bay pp 129-174. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).	Russia
154	Nigmatulina L.V. (2005) Impacts of waste waters imputes on ecological state of Amursky Bay. Thesis on Ph.D. on biological sciences. Vladivostok: TINRO-Center, pp 19.	Russia
155	Orlova T.Yu., Zhukova N.V., Stonik I.V. (1996) Bloom–forming diatom Pseudonitzschia pungens in Amyrskii Bay (the Sea of Japan): morphology, ecology and biochemistry, pp 147-150. Harmful and toxic algal blooms. UNESCO.	Russia
156	Orlova T.Yu., I.V. Stonik, O.G. Shevchenko (2009) Flora of planktonic microalgal of Amursky Bay, Sea of Japan. Biologia Morya, 35, 48-61. (Rus.).	Russia
157	Petrenko V.S. (2003) The main features of technogenesis on Primorye coasts. Thematic Edition of DVNIGMI, 4, 175-184. (Rus.).	Russia
158	Podorvanova N.F., Ivashinnikova T.S., Petrenko V.S., Khomichuk L.S. (1989) Main features of hydrochemistry of Peter the Great Bay (Japan Sea). Vladivostok: FEB AS USSR, pp 206. (Rus.).	Russia
159	Polyakov D.M., Botsul A.I. (2004) Geochemistry of some metals in the sediments of the marginal filter of the Razdolnaya River, Amur Bay, Sea of Japan. Geochemistry International, 42(4), 383-388.	Russia
160	Qualifying of territory around Vladivostok and adjacent areas on bases damped wastewaters (1988) Report, No 01870066599, of Far-Eastern Polytechnic Institute. Vladivostok, 65 pp.	Russia
161	Rachkov V.I. (2002) Characteristics of hydrochemical conditions of waters of Amursky Bay in warm period // Izv. TINRO, 131, 65-77.	Russia
162	Rachkov V.I. (2006) Hydrochemical conditions in the inner part of the Ussuri Bay for the period of Anadara mollusk spawning. Izv. TINRO, 146, 264-275.	Russia

163	Redkovskaya Z.P. (1980) Influence of chemical pollutants on oxygen regime of Peter the Great Bay pp. 94-103. Estimations of pollutant migrations and their impact on environment / Ed. V.S. Belen'ky. FERHRI Report, no 73.	Russia
164	Rodionov N.P. (1984) Prediction of pollutions of seas of the USSR, pp 118-150. Leningrad: GIMIZ. (Rus.).	Russia
165	Semkin. P.Ju., Tishchenko P.Ya., Lobanov V.B., Sergeev A.F., Tishchenko P.P., Koltunov A.M., Sagalaev S.G.,Chichkin R.V., Shvetsova M.G., Pavlova G.Yu. (2012) Features of chemical parameters distribution in the Ussuri Bay (Japan Sea) in summer season. Izv. TINRO, 168, 152-168.	Russia
166	Shulkin V.M., Kavun V.I. (1995) The use of marine bivalves in heavy metal monitoring near Vladivostok, Russia. Mar. Poll. Bull., 31, 330-333.	Russia
167	Shulkin V.M., Presley B.J., Kavun V.I. (2003) Metal concentrations in mussel Crenomytilus grayanus and oyster Crassostrea gigas in relation to contamination of ambient sediments. Environment International, 29, 493-502.	Russia
168	Shulkin V.M., G. I. Semykina. (2004) Seasonal and Annual Variability of the Concentration and Output of Nutrients by the Razdolnaya River (Primorskii Krai). Water Resources, 32(4), 1-9. (Rus.).	Russia
169	Shulkin V.M., Semykina G.I. (2012) Input of pollutants in Peter the Great Bay and assessment of their role in forming of ecological problems, pp 252-287. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).	Russia
170	Silina A.V., Ovsyannikova I.I. (1995) Long-term changes in the community of Japanese scallop and its epibionts in the polluted area of Amursky Bay, Sea of Japan. Biologiya Morya, 21, 59-66. (Rus.).	Russia
171	Some of regional consequences of anthropogenic impacts on marine environment (1990). Ed. A.V. Tkalin. Leningrad. Hydrometeoizdat, pp 107. (Rus.).	Russia
172	Stonik, I.V., and T.Yu. Orlova (2002) Phytoplankton of the coastal waters off Vladivostok (the North-western part of the East Sea) under Eutrophic conditions. Ocean and Polar Res., 24, 359-365.	Russia
173	Stonik, I.V., and T.Yu. Orlova (1998) Summer-autumn phytoplankton in Amursky Bay, the Sea of Japan. Biologia Morya, 24, 205-211. (Rus.).	Russia
174	Stonik I.V., Selina M.S. (1995) Phytoplankton as indicator of trophic state in Peter the Great Bay. Biologia Morya, 21, 403-406. (Rus.).	Russia
175	Toxic microalgae in Peter the Great Bay of the sea of Japan, pp 227-238. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).	Russia
176	Tishchenko, P. Y., A. F. Sergeev, V. B. Lobanov, V.I. Zvalinski, A. M. Koltunov, T. A. Mikhailik, P. P. Tishchenko, M. G. Shvetsova (2008) Hypoxia in near-bottom waters of the Amursky Bay. Bulletin Far Eastern Branch Russia Academy Science, 6, 115-125.	Russia
177	Tishchenko P.Ya., Sergeev A.F., Lobanov V.B., et al. (2008) Hypoxia in near-bottom waters of the Amursky Bay. Bulletin Far Eastern Branch Rus. Acad. Sci., 6, 115-125 (Rus.).	Russia
178	Tishchenko P. Ya., Lobanov V.B., Zvalinsky V. I., Sergeev A.F., T.I.Volkova, Koltunov A.M., Mikhajlik T.A., Sagalaev S.G., Tishchenko P.P., Shvetsova M.G. (2011a) Seasonal hypoxia of Amursky Bay (Japan Sea). Izv. TINRO, 165, 108-129. (Rus.).	Russia
179	Tishchenko P.P., Tishchenko P.Ya., Zvalinsky V.I., Sergeev A.F. (2011b) Carbonate system of Amursky Bay (Sea of Japan) under conditions of hypoxia. Oceanologiya, 51, 246-257. (Rus.).	Russia
180	Tkalin A.V., Belan T.A. and Shapovalov E.N. (1993) The state of marine environment near Vladivostok, Russia. Marine Pollution Bulletin, 26, 418-422.	Russia

181	Tkalin A.V. (1995) Investigation of marine environment radioactivity in the dumping areas and coastal zone of the Sea of Japan. Arctic Res. of the United States, 9, 88-89.	Russia
182	Tkalin A.V. (1996) Chlorinated hydrocarbonsin coastal bottom sediments of the Japan Sea. Environ. Poll., 91, 183-185.	Russia
183	Tkalin A.V., Presley B.J., Boothe P.N. (1996) Spatial and temporal variations of trace metals in bottom sediments of Peter the Great Bay, the Sea of Japan. Environ. Poll., 92, 73-78.	Russia
184	Tkalin A.V., Lishavskaya T.S. and Hills J.V. (1997) Organochlorine pesticides in mussels and bottom sediments from Peter the Great Bay near Vladivostok. Ocean Res., 19, 115-119.	Russia
185	Tkalin A.V. (1998) Assessment of state marine environment near Vladivostok on pollutant content in mussels and sediments, pp 114-124. Hydrometeorological processes on shelve: assessment of impact on marine environment. Proceedings of FERHRI. Vladivostok: Dalnauka. (Rus.).	Russia
186	Tkalin A.V., Lishavskaya T.S. and Shulkin V.M. (1998) Radionuclides and trace metals in mussels and bottom sediments around Vladivostok, Russia. Marine Pollution Bulletin, 36, 551-554.	Russia
187	Tkalin A.V., Samsonov D.P., Lishavskaya T.S. and Chernik G.V. (2000) New Data on Organochlorine Distributions in the Marine Environment near Vladivostok. Marine Pollution Bulletin, 40(10), 879–881.	Russia
188	Vaschenko M.A. (2000) Contamination of Peter the Great Bay (Sea of Japan) and its biological consequences. Biologiya morya, 26(3), 149-159 (Rus.).	Russia
189	Voronkov P.P. (1941a) Hydrochemical regime of Peter the Great Bay, Sea of Japan, pp 42-102. The Problems of sea chemistry. Hydrometeoizdat. (Rus.).	Russia
190	Voronkov P.P. (1941b) Daily variations of hydrochemical parameters in coastal waters of Peter the Great Bay, Sea of Japan, pp. 137-149. The Problems of sea chemistry. Hydrometeoizdat. (Rus.).	Russia
191	Zhadan P.M., Vaschenko M.A., Almyashova T.N., Slinko E.N. (2005) Monitoring of ecological state of the coastal ecosystems of Amursky Bay (Peter the Great Bay, Sea of Japan) based on biological and biogeochemical parameters, pp 201-227. State of Marine Ecosystems Influenced by River Runoff.	Russia
192	Zuenko Yu.I. (2008) Fisheries of Oceanography of the Japan Sea. Vladivostok: TINRO-center, pp 227. (Rus.).	Russia
193	Zvalinskiy V.I., Tischenko P.P., Mikhailik T.A., Tischenko P.Ya. (2012) Eutrophication of the Amursky Bay. pp 76-113. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).	Russia
194	Andersen, J. H. and J. H. Conley (2009) Eutrophication in coastal ecosystems towards better understanding and management strategies. Springer.	EU
195	Andersen J.H., Schlüter L., and Ærtebjerg G. (2006) Coastal eutrophication: recent developments in definitions and implications for monitoring strategies. J. Plankton Research, 28, 621-628.	EU
196	Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks and J. Woerner (2007) Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for coastal Ocean Science, Silver Spring, MD. 328 pp.	EU
197	Fennel 2010. A nutrient to fish model for the example of the Baltic Sesa. Journal of Marine Systems 81: 184-195.	EU
198	Ferreira JG, Andersen JH, Borja A, Bricker SB, Camp J, Cardoso da Silva M et al (2011). Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuarine, Coastal and Shelf Science 93: 117-131.	EU

199	Gislason 1999. Single and multispecies reference points for Baltic fish stocks. ICES Journal of Marine Science 56: 571-583.	EU
200	HELCOM (2006) Development of tools for assessment of eutrophication in the Baltic sea. Baltic Sea Environment Proceedings No. 104. Helsinki Commission, 62 pp.	EU
201	HELCOM (2008) Manual for marine monitoring in the COMBINE programme of HELCOM. http://www.helcom.fi/groups/monas/CombineManual/en_GB/main/.	EU
202	HELCOM (2009) Eutrophication in the Baltic Sea. An integrated thematic assessment of the effects of nutrient enrichment in the Baltic Sea. Baltic Sea Environment Proceedings No. 115B. Helsinki Commision 148 pp.	EU
203	OSPAR Commission (2003) OSPAR integrated report 2003 on the eutrophication status of the OSPAR maritime area based upon the first application of the comprehensive procedure. 59 pp.	EU
204	OSPAR Commission (2005) Common procedure for the identification of the eutrophication status of the OSPAR Maritime Area. Ref. No. 2005-3.	EU
205	OSPAR Commission (2008) Second OSPAR integrated report on the eutrophication status of the OSPAR maritime area. 107 pp.	EU
206	OSPAR, 2001. Draft common assessment criteria and their application within the omprehensive procedure of the common procedure. Meeting Of The Eutrophication Task Group, London, 9–11 October 2001. OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic.	EU
207	APHA, 1999. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, DC.	US
208	Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando and D.T.G. Farrow (1999) National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Service, Silver Spring, MD, 71 pp. .	US
209	Bricker, S. B., J. G. Ferreira and T. Simas (2003) An integrated methodology for assessment of estuarine trophic status. Ecological Modelling, 169, 39-60. .	US
210	Bricker, S.B., Ferreira, J.G., & Simas, T., 2003. An integrated methodology for assessment of estuarine trophic status. Ecological Modelling, 169, 39-60.	US
211	Bricker, S. B., J. G. Ferreira and T. Simas (2003) An integrated methodology for assessment of estuarine trophic status. Ecological Modelling, 169, 39-60.	US
212	Borja A, Bricker SB, Dauer DM, Demetriades NT, Ferreira JG, Forbes AT et al (2008). Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide. Marine Pollution Bulletin 56: 1519-1537.	US
213	Diaz, R. J. and R. Rosenberg (1995) Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. Oceanography and Marine Biology Annual Review, 33, 245-303.	US
214	Diaz, R. J. (2001) Overview of hypoxia around the world. Journal of Environmental Quality, 30, 275-281.	US
215	Diaz, R. J. and R. Rosenberg (2008) Spreading dead zones and consequences for marine ecosystems. Science, 321, 926-929.	US
216	Franks 2002. NPZ models of plankton dynamics: their construction, coupling to physics, and application. Journal of Oceanography 58: 379-387.	US

217	Link et al. 2010. The northeast US application of ATLANTIS: A full system model exploring marine ecosystem dynamics in a living marine resource management context. Progress in Oceanography 87: 1-4.	US
218	Nixon, S. W. (2009) Eutrophication and the macroscope. Hydrobiologia, 629, 5-19.	US
219	Nixon, S.W., 1995. Coastal marine eutrophication - a definition, social causes, and future concerns. Ophelia. 41, 199-219.	US
220	Wilkerson F, Dugdale R, Hogue V, Marchi A (2006). Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts: J ERF 29: 401-416.	US
221	Begley and Howell. 2004. An overview of Gadget, the globally applicable area-disagreed general ecosystem toolbox. ICES CM 2004/FF:13.	-
222	Christensen and Ferdana 2008. Overview of Ecopath with Ecosim (EwE.6) and the ecospeed project.	-
223	Christensen and Walters 2004. Ecopathwith Ecosim: methods, capabilities and limitations. Ecological Modelling 172: 109-139.	-
224	Cloern JE (2001). Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series 210: 223-253.	-
225	CEARAC 2011. Integrated report on eutrophication assessment in selected sea area in the NOWPAP region: evaluation of the NOWPAP Common Procedure. 28, 2011, pp 111. ISBN 978-4-9902809-5-6.	-
226	Dame and Christian 2006. Uncertainty and the use of network analysis for ecosystem-based fishery management. Fisheries 31: 331-341.	-
227	Fulton et al. 2004. Biogeochemical marine ecosystem models I: IGBEM—a model of marine bay ecosystems. Ecological Modelling 174: 267-307.	-
228	GEOHAB (2006) Global Ecology and Oceanography of Harmful Algal Blooms, Harmful Algal Blooms in Eutrophic Systems. P. Glibert (ed.). IOC and SCOR, Paris and Baltimore, 74 pp.	-
229	Garrison and Link 2005. An expanded Multispecies Virtual Population Analysis Approach (MSVPAX) to evaluate predator-prey interactions in exploited fish ecosystems. Version 1.2 User manual and model description.	-
230	Howell and Bogstad 2010. A combined Gadget/FLR model for management strategy evaluation of the Barents Sea fisheries. ICES Journal of Marine Science 67: 1998-2004.	-
231	M.J.R.Fasham (1995) variations in the seasonal cycle of biological production in subarctic oceans: A model sensitivity analysis, Deep-Sea Research I, Vol.42, No.7, 1111-1149.	-
232	M. Kawamiya et al. (1995) An ecological-physical coupled model applied to Station Papa, J. Oceanog., Vol.51, 635-664.	-
233	M. J. R. Fasham et al. (1990) A nitrogen-based model of plankton dynamics in the oceanic mixed layer, J. Marine Research, Vol.48, 591-639.	-
234	Magnusson 1995. An overview of the multispecies VPA — theory and applications. Reviews in Fish BIology and Fisheries 5: 195-212.	-

235	NOWPAP (2008) Regional Action Plan on Marine Litter. 25pp.	-
236	NOWPAP (2010) Threats to marine and coastal biodiversity in the NOWPAP region.	-
237	NOWPAP CEARAC (2005) Integrated report on Harmful Algal Blooms (HABs) for the NOWPAP Region.	-
238	NOWPAP CEARAC (2007) Booklet of countermeasures against Harmful Algal Blooms (HABs) in the NOWPAP Region.	-
239	NOWPAP CEARAC (2009) Procedures for the assessment of eutrophication status including evaluation of land-based sources of nutrients for the NOWPAP region.	-
240	NOWPAP POMRAC (2006) National reports on atmospheric deposition of contaminants into the marine and coastal environment in NOWPAP region. POMRAC Technical Report No 1.	-
241	NOWPAP POMRAC (2007) Regional overview on atmospheric deposition of contaminants to the marine and coastal environment in NOWPAP Region. POMRAC Technical Report No 3.	-
242	NOWPAP POMRAC (2009) Regional overview on river and direct inputs of contaminants into the marine and coastal environment in NOWPAP Region with special focus on the land based sources of pollution. POMRAC Technical Report No 7.	-
243	NOWPAP POMRAC (2010) Regional overview on integrated coastal and river basin management (ICARM) in the NOWPAP Region. POMRAC Technical Report No 5.	-
244	NOWPAP CEARAC, 2011. Integrated Report on Eutrophication Assessment in Selected Sea Areas in the NOWPAP Region: Evaluation of the NOWPAP Common Procedure. NOWPAP CEARAC, Toyama, Japan.	-
245	Nixon S.F. (2009) Eutrophication and the macroscope. Hydrobiologia, 629, 5-19. Orlova T.Yu. (2012)	-
246	OECD (1982) Eutrophication of water, monitoring assessment and control. Organization of Economic Co-operation and Development, Paris.	-
247	Painting S. J., M.J. Devlin, S.I. Rogers, D.K. Mills, E.R. Parker, H.L. Rees. 2005. Assessing the suitability of OSPAR EcoQOs for eutrophication vs ICES criteria for England and Wales. Marine Pollution Bulletin 50: 1569–1584.	-
248	POMRAC Technical Report No 4 (2006). Regional overview on river and direct inputs of contaminants into the marine and coastal environment in NOWPAP region. POMRAC, Vladivostok, Russian Federation, pp 64.	-
249	POMRAC Technical Report No 7 (2009). Regional overview on river and direct inputs of contaminants into the marine and coastal environment in NOWPAP region. With Special Focus on the Land Based Sources of Pollution. POMRAC, Vladivostok, Russian Federation, pp 104.	-
250	Redfield, A. C., B. H. Ketchum, F. A. Richards (1963) The influence of organisms on the composition of seawater. The Sea vol. 2, Ed. M. N. Hill, Interscience, New York.	-
251	Redfield A.C. 1934. On the proportions of organic derivatives in sea water and their relation to the composition of plankton. In: Daniel, R.J. (Ed.), James Johnstone Memorial Volume. University of Liverpool Press, Liverpool, UK, pp. 176-192.	-
252	Salmi, T., A. Määttä, P. Antika, T. Ruoho-Airola, and T. Amnell (2002) Detecting trends of annual values of atmospheric pollutions by the Mann-Kendall test and Sen's slope estimates -The Excel template application MAKESENS-. Finnish Meteorological Institute, 35pp, Helsinki.	-

253	Strickland, J. D. H. & T. R. Parsons, 1972. A practical handbook of seawater analysis. Fisheries Research Board of Canada Bulletin 167: 311.	-
254	Smayda, T.J. 1990. Novel and nuisance phytoplankton blooms in the sea: evidence of a global epidemic. In: Grane´ li, E., Sundstrom, B., Edler, L., Anderson, D. (Eds.), Toxic Marine Phytoplankton. Elsevier, pp. 29-40.	-
255	Salmi, T., Määttä, A., Antika, P., Ruoho-Airola, T. and Amnell, T. (2002) Detecting trends of annual values of atmospheric pollutions by the Mann-Kendall test and Sen's slope estimates -The Excel template application MAKESENS-. Finnish Meteorological Institute, pp. 35, Helsinki.	-
256	Takeshi Horie (1991) Numerical modeling for the prediction of sedimentary improvement by sand capping over a contaminated seabed, J. Hydraulic Research, Vol.29, No.6, 829-850.	-
257	UNEP/GEF (2009) Strategic action programme for the Yellow Sea Large Marine Ecosystem. UNEP/GEF YSLME project, Ansan, Republic of Korea, 52 pp.	-

Report on assessment of eutrophication status in Jiaozhou Bay, China

Zhiming Yu and Zaixing Wu

Institute of Oceanology, Chinese Academy of Sciences

7 Nanhai Road, Qingdao, China 266071

July 2013

Contents

1. Introduction and Objectives

Anthropogenic activities, such as the usage of fertilizer and discharge of human waste, have accelerated the fluxes of nutrients to coastal aquatic systems (Nixon, 1995). The Northwest Pacific region (parts of China, Japan, Korea and southeast Russia) is one of the most densely populated areas in the world and its coastal systems are also subject to significant human-induced nutrients modifications (NOWPAP CEARAC Report 2011).

Rapid development of Chinese economy in recent decades focused on manufacturing and urbanization, much of which is located in the coastal zone. This has resulted in a substantial increase in nutrient loads into estuaries and coastal areas through river flows, thereby stimulating phytoplankton growth (Shen, 2001). Nutrients loads have resulted in nutrient enrichment problems in coastal waters, including high nutrient concentrations. For dissolved inorganic nitrogen (DIN, summation of nitrate, nitrite, ammonia) and dissolved inorganic phosphorus (DIP), the benchmark of Class 4 according to the China's National Seawater Quality Standard (NSQS, 1997) were 0.5 mg/L and 0.045 mg/L, respectively. In the Bohai Sea, from 2007 to 2009, monitored DIN in most part of Bohai Bay and Laizhou Bay exceeded 0.5 mg/L, while monitored DIP in a major part of these two bays exceeded 0.045 mg/L.

Red tides and large-scale hypoxic conditions were some of the other eutrophication symptoms that took place in China coastal seas. In recent years, the occurrences of red tide events have become frequent in China coastal lines (Huang, 2003). Each year, more than 65 red tide events were observed in Chinese national marine waters from 2006 to 2009 (State Oceanic Administration of China, 2006 to 2009). An issue of concern in the Changjiang river estuary is the occurrence of hypoxia in near-bottom waters off the Changjiang estuary and its adjacent coastal waters (Li et al., 2002). Over the last two decades, minimum values of DO in the low oxygen region of the Changjiang Estuary have decreased from 2.85 to 1 mg/L (Xiao et al., 2007).

Since eutrophication have become a main ecological problem in coastal areas in China, the objective of the study is to assess the trophic status of a typical coastal area in NOWPAP region using refined Common Procedure.

1.1 Selection of assessment area

The Jiaozhou Bay, which is located in Qingdao, is a semi-enclosed bay in the North Yellow Sea of China. In this case study, the Jiaozhou Bay was selected to be a target area for eutrophication assessment mainly because it is within the geographic scope of NOWPAP. Furthermore, the screening procedure applied to Jiaozhou Bay has indicated that more than one red tide event was recorded in inner Jiaozhou Bay and its adjacent coastal waters in the past three years.

Jiaozhou Bay covers an area of about 390 km^2 with an average depth of 7 m and is connected to the Yellow Sea via a narrow opening (2.5 km). The Jiaozhou Bay ecosystem is a very typical marine ecosystem in China since it is impacted to a large extent by human activities such as port, aquaculture and riverine nutrient input. Jiaozhou Bay is fed by several rivers and among these, Haipo river takes the highest DIN load into the bay (about 3024 t in 2001, and accounts for 39% of the total DIN load into the bay), followed by the Dagu river (about 2295 t/a, Zhang and Sun, 2007).

Fig. 1 The geographical location of the Jiaozhou Bay

1.2 Collection of relevant information

1.2.1 Information on the assessment area that is necessary and relevant to eutrophication assessment

i) Environmental monitoring/survey data:

The data on red tides or harmful algal blooms in Jiaozhou Bay was obtained from Bulletin of Marine Environmental Quality of Qingdao, Bulletin of Marine Environmental Quality of Shandong Province, Bulletin of Marine Environmental Quality of China, and via some published researches in the Jiaozhou Bay (Wu et al., 2005). HAB data were collected from this area over the past 13 years (from 1997 to 2009). Whenever a HAB event occurred, the location was recorded using a global positioning system (GPS) and a sample was collected and analyzed immediately on board the monitoring vessel to identify the dominant algal species. Each record contained the location, area, start and finish time of the bloom, dominant species and the cellular abundance of the dominant species.

The nutrients, Chl-a, DO, COD, etc. were collected from the Jiaozhou Bay Marine Ecosystem Research Station, which implemented a long-term monitoring activities in Jiaozhou Bay. Thirty years of data (form 1997 to 2009) were obtained from the monitoring station database and its publications (Sun et al., 2010; Sun et al., 2011).

ii) Pollutant sources:

Pollutant sources (e.g. municipal, industrial, agricultural, marine aquaculture, atmospheric deposition) were obtained through published references. Since no long time series pollutant sources were obtained, it was not contained in the assessment.

iii) Supplementary information:

The supplementary information (e.g. oceanography, meteorology, catchment area, population, wastewater management, fishery status) were obtained through published references. These information was used to interpret the assessment results.

iv) Information on methods of field measurement and chemical analysis:

At least four cruises were carried out annually in February, May, August and November in the Jiaozhou Bay, where 14 sampling sites were located (Figure 2). These sampling sites were selected according to their geographical location (e.g., some were located near the Sewage Treatment Plant, while some were near the aquaculture area). The four surveys were conducted from inner Jiaozhou Bay to the mouth and eventually, to the outside of Jiaozhou Bay. Indicators such as T, salinity, pH, DO, COD, nutrients (TN, TP, DIN and DIP), Chl-a, etc. in these 14 sites were monitored.

Fig.2 The sampling sites in Jiaozhou Bay

The methods of field measurement and chemical analysis for water quality and biological parameters were all standard methods specified by the Marine monitoring specification (GB 17378.4 - 1998), the Marine investigation specification (GB/T 12763.4 - 1991) and the National Standard (GB 13191 - 1991) and some published papers (Strickland et al., 1972).

1.2.2 Eutrophication related information/data from organizations:

i) Organizations that monitor water quality:

Organizations that monitor water quality for environmental conservation purposes includes: State Oceanic Administration (SOA) of China, Ocean university of China (located in Qingdao) and Jiaozhou Bay Marine Ecosystem Research Station, which is affiliated with the Chinese Academy of Sciences. Among these organizations, the

Jiaozhou Bay Marine Ecosystem Research Station carried out a regular monitoring activity at a monitoring frequency of 4 – 12 times per year.

ii) Organizations that monitor harmful algal blooms:

Organizations that monitor HABs for protection of fishery resources includes: State Oceanic Administration, Qingdao Ocean and fishery Administration and North China Sea Branch of SOA. Qingdao Ocean and fishery Administration and North China Sea Branch are regional-level monitoring stations for HABs which are affiliated with SOA and are part of the whole monitoring network for China coastal areas. The data were reported annually via Bulletin of Marine Environmental Quality of Qingdao, and survey frequency was not reported.

iii) Organizations that have supporting environmental information:

Organizations that have supporting environmental information (e.g. oceanographic data, meteorological data) includes: State Oceanic Administration, Jiaozhou Bay Marine Ecosystem Research Station. The data were stored in the Jiaozhou Bay Marine Ecosystem Research Station Database.

The collected environmental monitoring/survey information are presented in Table1.

1.3 Selection of assessment parameters

1.3.1 Categorization of monitored parameters

From the selected environmental monitoring programs, all eutrophication-related parameters that are monitored within the assessment area were categorized into one of the following 4 assessment categories (Table 2):

i) Category I Parameters that indicate degree of nutrient enrichment

ii) Category II Parameters that indicate direct effects of nutrient enrichment

iii) Category III Parameters that indicate indirect effects of nutrient enrichment

iv) Category IV Parameters that indicate other possible effects of nutrient enrichment

1.3.2 Selection of assessment parameters for each assessment category

Considering assessment parameters that are recommended by the assessment procedure on the basis of their data reliability and continuity, assessment parameters were selected as follows (See also Table 2):

i) Category I: Parameters that indicate degree of nutrient enrichment include riverine input of DIN, annual mean DIN concentration, annual mean DIP concentration and annual mean DIN/DIP ratio. Winter DIN or DIP was recommended by revised NOWPAP Common Procedure to assess the nutrient enrichment problems, for the simple reason that Biomass and uptake of nutrients by phytoplankton was the lowest and nutrient concentrations the highest in winter. Winter nutrient concentrations could reflect the nutrient pollutions or nutrient pressures without considering the impact (e.g. uptake) of phytoplankton biomass. But in Jiaozhou Bay, winter nutrient concentrations were the lowest in the four seasons according to monitoring data and usage of only winter DIN could not reflect the nutrient enrichment problems. Therefore, in this case study, annual average DIN and DIP concentrations were used to substitute winter nutrients.

ii) Category II: Parameters that indicate direct effects of nutrient enrichment, including maximum of Chlorophyll a, mean of Chlorophyll a and red tide events (See also Table 2).

iii) Category III: Parameters that indicate indirect effects of nutrient enrichment, including bottom DO, COD and fish kill incidents.

iv) Category IV: Parameters that indicate other possible effects of nutrient enrichment, including shell fish poisoning incidents.

Table1 The collected environmental monitoring/survey information

Survey area	Governing organization	Survey title	Aim	Survey period	Main survey parameters	Survey frequency
China coastal water	State Oceanic Administration	Bulletin of Marine Environmental Quality of China	Survey and assessment of marine environmental quality	1990~2009	COD, nutrient, petroleum, heavy metals, PCB, BHC, DDT, diversity index, pollutant sources, red tides	Not reported
China coastal water	State Oceanic Administration	Bulletin of Marine disaster of China	Survey and assessment of marine disaster	1990~2009	red tides	Not reported
Jiaozhou Bay	Jiaozhou Bay Marine Ecosystem Research Station	Atlas of long-term changes in the Jiaozhou Bay ecosystem	Survey and assessment of marine environmental quality	1997~2009	COD, nutrient, petroleum, heavy metals, PCB, BHC, DDT, diversity index, pollutant sources, red tides	4-12 times/year
Jiaozhou Bay	Jiaozhou Bay Marine Ecosystem Research Station	Lakes, wetland and Bays ecosystem dataset of China: Jiaozhou Bay marine ecosystem	Survey and assessment of marine environmental quality	2001-2006	COD, nutrient, petroleum, heavy metals, PCB, BHC, DDT, diversity index, pollutant sources, red tides	4-12 times/year
Riverine input of DIN,	Published papers	Published papers	Publishing of Riverine input of DIN	1980s.1999, 2001, 2005, 2008	DIN flux	Not reported

Table 2 Assessment parameters used in the Jiaozhou Bay

Category	Assessment parameter
Category I	Riverine input of DIN
	Annual mean DIN concentration
	Annual mean DIP concentration
	Annual mean DIN/DIP ratio
Category II	Annual maximum of Chlorophyll a
	Annual mean of Chlorophyll a
	Red tide events
Category III	Bottom annual mean DO
	Annual meanCOD
	Fish kill incidents
Category IV	Shell fish poisoning incidents

1.3.3 Setting subareas

According to the differences in the geographical characteristics of Jiaozhou Bay, three sub-areas were divided. The sub-areas were demonstrated in Figure 3 in red polygon. Sub-area A represents inner Jiaozhou Bay, which was influenced by large amount of riverine nutrient load. Sub-area B points to the mouth of Jiaozhou Bay, which includes the narrow opening. And sub-area C is the outside of the Jiaozhou Bay and is the near shore area of North Yellow Sea. In fact, although sub-area C did not belong to Jiaozhou Bay, it is adjacent to Jiaozhou Bay and thus, the eutrophication status was also assessed to fully recognize the trophic status of Jiaozhou Bay. Sampling sites 1 to 7 are located in sub-area A, while sites 8, 9 are located in sub-area B and sites 10, 12, 13 are located in sub-area C. Monitoring data of site 11 and 14 were not obtained in this case study, which precluded these two monitoring sites from consideration in the assessment process.

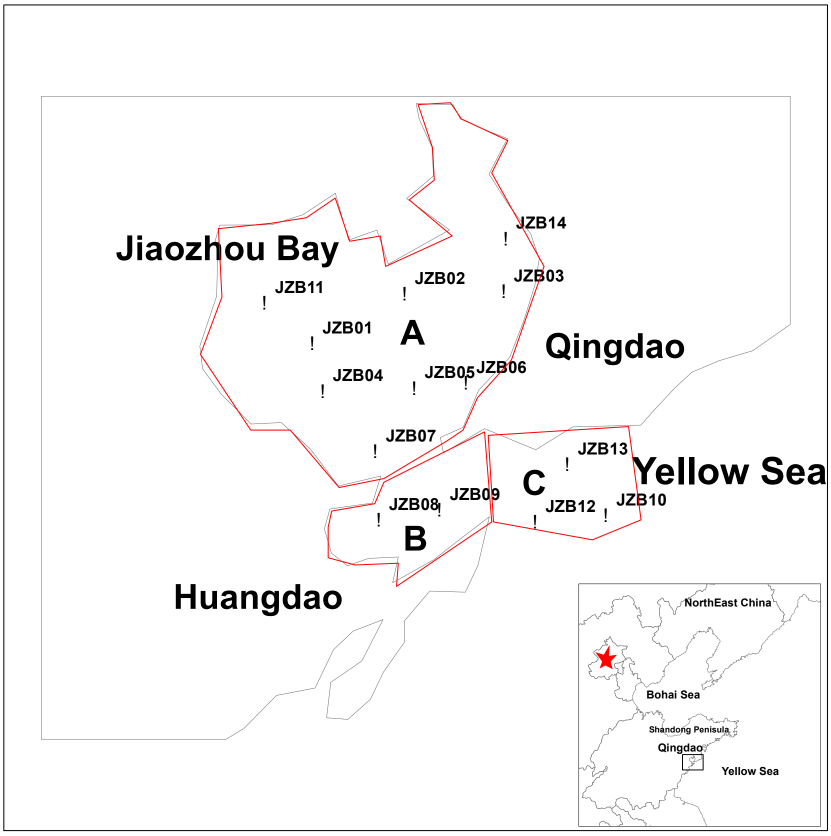


Fig. 3 Sub-areas of Jiaozhou Bay

1.3.4 Setting of assessment period

In order to assess the trophic status of the Jiaozhou Bay through both current status and trend, long-term monitoring data should be used in the assessment. In the Jiaozhou Bay case study, 13 years of data was set as the assessment period in accordance with the availability of reliable data. For bottom DO, only 6 years of data were collected and used in the assessment for current status and trend.

2. Data processing and Preparation of data sets

Concentration values of each assessment parameters were measured using commonly accepted methods. DIN concentration was based on the summation of ammonia, nitrite and nitrate (NH_4, NO_2 and NO_3). The evaluation concentrations used have been the annual mean values for DIN, DIP, Chlorophyll-a, DO (bottom) and COD. Also, annual maximum of Chlorophyll-a was used. The red tide data were represented by red tide events with a unit of times/year or times/3 years. The riverine DIN load was obtained through published papers in which the DIN load was calculated through the addition of DIN flux from different rivers.

With the exception of maximum of Chlorophyll a and red tide events, all parameters are based on annual mean values. The annual mean values were obtained by averaging the values of each parameter monitored in February, May, August and November of a year. The annual mean dissolved oxygen was assessed for bottom concentrations.

3. Setting of assessment criteria

3.1 Setting of identification criteria of the assessment data

Eutrophication status based on each assessment parameter was assessed by identifying its current status and/or trend. Identification tools applied to each assessment parameter in Jiaozhou Bay were listed below (Table 3). The parameters of annual mean DIN, DIP, DIN/DIP ratio, COD, Chla and DO were identified by comparison and trend. The parameters of red tide events, shell fish poisoning incidents and fish kill incidents were identified by occurrence and trend.

Table 3 Identification tools applied to each assessment parameter in Jiaozhou Bay

Category	Assessment parameter	Units	Assessment value	Identification tools		
				Comparison	Occurrence	Trend
I	Riverine input of DIN	t/year	Annual			√
	DIN	mg/L	Annual mean	√		√
	DIP	mg/L	Annual mean	√		√
	DIN/DIP ratio	-	Annual mean	√		√
II	Maximum of Chlorophyll a	μg/L	Annual maximum	√		√
	Red tide events	Time/year	Annual		√	√
	Mean of Chl-a	μg/L	Annual mean	√		√
III	DO (Bottom)	mg/L	Annual mean	√		√
	COD	mg/L	Annual mean	√		√

	Fish kill incidents	time/year	Annual occurrence	√	√
IV	Shellfish poisoning incidents	Time/year	Annual	√	√

3.2 Setting of classification criteria of the assessment parameters

According to the National Sea Water Quality Standard of China (NSQS, 1997) and several studies on coastal eutrophication (Chen et al., 2007; Su et al., 2008; Bricker et al., 2003), the thresholds and ranges of water quality parameters were presented in Table 4. In this study, the NSQS Class II was selected as criteria for each parameter for the reason that Class II was suitable for aquaculture water bodies. Jiaozhou Bay is an important Bay for shell fish aquaculture and a fairly large part of Jiaozhou Bay is covered by aquaculture farms. So 0.3 mg l^{-1} for DIN (21.4 μM), 0.03 mg l^{-1} for DIP (0.97μM), 20μg l^{-1} for maximum of Chl-a, 5 μg l^{-1} for mean of Chl-*a*, 2 mg l^{-1} for bottom DO, and 3 mg l^{-1} for COD were used as criteria of the assessment. As for DIN/DIP ratio, the Redfield value 16 was used in this study (Table 5).

Red tide events, fish kill incidents and shell fish poisoning incidents were rated as High or Low based on the occurrence of one or more incident, or no incident in the recent three years, respectively.

Table 4 Thresholds of assessment parameters in the National Sea Water Quality Standard of China (NSQS, 1997)

Parameters	Class			
	I	II	III	IV
DIN(mg l^{-1})	0.2	0.3	0.4	0.5
DIP(mg l^{-1})	0.015	0.03	0.03	0.045
COD(mg l^{-1})	2	3	4	5

Table 5 Reference concentrations used in this study

Category	Parameters	Reference concentrations
I	DIN	0.3 mg l^{-1}(21.4 μM)
	DIP	0.03 mg l^{-1}(0.97μM)
	DIN/DIP ratio	16
II	maximum of Chlorophyll a	20μg l^{-1}
	mean of Chl-a	5 μg l^{-1}
	Red tide events	1 event/3 years
III	DO (bottom)	2 mg l^{-1}
	COD	3 mg l^{-1}
	Fish kill incidents	1 event/3 years
IV	Shell fish poisoning incident	1 event/3 years

4. Assessment process and results

4.1 Assessment categories

Eutrophication assessment of Jiaozhou Bay was based on the data from the 12 sampling sites that were evenly distributed in Jiaozhou Bay. Each parameter of each sampling site in the study area was analyzed to assess the eutrophication status.

4.1.1 Assessment of Category I

Riverine input of DIN in the late 1980s, 1999, 2001, 2005 and 2008 were obtained through published research papers. Since long-term monitoring data of riverine input of TN, TP and DIP cannot be collected, only riverine inputs of DIN were used as an indicator to reflect anthropogenic pressures in this study (Zhang and Sun, 2007; Wang, 2009). Riverine DIN loading in the recent twenty years showed an upward trend, indicating increasing anthropogenic pressures to the Jiaozhou Bay. Riverine input of DIN was presented in Figure 4. The DIN concentrations in sub-area A were higher than reference concentration in the recent 3 years and showed an upward trend for all sampling sites from the years 1997 to 2009. On the contrary, the DIN concentrations in sub-area B and C were lower than reference values in the recent 3 years but showed no obvious trend according to the Mann-Kendall test. DIP concentrations in most sampling sites were higher than reference concentration in the recent 3 years and an upward trend was observed in all sub-areas. The DIP concentrations in Jiaozhou Bay increased rapidly in recent years. At the same time, a decrease of DIN/DIP ratio was observed. Although decreasing trend observed, for most sampling sites in sub-area A, DIN/DIP ratio was higher than the Redfield value (a ratio of 16) in recent 3 years. The decreasing DIN/DIP ratio was also observed in the other two sub-areas. Annual mean concentrations of DIN, DIP and ratio of DIN/DIP in the recent 13 years were presented in Figures 5, 6 and 7.

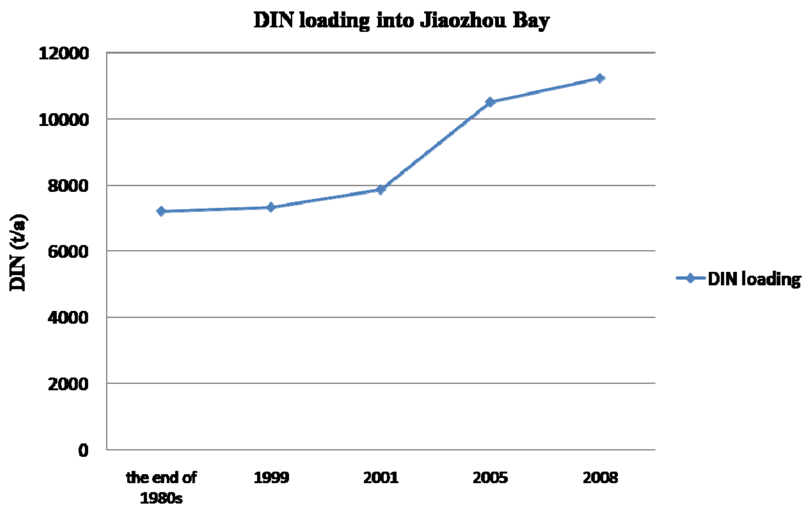


Figure4. Riverine DIN load in recent twenty years

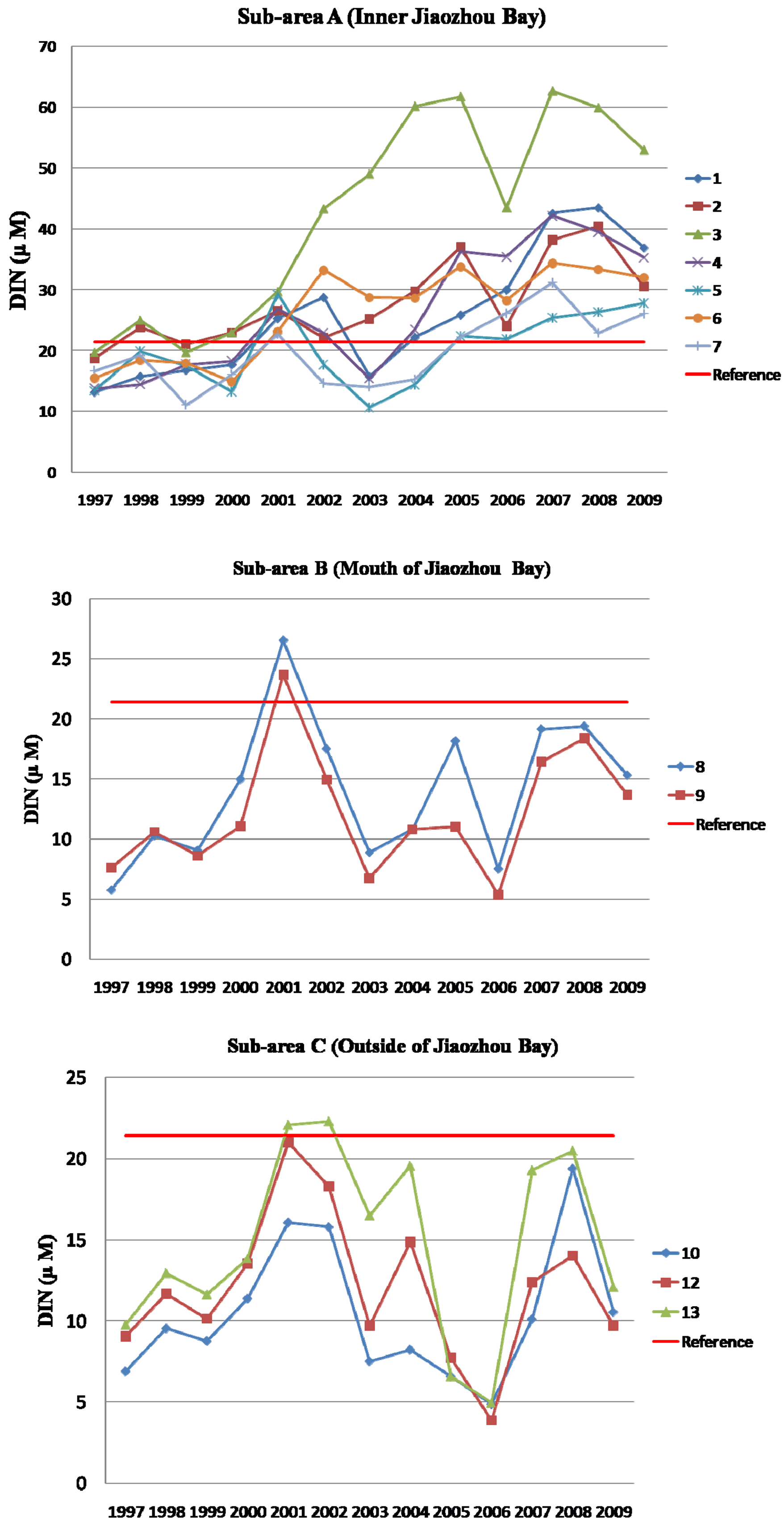


Figure5. Long-term trend of annual mean DIN concentration from 1997 to 2009 (Three sub-areas)

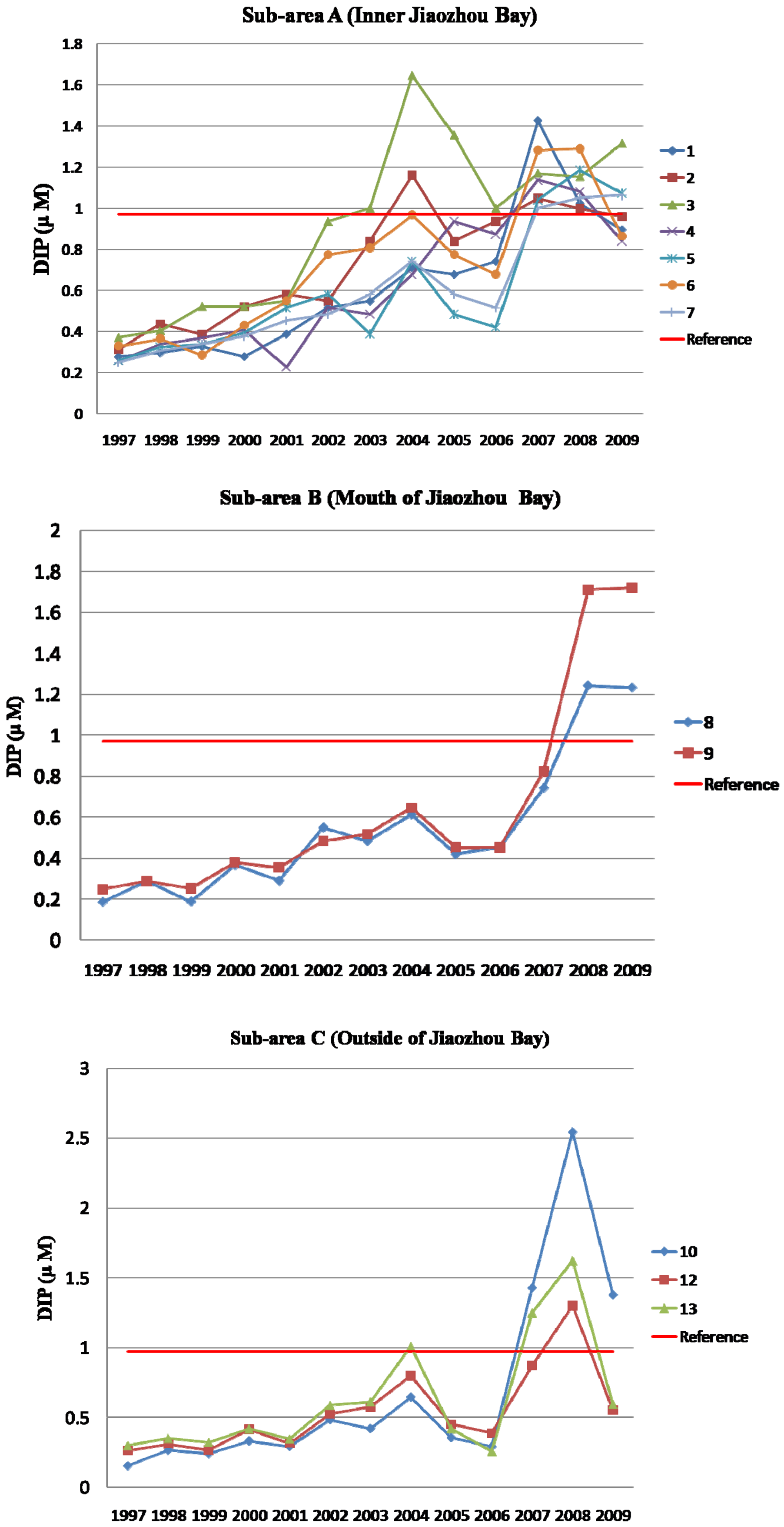


Figure6. Long-term trend of annual mean DIP concentration from 1997 to 2009 (Three sub-areas)

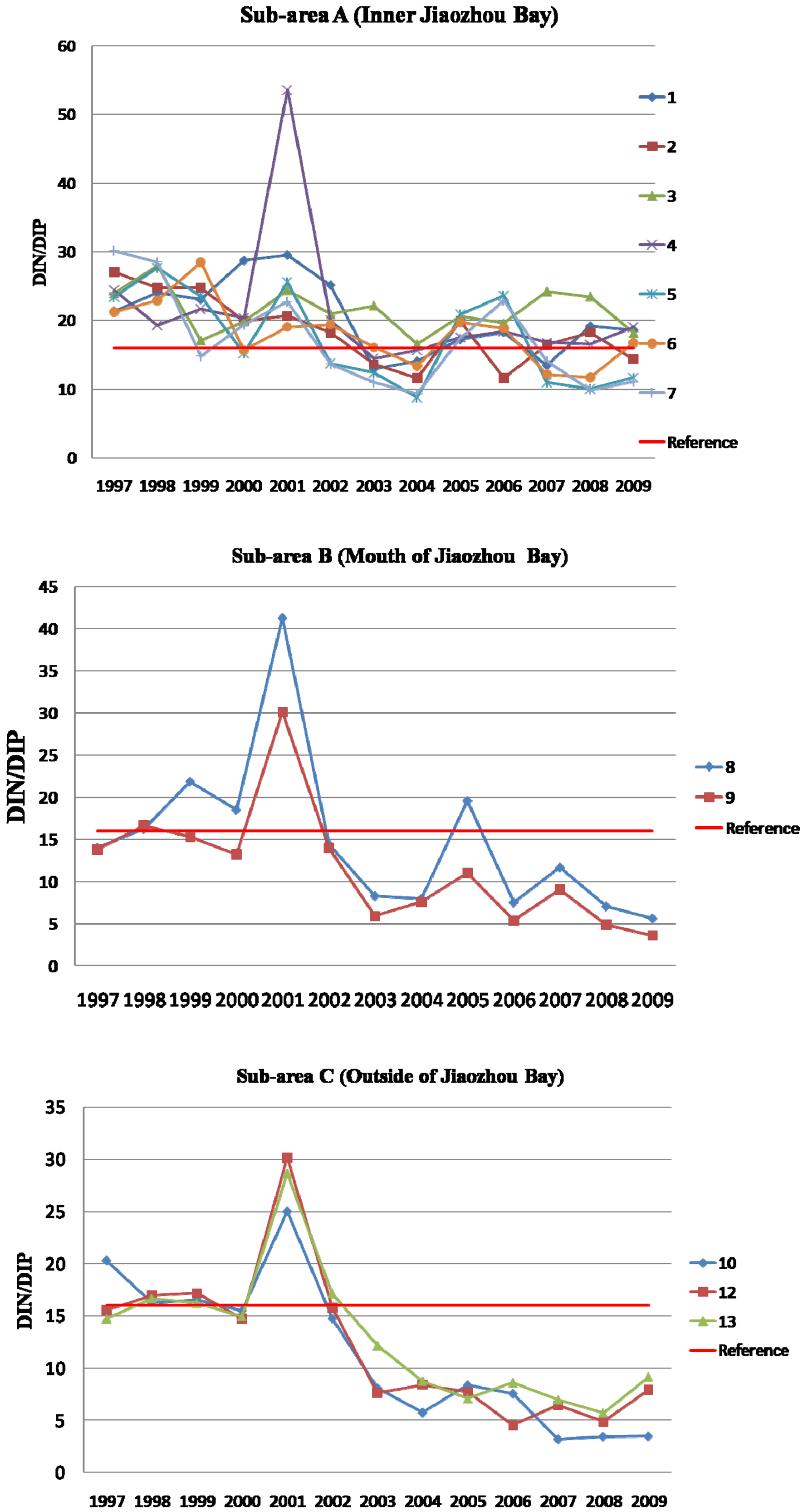


Figure7. Long-term trend of annual mean DIN/DIP ratio from 1997 to 2009 (Three sub-areas)

Results of non-parametric Mann-Kendall test was presented in Table 6. Generally, DIN and DIP exhibited an upward trend, but there was no trend in DIN/DIP ratio (Table 6).

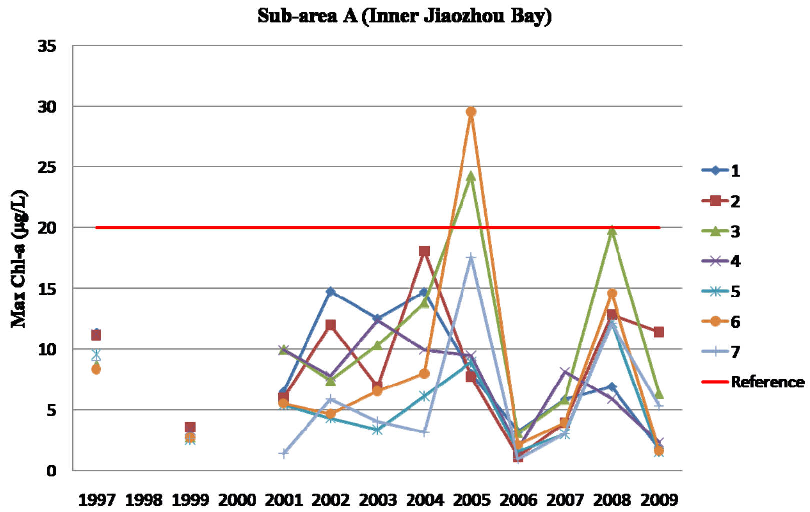
Table 6 Results of non-parametric Mann-Kendall test in all sampling sites

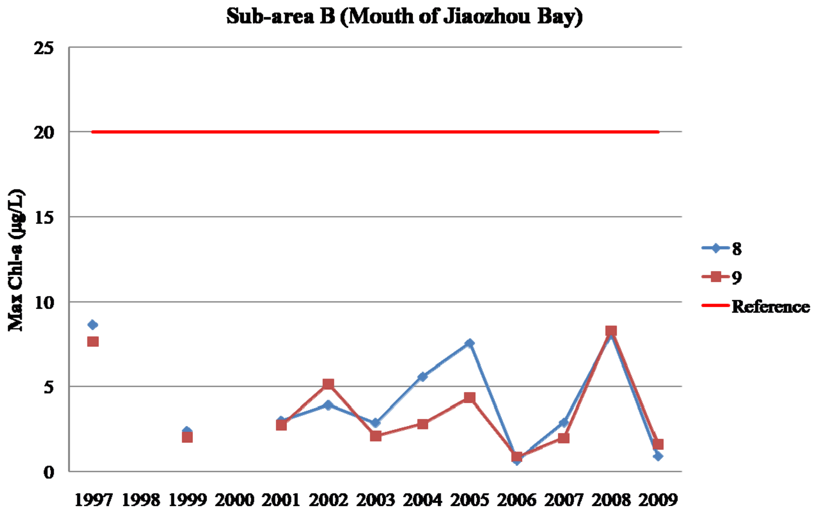
Parameters	Ranges of z value	p value	Overall trend
Riverine input DIN	Not tested	-	Upward trend
DIN (Sub-area A)	1.647-3.111	All <0.05	Upward trend
DIN (Sub-area B)	1.159-1.525	All >0.05	No trend
DIN (Sub-area C)	0.305-0.427	All >0.05	No trend
DIP (Sub-area A)	3.355-3.966	All <0.05	Upward trend
DIP (Sub-area B)	3.477-3.667	All <0.05	Upward trend
DIP (Sub-area C)	2.989-3.056	All <0.05	Upward trend
DIN/DIP ratio (Sub-area A)	-2.623 to -0.798	Most <0.05	Downward trend
DIN/DIP ratio (Sub-area B)	-2.989 to -2.379	All <0.05	Downward trend
DIN/DIP ratio (Sub-area C)	-3.355 to -2.623	All <0.05	Downward trend

4.1.2 Assessment of Category II

Maximum Chl-a, mean of Chl-a and red tide events were presented in Figures 8, 9 and 10. In all three sub-areas, Maximum of Chl-a was generally lower than reference concentration in the recent 3 years with no obvious trend. Meanwhile, annual mean of Chl-a was lower than reference value in recent 3 years and again, with no observable trend. Red tide events often occurred in inner Jiaozhou Bay before the year 2004 and showed a downward trend since then. And in the recent 3 years (2007-2009), only one red tide event was observed in this sub-area. For the mouth of Jiaozhou Bay (Sub-area B), no red tide event was recorded since 1997. Outside of

Jiaozhou Bay (Sub-area C), red tide events began to occur at a high frequency in the recent five years, displaying an upward trend.





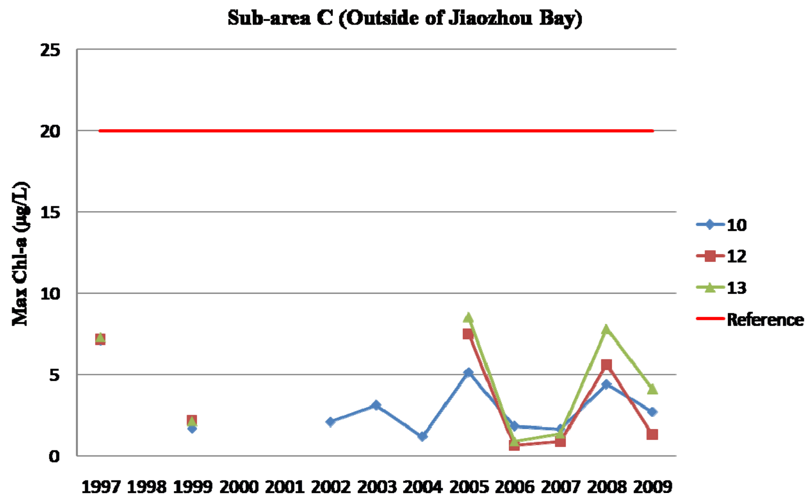


Figure8. Long-term trend of annual maximum Chl-a from 1997 to 2009 (three sub-areas)

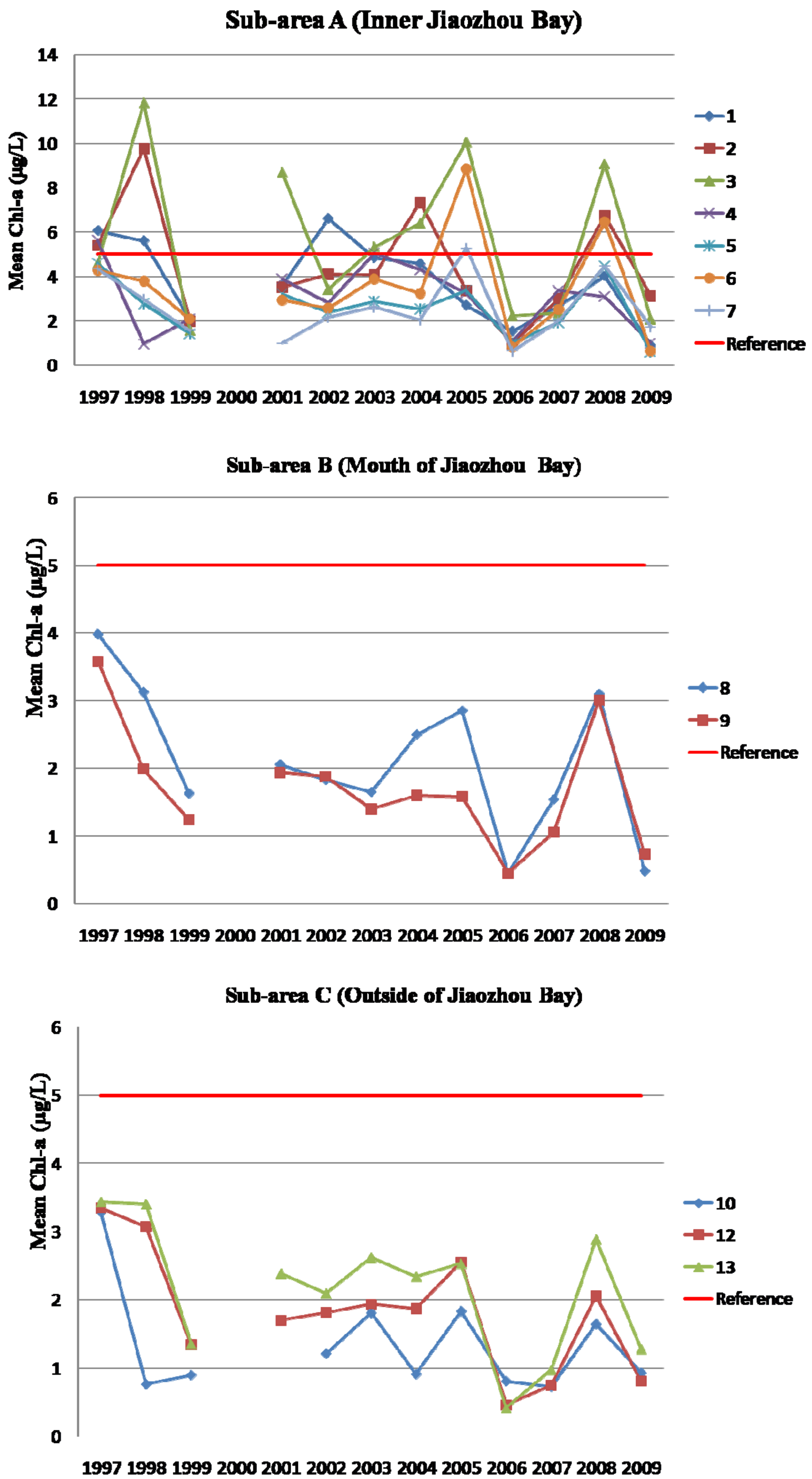
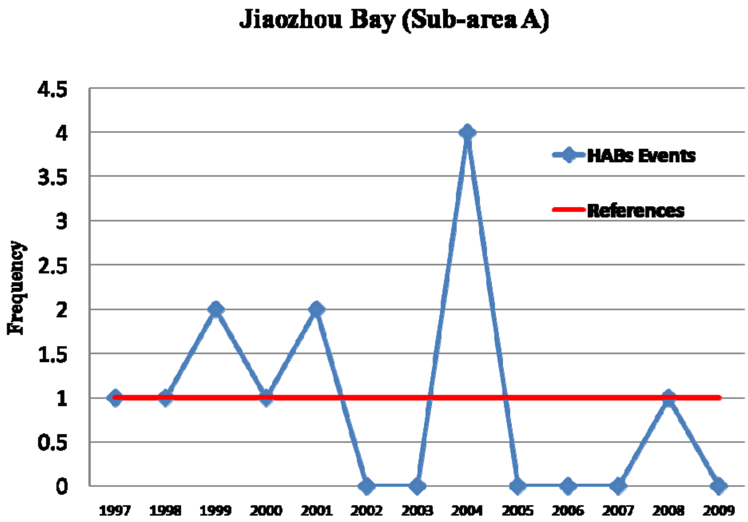


Figure9. Long-term trend of annual mean Chl-a from 1997 to 2009 (three sub-areas)



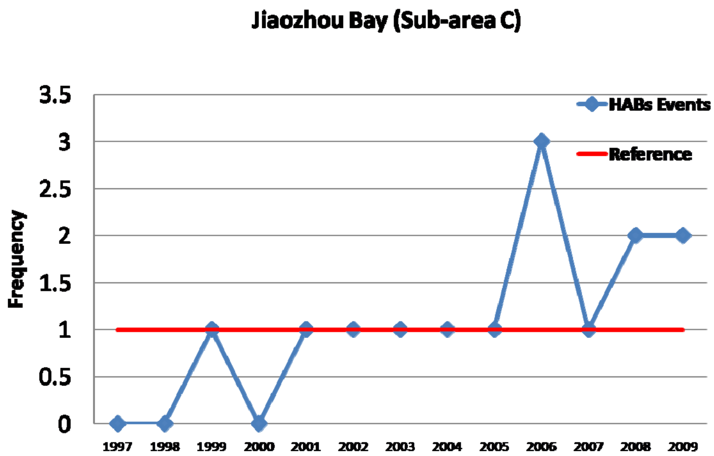


Figure10. Occurrences of red tides from 1997 to 2009 (sub-area A and sub-area C)

Results of non-parametric Mann-Kendall test was presented in Table 7. Maximum Chl-a and Minimum Chl-a showed no obvious trend, although there was a downward trend for red tide events in sub-area A and an upward trend in sub-area C (Table 7).

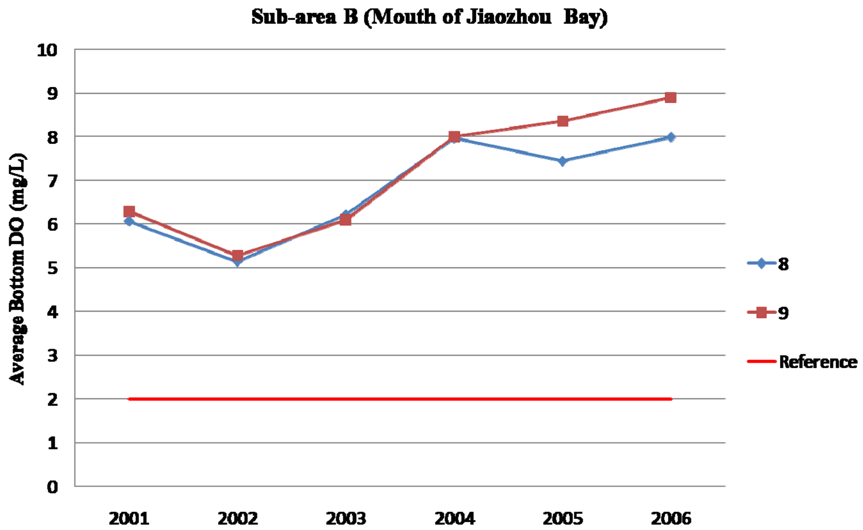
Table 7 Results of non-parametric Mann-Kendall test for Chl-a and red tide events in all sampling sites

Parameters	Ranges of z value	p value	Overall trend
Max Chl-a (Sub-area A)	-1.55to 0.6	All >0.05	No trend
Max Chl-a (Sub-area B)	-0.77 to -0.31	All >0.05	No trend

Max Chl-a (Sub-area C)	-0.17	>0.05	No trend
Mean Chl-a (Sub-area A)	-2.12 to -0.48	Most >0.05	No trend
Mean Chl-a (Sub-area B)	-1.98 to -1.44	All >0.05	No trend
Mean Chl-a (Sub-area C)	-1.44 to -0.311	All >0.05	No trend
Red tide events (Sub-area A)	-1.38	<0.05	Downward trend
Red tide events (Sub-area C)	2.9687	<0.05	Upward trend

4.1.3 Assessment of Category III

The comparison and trend for COD, DO (bottom) and fish kill incidents were presented in Figure 11 and 12. In general, COD concentration in Jiaozhou Bay was lower than 3 mg l^{-1} for all sub-areas. COD values in a majority of sites showed no obvious trend in these 13 years in all sub-areas according to non-parametric Mann-Kendall test. Bottom DO concentration was generally higher than 2 mg l^{-1} for all sub-areas in these 6 years. Meanwhile, an upward trend was observed for bottom DO. There were no fish kill incidents recorded from the year 1997 to 2009 and they were, therefore, rated as "low" and "no trend".



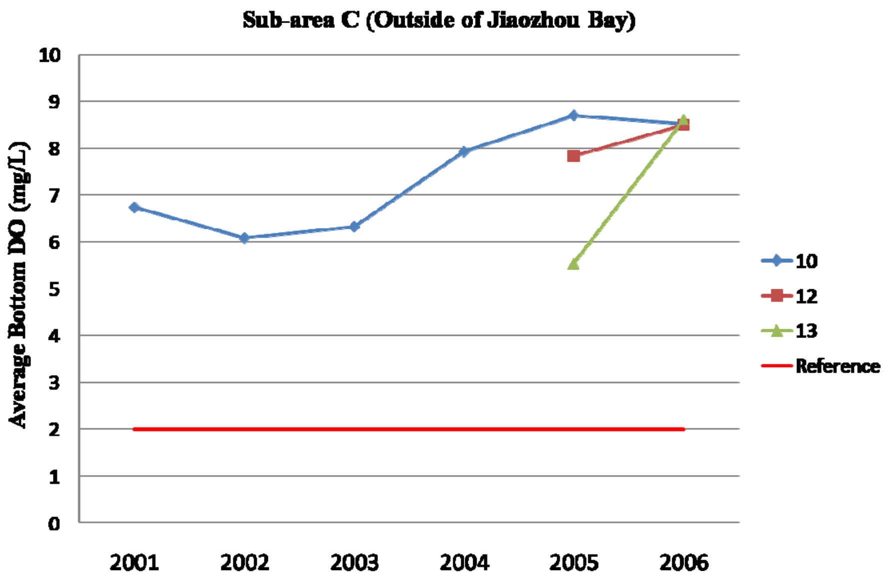


Figure11. Long-term trend of annual mean DO (bottom layers) from 1997 to 2009 (three sub-areas)

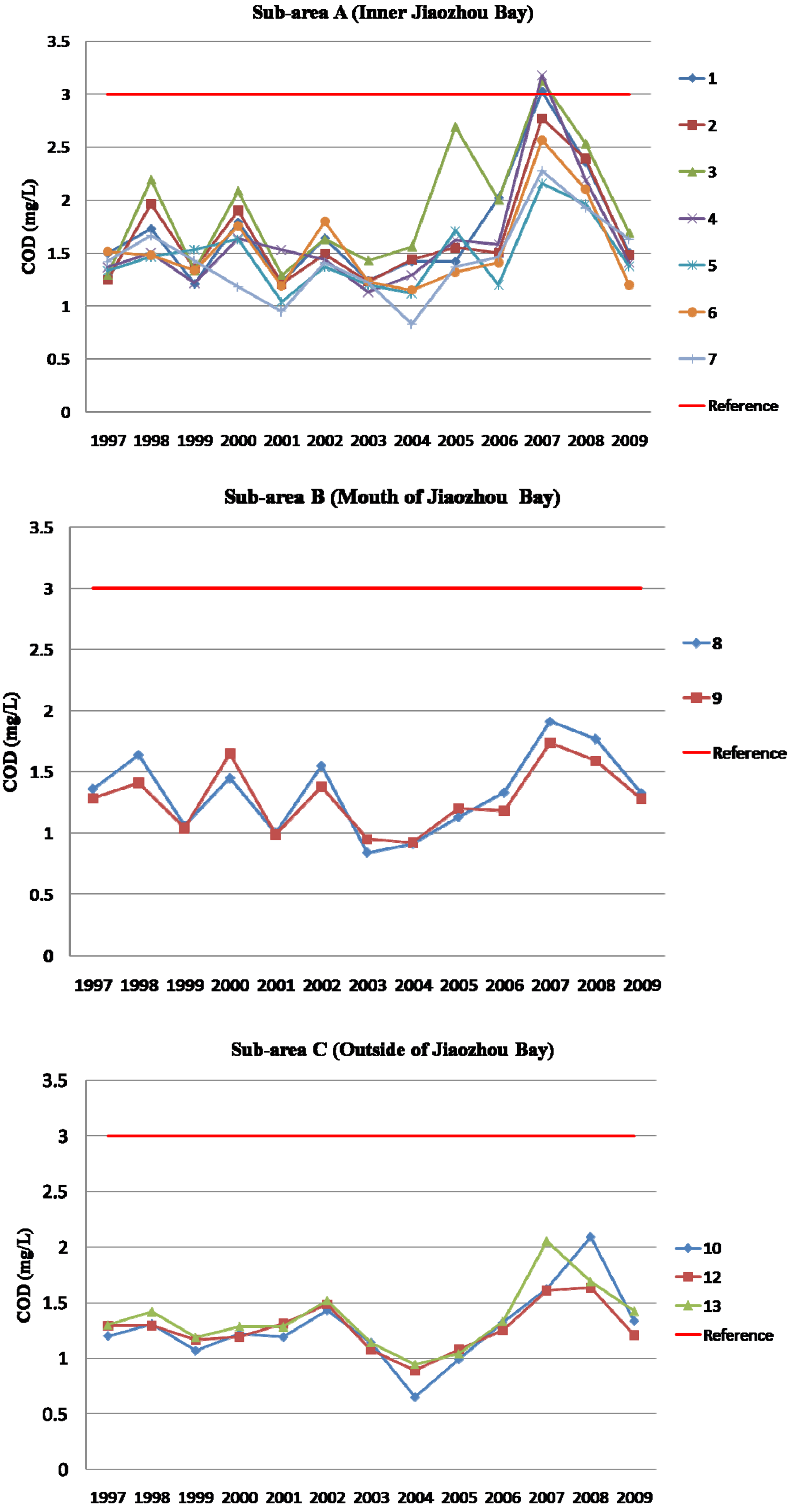


Figure12. Long-term trend of annual mean COD from 1997 to 2009 (three sub-areas)

Results of non-parametric Mann-Kendall test was presented in Table 7. There was no trend in all three sub-areas (Table 7).

Table 7 Results of non-parametric Mann-Kendall test for Chl-a and red tide events in all sampling sites

Parameters	Ranges of z value	p value	Overall trend
Bottom DO	Not tested	-	Upward trend
COD (Sub-area A)	0-1.711	Most >0.05	No trend
COD (Sub-area B)	0.06-0.305	All >0.05	No trend
COD (Sub-area C)	0.549-1.15	All >0.05	No trend

4.1.4 Assessment of Category IV

There was no shell fish poisoning incidents recorded in all sub-areas of Jiaozhou Bay from the year 1997 to 2009, and the shell fish poisoning incident was subsequently rated as low.

4.2 Assessment results

The three sub-areas of Jiaozhou Bay exhibited different eutrophication status for the four assessment categories (category I to IV). This may be attributed to the geographical location, the hydrodynamic conditions and nutrient loads of the sub-areas. The eutrophication assessment results of Jiaozhou Bay were presented in Table 8 to 10 for each sub-area.

For Category I, Riverine input of DIN showed an upward trend. The DIN concentrations in sub-area A were higher than reference concentration in the recent 3 years with an upward trend for most sampling sites. On the contrary, the DIN concentrations in sub-area B and C were lower than reference values in the recent 3 years with no observable trend according to Mann-Kendall test. The Mann-Kendall test could be possibly impacted by extremely low DIN concentrations in 2006 (see figure 5). DIN concentrations in sub-area B and C in the recent 3 years were much higher than those in the years 1997, 1998 and 1999. Therefore, without regard to Mann-Kendall test, DIN concentrations in sub-area B and C were rated as “Low” and

"Increasing trend". DIP concentrations in most sampling sites were higher than reference concentration in the recent 3 years with an upward trend observed in all sub-areas. The DIP concentrations in Jiaozhou Bay increased rapidly in recent years compared to DIN. A relatively mild upward trend of DIN occurred as a result of a decrease in ammonia effluents (Sun et al., 2011). This has resulted in a decrease of DIN/DIP ratio, but for most sampling sites in sub-area A, DIN/DIP ratio was higher than the Redfield value (a ratio of 16) in the recent 3 years. The decreasing DIN/DIP ratio was also observed in the other two sub-areas. Therefore, the Category I was rated as "HI" for sub-area A and "LI" for sub-area B and C.

For Category II, in all three sub-areas, Maximum of Chl-a was generally lower than reference concentration in the recent 3 years with no obvious trend observed in 13 years. Meanwhile, annual mean of Chl-a was lower than reference value in the recent 3 years and again, with no observable trend. Red tide events often occurred in inner Jiaozhou Bay before the year 2004 and showed a downward trend since then. In the recent 3 years (2007-2009), only one red tide event was observed in this sub-area. For the mouth of Jiaozhou Bay (Sub-area B), no red tide event was recorded since 1997. On the other hand, red tide events begin to occur at a high frequency in the recent 5 years outside of Jiaozhou Bay (Sub-area C), demonstrating an upward trend. Therefore, considering all the parameters in category II, the Category II was rated as "LN" in all three sub-areas..

For Category III, in general, COD concentration in the Jiaozhou Bay was lower than 3 mg l^{-1} for all sub-areas. COD values in a majority of sites showed no obvious trend in these 13 years in all sub-areas according to non-parametric Mann-Kendall test. Bottom DO concentration was generally higher than 2 mg l^{-1} for all sub-areas. Meanwhile, an upward trend was observed for bottom DO. This result indicated that Low DO or high COD were not the main eutrophication symptoms in the Jiaozhou Bay. There were no fish kill incidents recorded from the year 1997 to 2009 and the fish kill incidents was rated as "low" and "no trend". Therefore, considering all the parameters in category III, the Category III was rated as LN in all three sub-areas..

For Category IV, there was no shell fish poisoning incidents recorded in all sub-areas of Jiaozhou Bay from the year 1997 to 2009, and the shell fish poisoning incident was rated as “low” and “no trend”. So the Category IV was rated as LN in sub-areas A, B and C.

Table 8 Identification of eutrophication status in sub-area A of Jiaozhou Bay

Category	Assessment parameter	Comparison	Occurrence	Trend	Parameter identification	Category identification
I	Riverine DIN loads	×	×	I	I	HI
	DIN	H	×	I	HI	
	DIP	H	×	I	HI	
	DIN/DIP ratio	H	×	D	HD	
II	Max of Chl-a	L	×	N	LN	LN
	Mean of Chl-a	L	×	N	LN	
	Red tide events	×	L	D	LD	
III	DO (bottom)	L	×	D	LD	LN
	COD	L	×	N	LN	
	Fish kill incidents	×	L	N	LN	
IV	Shell fish poisoning incidents	×	L	N	LN	LN

Table 9 Identification of eutrophication status in sub-area B of Jiaozhou Bay

Category	Assessment parameter	Comparison	Occurrence	Trend	Parameter identification	Category identification
I	Riverine DIN loads			×	×	LI
	DIN	L	×	I	LI	
	DIP	H	×	I	HI	
	DIN/DIP ratio	L	×	D	LD	
II	Max of Chl-a	L	×	N	LN	LN
	Mean of Chl-a	L	×	N	LN	
	Red tide events	×	L	N	LN	
III	DO (bottom)	L	×	D	LD	LN

	COD	L	×	N	LN	
	Fish kill incidents	×	L	N	LN	
IV	Shell fish poisoning incidents	×	L	N	LN	LN

Table 10 Identification of eutrophication status in sub-area C of Jiaozhou Bay

Category	Assessment parameter	Comparison	Occurrence	Trend	Parameter identification	Category identification
I	Riverine DIN loads			×	×	LI
	DIN	L	×	I	LI	
	DIP	H	×	I	HI	
	DIN/DIP ratio	L	×	D	LD	
II	Max of Chl-a	L	×	N	LN	LN
	Mean of Chl-a	L	×	N	LN	
	Red tide events	×	L	I	LI	
III	DO (bottom)	L	×	D	LD	LN
	COD	L	×	N	LN	
	Fish kill incidents	×	L	N	LN	
IV	Shell fish poisoning incidents	×	L	N	LN	LN

5. Conclusion and recommendations

5.1 Conclusion

The results of eutrophication assessment using NOWPAP Common Procedure indicated that the nutrient pressures in inner Jiaozhou Bay was much higher than the mouth and outside of Jiaozhou Bay. Moreover, nutrient pressures showed an upward trend in all sub-areas, indicating more and more severe anthropogenic activities in coastal areas.

For all sub-areas, ecological effects (direct or indirect) were all not so apparent. Especially in inner Jiaozhou Bay, red tide events occurred at a relatively low frequency after the year 2004. That is to say, high nutrient load and high nutrient concentrations did not result in severe ecological effects. In the Bohai Bay, decreasing frequency of red tide events may be mainly due to highly suspended particulate material according to investigation data (Qiao et al., 2011). But in Jiaozhou Bay, the reason for the reduction in frequency of red tide events still requires further investigation.

Nutrient concentrations may not have a direct relationship with ecological effects in coastal areas. This can be shown from the fact that red tide events in sub-area C were frequent in recent years (2006-2009) despite the relatively low nutrient concentrations, Chl-a levels and COD compared to those in inner Jiaozhou Bay. The high frequency of red tide events could be due to the increase in nutrients (DIN, DIP) in this sub-area.

The results also indicated that to fully assess the eutrophication status of coastal areas, nutrient enrichment indicators by themselves would not be adequate, since ecological effects were another important part reflecting eutrophication status.

5.2 Recommendations

The results of eutrophication assessment of Jiaozhou Bay have indicated that the control of nutrient pollution into the bay is a major management strategy for eutrophication management of Jiaozhou Bay, especially in sub-area A. Although nutrient concentrations of the mouth and outside of Jiaozhou Bay were relatively low, control of the sewage treatment plant is also essential, since in these two sub-areas, relatively low nutrient concentrations could stimulate occurrence of red tide events. Further research on the cause for increasing frequency of red tides in recent years outside of Jiaozhou Bay is needed to assist in the control of red tides. Strategies on emergency disposal of red tides are also needed to prevent ecological or economic losses.

References

Bricker, S.B., Ferreira, J.G., & Simas, T., 2003. An integrated methodology for assessment of estuarine trophic status. Ecological Modelling, 169, 39-60.

Chen, M.Y., Yu, Z.M., Song, X.X., & Cao, X.H., 2007. Evaluation of fuzzy synthesis to assess the seawater eutrophication in the Changjiang estuary. Marine Sciences, 31(11), 47-54(in

Chinese with English abstract).

Huang X P, Huang L M, Yue W Z. 2003. The characteristics of nutrients and eutrophication in the Pearl River estuary, South China. Mar. Pollut. Bull., 47 (1-6):30-36.

Li, D., Zhang, J., Huang, D., et al., 2002. Oxygen depletion off the Changjiang (Yangtze River) Estuary. Science in China 45:1137–1146.

NOWPAP CEARAC, 2011. Integrated Report on Eutrophication Assessment in Selected Sea Areas in the NOWPAP Region: Evaluation of the NOWPAP Common Procedure. NOWPAP CEARAC, Toyama, Japan.

Nixon, S.W., 1995. Coastal marine eutrophication - a definition, social causes, and future concerns. Ophelia. 41, 199-219.

NSQS, 1997. National seawater quality standard. GB 3097-1997 (in Chinese) .

Qiao, L.L., Wang, Y.Z., Li, G.X., Deng, S.G., Liu, Y., Mu, L., 2011. Distribution of suspended particulate matter in the northern Bohai Bay in summer and its relation with thermocline. Estuar. Coast. Shelf. Sci. 93, 212-219.

Shen, Z. L., 2001. Historical changes in nutrient structure and its influences on phytoplantkon composition in Jiaozhou Bay. Estuar. Coast. Shelf Sci., 52 (2):211-224.

State Oceanic Administration, 2006. Bulletin of Marine Environmental Quality of China (in Chinese)

State Oceanic Administration, 2007. Bulletin of Marine Environmental Quality of China (in Chinese)

State Oceanic Administration, 2008. Bulletin of Marine Environmental Quality of China (in Chinese)

State Oceanic Administration, 2009. Bulletin of Marine Environmental Quality of China (in Chinese)

Strickland, J. D. H. & T. R. Parsons, 1972. A practical handbook of seawater analysis. Fisheries Research Board of Canada Bulletin 167: 311.

Su, C., Shen, Z.L., Yao, Y., & Cao, H.R., 2008. Assessment of eutrophication in the Yangtze River estuary and its adjacent waters. Advances in Water Science, 19(1), 99–105(in Chinese with English abstract).

Sun, S., et al., 2011. Atlas of long-term changes in the Jiaozhou Bay ecosystem. Beijing. Ocean Press. p: 60-179.

Sun, S., et al., 2011. Lakes, wetland and Bays ecosystem dataset of China: Jiaozhou Bay marine ecosystem. Beijing. Agricultural Press of China. p:80-135.

Sun, X. X., Sun, S., Zhao, Z. X., et al. 2011. Long term changes in nutrient concentrations and structure in the Jiaozhou Bay. Oceannologia et limnologia sinica. 42 (5): 662-669.

Xiao, Y. J., Ferrerira, J. G., Bricker, S. B., et al. 2007. Trophic assessment in Chinese coastal systems: review of methods and application to the Changjiang (Yangtze) estuary and Jiaozhou Bay. Estuaries Coasts, 30 (6):901-918.

Wang gang. 2009. Research on the pollutants fluxes from point sources and aquaculture farms. Master thesis (in Chinese).

Wu, Y. L., Sun, S., Zhang, Y. S., et al. 2005. The impact of long term changes of environment to the structures of phytoplanktons in Jiaozhou Bay. Chinese Journal of Oceanology and Limnology. 36 (6): 487-499.

Zhang, X. Q., Sun, Y. L., 2007. Research on the control of total pollutants loads into the Jiaozhou

Bay. Marine Environmental Sicence. 26(4): 347-351.

Zou, J.Z., Dong, L.P., & Qin, B.P., 1983. Preliminary Study of eutrophcaion and algal bloom in Bohai Bay. Marine Environmental Science, 2(2), 41-54 (in Chinese).

A Case Study Report on

Assessment of Eutrophication Status

in Toyama Bay, Japan

Northwest Pacific Region

Environmental Cooperation Center

July 2013

Contents

1. Scope of the assessment

1.1 Objective of the assessment

Toyama Bay is fed by several Class-A rivers and other small river, and river-based nutrients are supplied into the surface water of the bay. Nutrients included in the river water are not only natural ones, but also ones originated from anthropogenic sources such as industrial activities, domestic life and livestock. Therefore, in terms of nutrient loads, the coastal environment of the closed-off section of Toyama Bay has been influenced strongly by the Oyabe River and the Jinzu River. In this area, phytoplankton blooms increase in summer, and they lead increase of chemical oxygen demand (COD). In order to improve the coastal environment of Toyama Bay, it is essential to understand nutrient loads from rivers, nutrient concentration in the sea area, and biochemical reaction caused by nutrient concentration. For that purpose, a new eutrophication assessment following the Procedures for assessment of eutrophication including evaluation of land based sources of nutrients for the NOWPAP region (so-called 'the NOWPAP Common Procedures') was implemented to identify the problems and effective countermeasures.

1.2 Selection of assessment area

In Toyama Bay Case Study, this bay was selected for implementing eutrophication assessment, as this place has been a target of several existing assessments, and plenty of data from them are available (Fig.1.1). In this case study, the sea area of Toyama Bay was defined in consideration of geographical conditions of the water body and municipal borderlines between neighboring prefectures: to the south from the line drawn between the border Toyama-Niigata and Cape Rokkozaki. However, it is necessary to collect as much data as possible to implement this case study as well as to coordinate with relevant organizations for releasing the study results. Thus, in order to examine collected data free from restrictions as much as possible, it was decided to focus on only the water area where Toyama prefecture has implemented the environmental assessments, and the coastal area along Noto Peninsula and Nanao Bay was excluded.

Toyama Bay is located to the east of Noto Peninsula, at the center of the eastern part of NOWPAP sea area. For descriptive purposes, the area is defined inside the line drawn between Cape Rokkozaki and the border of Toyama-Niigata. This is a semi-enclosed bay with the surface area of approximately 2,120 km^2 and 1,250 m as the deepest spot, The entire volume is approximately 1, 280 km^3. The depth of 3,000 m is a border of two different waters: mainly the Tsushima Warm Current flows on top while Japan Sea Proper Water flows below the borderline. Five Class-A rivers (the Oyabe River, the Sho River, the Jinzu River, the Joganji River and the Kurobe River) and twenty-nine Class-B rivers flow into the coastal area of Toyama Bay, so it is said that the coastal area is strongly influenced by river water.

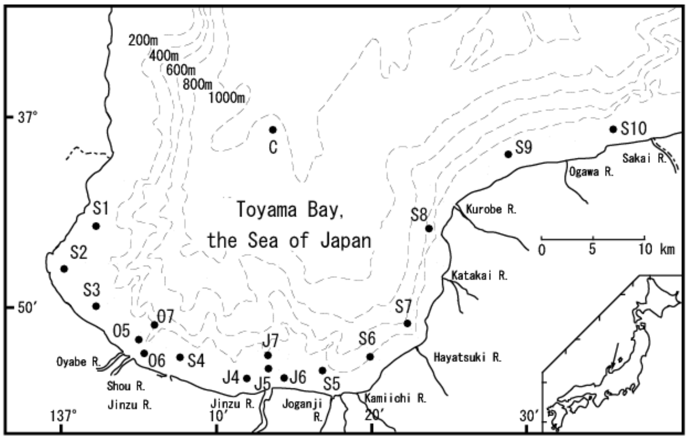


Fig. 1.1 Schematic view of Toyama Bay

1.3 Collection of relevant information

Table 1.1 shows the information/data collected for the eutrophication assessment in Toyama Bay Case Study.

Table 1.1 Information/data collected for the eutrophication assessment of Toyama Bay Case Study

Survey type	Responsible organization	Survey name	Objective	Survey period	Main survey parameters	Survey frequency	No. of station
Water quality monitoring by environ-mental authorities	Toyama Pref. (Environmental Conservation Division)	Water quality survey of public waters (Water quality survey of sea water)	Monitoring of water quality status	1976 - present (TN, TP: 1997-)	DO, COD, TN, TP	1/month	23 (Coastal: 10 the Jinzu: 7 the Oyabe: 6)
	Toyama Pref. (Environmental Conservation Division)	Survey of water quality conservation measures of Toyama Bay (Comple-mentary survey)	Understanding of eutrophication status in Toyama Bay sea area	1997-	DIN,DIP, chrolophyll-*a*, TN, TP	1/month	9
	Toyama Pref. (Environmental Conservation Division)	Accident report on water quality	Understanding of water quality accidents	1975-	accident site, extent of pollution, cause of emission, influence to fish	When an accident occurs	
Environ-mental survey/ research	Toyama Pref. (Environmental Conservation Division)	Basic research on a prediction model	Accuracy improvement of a prediction model by organizing data of nutrients from rivers	2005-	estimate of input loads (TN, TP) (1985-2004)	2005 ONLY	
Water pollution monitoring by fisheries authorities	Toyama Prefectural Agricultural, Forestry and Fisheries Research Center, Fisheries Research Institute	Red tide survey	Survey of red-tide events and report of related information	1966-	extent of occurrence, types of phytoplankton , density	When red tide occurs	
others	Toyama Pref. (Public Health Division)	Report on food poisoning incidents	Prevention of outspread of food poisoning	1994-	date, place, food of cause	When food poisoning occurs	

1.4 Selection of assessment parameters

1.4.1 Assessment categories of Toyama Bay case study

Based on the Common Procedures, the parameters for the eutrophication assessment were categorized into the four assessment categories shown in Table 1.2.

Table 1.2 Assessment categories of Toyama Bay case study

Category I	Degree of nutrient enrichment (nutrient input, nutrient concentration etc.)
Category II	Direct effects of nutrient enrichment (increase of phytoplankton, chlorophyll-*a* etc.)
Category III	Indirect effects of nutrient enrichment (increase of organic material, decrease of DO etc.)
Category IV	Other possible effects of nutrient enrichment (shellfish poisoning etc.)

1.4.2 Assessment parameters of Toyama Bay case study

Table 1.3 shows the assessment parameters that were used for Categories I-IV.

Table 1.3 Assessment parameters used for Toyama Bay Case Study

Category	Assessment parameter
I. Degree of nutrient enrichment	(1) TN input from river
	(2) TP input from river
	(3) TN input from sewage treatment plant
	(4) TP input from sewage treatment plant
	(5) TN concentration
	(6) TP concentration
	(7) Winter DIN concentration
	(8) Winter DIP concentration
	(9) Winter DIN/DIP ratio
II. Direct effects of nutrient enrichment	(10) Annual maximum chlorophyll-*a* concentration
	(11) Annual mean chlorophyll-*a* concentration
	(12) Red tide (diatom sp.)
	(13) Red tide (dinoflagellate sp.)
III. Indirect effects of nutrient enrichment	(14) DO
	(15) Abnormal fish kill
	(16) COD
IV. Other possible effects of nutrient enrichment	(17) Red tide (*Noctiluca* sp.)
	(18) Shellfish poisoning

1.5 Setting of sub-areas

The result of the preliminary eutrophication assessment of Toyama Bay using satellite data (Fig. 1.2) was used as reference for dividing sub-areas. Chlorophyll-*a* concentration in the closed-off section of bay is high, and the left and east sides of the Jinzu River mouth showed increasing tendency. On the other hand, in the coastal area along Himi city to the Oyabe River mouth, chlorophyll-*a* concentration is low but showing increasing trend.

In this case study, Toyama Bay was divided into three sub-areas: (A)-Coastal Area, the area with high chlorophyll-*a* concentration (>5 µg/L) and increasing trend in some spots; (B)-Inner Area, the area with low chlorophyll-*a* (≤5µg/L) and increasing trend; and (C)-Offshore Area, the area with low chlorophyll-*a* concentration and no trend (Fig. 1.3).

As mentioned above, Nanao Bay at Noto Peninsula and Uchinada Coastal area were excluded from this assessment.

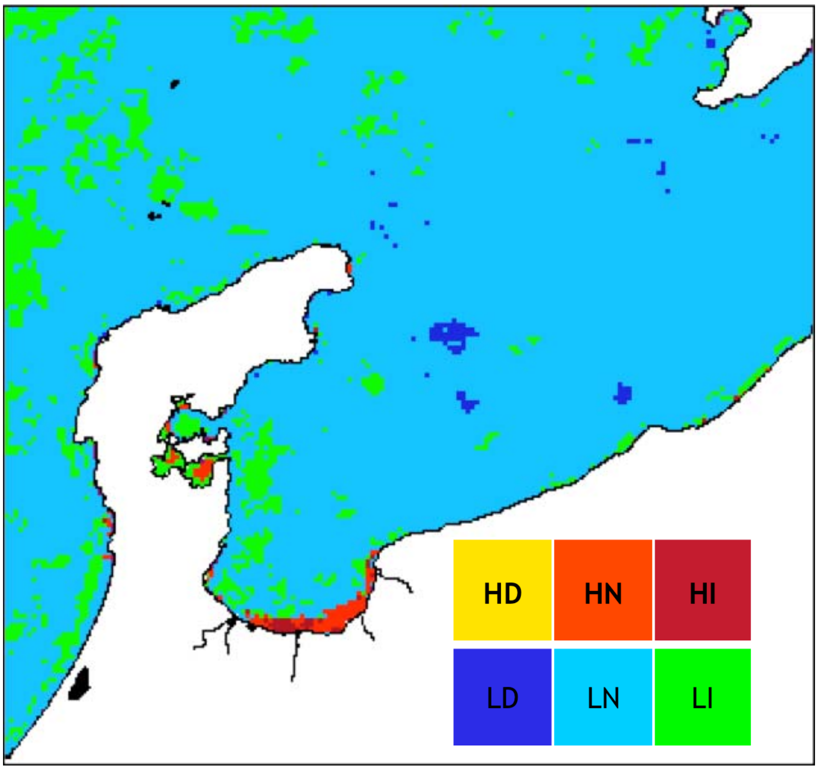


Fig. 1.2 Results of the preliminary eutrophication assessment of Toyama Bay based on remotely observed satellite

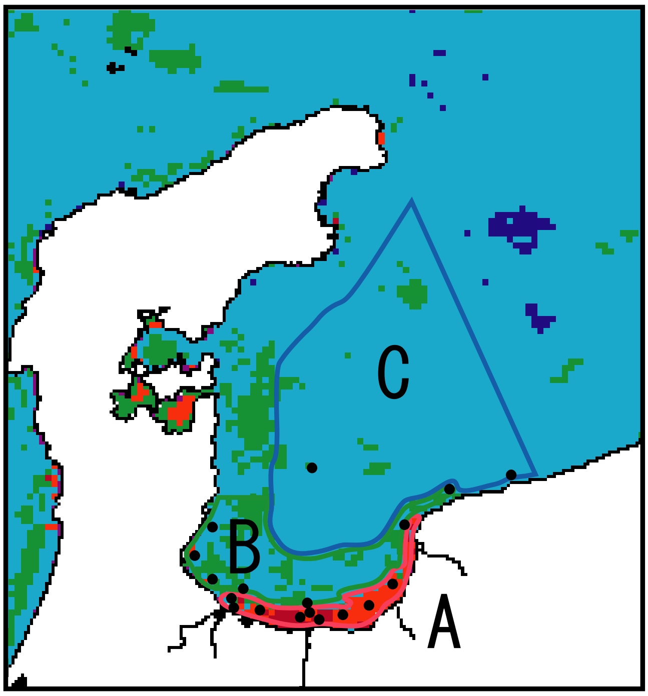


Fig. 1.3 Sub-areas in Toyama Bay
(A) Coastal Area, (B) Intermediate Area, (C) Offshore Area

Table 1.4 List of data collection stations

Sub-area	Station	Latitude	Longitude	Survey name
(A) Coastal Area	J4	36.7767°	137.2039°	Water quality survey of public waters
	J5	36.7828°	137.2222°	
	J6	36.7764°	137.2406°	
	O5	36.8072°	137.0847°	Survey of water quality conservation measures of Toyama Bay
	O6	36.7939°	137.0914°	
	S4	36.7894°	137.1356°	
	S5	36.7789°	137.2786°	
	S6	36.7931°	137.3311°	
	S7	36.8256°	137.3703°	
(B) Intermediate Area	J7	36.7981°	137.2222°	
	O7	36.8197°	137.0997°	
	S1	36.9081°	137.0461°	
	S2	36.8714°	137.0119°	
	S3	36.8353°	137.0444°	
	S8	36.9131°	137.3953°	
	S9	36.9700°	137.4803°	
(C) Offshore Area	S10	36.9925°	137.5886°	
	C	37.0033°	137.2300°	

2. Data processing

Eutrophication related information/data (1-3 Collection of relevant information) were collected from Division of Civic Affairs, Environment and Cultural Department, Toyama Prefecture and the Fisheries Research Institute of Toyama Prefectural Agricultural, Forestry and Fisheries Research Center. They are part of official government data, and it means that any unreliable information is removed from them before the data is released in public. Therefore, screening of the collected data was not applied in this case study.

The collected data was processed as shown in Table 2.1-2.3 explains data processing methodologies.

Table 2.1 Data processing methodologies applied for Toyama Bay Case Study (Category I)

	Assessment parameter	Data processing methodology
I	(1) TN input from river	For volume of flow into Toyama Bay from Class-A rivers, the mean volume of flow per day in Water Information System of Ministry of Land, Infrastructure, and Transport, Japan was used. TN concentration from Class-A rivers was collected from monthly data at the lowest point of a river in 'water quality survey of public waters.' Monthly TN input was calculated by multiplying the mean volume of river flow per day by TN concentration, then, the annual mean TN was calculated by averaging the monthly data (Apr.-Mar.). The trend of the annual mean value from 1978-2009 was also analyzed.
	(2) TP input from river	For volume of flow into Toyama Bay from Class-A rivers, the mean volume of flow per day in Water Information System of Ministry of Land, Infrastructure, and Transport, Japan was used. TP concentration from Class-A rivers was collected from monthly data at the lowest point of a river in Water quality survey of public waters. Monthly TP input was calculated by multiplying the mean volume of river flow per day by TP concentration, then, annual mean TP was calculated by averaging the monthly data (Apr.-Mar.). The trend of the annual mean value from 1978-2009 was also analyzed.
	(3) TN input from sewage treatment plant	
	(4) TP input from sewage treatment plant	
	(5) TN concentration	Annual mean value was calculated by averaging the twelve monthly data acquired through the 'water quality survey of public waters.' The mean value of the recent three years (2007-2009) was compared with the reference standard. The trend of the annual mean value from 1985-2009 was also analyzed.
	(6) TP concentration	The annual mean value was calculated by averaging the twelve monthly data acquired through the 'water quality survey of public waters.' The mean value of the recent three years (2007-2009) was compared with the reference value. The trend of the annual mean value from 1985-2009 was also analyzed.
	(7) Winter DIN concentration	The winter mean value was calculated by averaging the monthly data

	Assessment parameter	Data processing methodology
		of 3 winter months (Jan.-Mar.). Data was acquired from the 'survey of water quality conservation measures of Toyama Bay.' The mean value of the recent three years (2007-2009) was compared with the reference value. The trend of the winter mean value from 1997-2009 was also analyzed.
	(8) Winter DIP concentration	The winter mean value was calculated by averaging the monthly data of three winter months (Jan.-Mar.). Data was acquired from the 'survey of water quality conservation measures of Toyama Bay.' The mean value of the recent three years (2007-2009) was compared with the reference standard. The trend of the winter mean value from 1997-2009 was also analyzed.
	(9) Winter DIN/DIP ratio	Calculated by converting the winter DIN and DIP concentrations into Molar concentration. The mean value of the recent three years (2007-2009) was compared with the reference value. Trend of the winter mean value from 1997-2009 was also analyzed. Winter DIN/DIP ratio was not used in the classification of assessment category if both winter DIN and DIP concentrations were below the reference values respectively.

Table 2.2 Data processing methodologies applied for Toyama Bay Case Study (Category II~IV)

	Assessment parameter	Data processing methodology
II	(10) Annual maximum chlorophyll -*a* concentration	The annual maximum value was determined by the selecting maximum value of the monthly data of the 'survey of water quality conservation measures of Toyama Bay.' The mean of the annual maximum value of the recent three years (2007-2009) was compared with the reference value. The trend of the annual maximum value from 1985-2009 was also analyzed.
	(11) Annual mean chlorophyll-*a* concentration	The annual mean value was calculated by averaging the twelve monthly data acquired through the 'survey of water quality conservation measures of Toyama Bay.' The mean of the annual mean value of the recent three years (2007~~7~~-2009~~9~~) was compared with the reference value. The trend of the annual mean value from 1985-2009 was also analyzed.
	(12) Red tide (diatom sp.)	The number of diatom red tide was counted by referring to the red tide survey of the Fisheries Research Institute of Toyama prefectural Agricultural, Forestry and Fisheries Research Center. The total number of diatom red tide in the recent three years (2007~~7~~-2009~~9~~) was compared with the reference value. The trend of diatom red tide was analyzed from 1966-2009~~9~~.
	(13) Red tide (dinoflagellate sp.)	The number of dinoflagellate red tide was counted by referring to the red tide survey of the Fisheries Research Institute of Toyama prefectural Agricultural, Forestry and Fisheries Research Center. The total number of dinoflagellate red tide in the recent three years (2007~~7~~-2009~~9~~) was compared with the reference value. The trend of dinoflagellate red tide was analyzed from 1966-2009~~9~~. *Noctiluca* sp. was not included.
III	(14) Annual minimum DO concentration	The annual minimum value was determined by selecting the minimum value of the monthly data of the 'water quality survey of public waters.' The mean of the annual minimum value of the recent three years (2007-2009) was compared with the reference value. The trend of the annual minimum value from 1985-2009 was also analyzed. DO at bottom layer was not used because annual minimum values in Toyama Bay was at health state.
	(15) Abnormal fish kill	The number of abnormal fish kill was counted by referring to the data collected by Toyama Prefecture. The total number of abnormal fish kill in the recent three years (2007-2009) was compared with the reference value. The trend of abnormal fish kill was analyzed from 1985-2009.
	(16) COD	The annual mean value was calculated by averaging the twelve monthly data acquired through the 'water quality survey of public waters.' The mean value of the recent three years (2007-2009) was compared with the reference value. The trend of the annual mean value from 1985-2009 was also analyzed.
IV	(17) Red tide (*Noctiluca* sp.)	The number of *Noctiluca* red tide was counted by referring to the red tide survey of the Fisheries Research Institute of Toyama prefectural Agricultural, Forestry and Fisheries Research Center. The total number of *Noctiluca* red tide in the recent three years (2007-2009) was compared with the reference value. The trend of *Noctiluca* red tide was analyzed from 1966-2009.
	(18) Shellfish poisoning	The number of shellfish poisoning was counted by referring to the data collected by Toyama Prefecture. The total number of shellfish poisoning in the recent three years (2007-2009) was compared with the reference value. The trend of shellfish poisoning was analyzed from 1994-2009.

Table 2.3 Analytical method of chemical assessment parameters

Category	Assessment parameter		Analysis method used in the 'Water quality survey of public waters'	Analysis method used in the 'Survey of water quality conservation measures of Toyama Bay'
I	TN concentration		Copper-cadmium column reduction method (Methods stipulated in 45.4 of JIS (Japanese Industrial Standard) K0102.)	Copper-cadmium column reduction method (Methods stipulated in 45.4 of JIS (Japanese Industrial Standard) K0102.)
	TP concentration		Molybdenum-blue spectrophotometric method (Methods stipulated in 46.3 of JIS K0102) (unconcentrated, analysis with the AutoAnalyzerTM)	Molybdenum-blue spectrophotometric method (Methods stipulated in 46.3 of JIS K0102) (unconcentrated, analysis with the Auto Analyzer)
	DIN	Ammonium	-	Methods stipulated in 5.5.3 of Manual on Oceanographic Observation (Japan Meteorological Agency) Indophenol blue method, non-concentrated, analysis using AutoAnalyzer
		Nitrate	-	Methods stipulated in 5.5.3 of Manual on Oceanographic Observation (Japan Meteorological Agency) Naphthylethylenediamine absorptiometry after copper cadmium column reducing, non-concentrated, analysis using AutoAnalyzer
		Nitrite	-	Methods stipulated in 5.5.3 of Manual on Oceanographic Observation (Japan Meteorological Agency) Naphthylethylenediamine absorptiometry, non-concentrated, analysis using AutoAnalyzer
	DIP		-	Methods stipulated in 5.5.3 of Manual on Oceanographic Observation (Japan Meteorological Agency) Ascorbic acid reduction absorptiometry, non-concentrated, analysis using AutoAnalyzer
II	Chlorophyll-*a* concentration		-	Fluorometry stipulated in 9.2.4 of Research Methods of Studying Ocean Environment
III	DO		Winkler sodium azide modification method	Winkler sodium azide modification method
	COD		Methods stipulated in 17 of JIS K0102 (potassium permanganate method)	Methods stipulated in 17 of JIS K0102 (potassium permanganate method)

3. Setting of assessment criteria

3.1 Setting of standard

In Japan, there are two types of quality standards that can be applied for the eutrophication assessment: 'Environmental water quality standard' and 'Fisheries water quality standard' (Table 3.1). For the case study of Toyama Bay, reference values were set for each assessment parameter by referring to the above water quality standards (see Table 3.2). Values of total nitrogen (TN) and total phosphorus (TP) concentrations were set to be equivalent to the 'Environmental water quality standard Type II.' In addition, values of dissolved oxygen (DO) and chemical oxygen demand (COD) were set to be equivalent to the 'Fisheries water quality standard' and the 'Environmental water quality standard Type B' respectively. Since there are no water quality standards for winter DIN and DIP concentrations, their reference values were set through a regression analysis of winter DIN and TN concentration (winter DIP and TP concentration) in Toyama Bay. Based on the identified relationship, the reference value of DIN (DIP) was calculated with TN: 0.3 mg/L (TP: 0.03 mg/L) (see Fig.3.1 and 3.2). The reference values of annual maximum/mean chlorophyll-*a* concentrations were set based on Bricker *et al.* (2003), which are 20 µg/L (upper threshold of medium eutrophication level) and 5 µg/L (lower threshold of medium eutrophication level) respectively (see Table 3.2).

Table 3.1 Standards of the 'Environmental water quality standard' and 'Fisheries water quality standard'

Cate-gory	Assessment parameter	Environmental water quality standard	Water use	Fisheries water quality standard	Water use
I	TN concentration	0.2 mg/l	Type I[2]		
		0.3 mg/l	Type II	0.3 mg/l	Fishery Type 1[4]
		0.6 mg/l	Type III	0.6 mg/l	Fishery Type 2
		1.0 mg/l	Type IV	1.0 mg/l	Fishery Type 3
	TP concentration	0.02 mg/l	Type I		
		0.03 mg/l	Type II	0.03 mg/l	Fishery Type 1
		0.05 mg/l	Type III	0.05 mg/l	Fishery Type 2
		0.09 mg/l	Type IV	0.09 mg/l	Fishery Type 3
	Winter DIN concentration	None		0.07-0.1 mg/l	Min. concentration required for laver farming (not limited to winter)
	Winter DIP concentration	None		0.007-0.014 mg/l	Min. concentration required for laver farming (not limited to winter)
	Winter DIN/DIP ratio	None		None	
II	Chlorophyll-*a* concentration	None		None	
III	DO	7.5 mg/l	Type A[3]	6 mg/l	General
		5 mg/l	Type B		
		2 mg/l	Type C		
	COD1)	2 mg/l	Type A	1 mg/l	General
		3 mg/l	Type B	2 mg/l	Laver farm or enclosed bay
		8 mg/l	Type C		

1) COD standards of 'Environmental water quality standard' and 'Fisheries water quality standard' are in COD_{Mn} and COD_{OH} respectively (COD_{OH} = 0.6 x COD_{MN})
2) Type I: Conservation of natural environment
Type II: Fishery class 1, bathing
Type III: Fishery class 2
Type IV: Fishery class 3, industrial water, conservation of habitable environment for marine biota
3) Type A: Fishery class 1, bathing, conservation of natural environment
Type B: Fishery class 2, industrial water
Type C: Conservation of environment
4) Fishery Type 1: Stable and well-balanced catch of various fishery species including benthic fish/shellfish
Fishery Type 2: Large catch of fishery species, except certain benthic fish/shellfish
Fishery Type 3: Catch of fishery species tolerant to pollution

Table 3.2 Reference values applied for the eutrophication assessment of Toyama Bay Case Study

	Assessment parameter	Reference value	Remarks
I	(1) TN input from river	-	
	(2) TP input from river	-	
	(3) TN input from sewage treatment plant	-	
	(4) TP input from sewage treatment plant	-	
	(5) TN concentration	0.3 mg/L	Environmental water quality standard Type II
	(6) TP concentration	0.03 mg/L	Environmental water quality standard Type II
	(7) Winter DIN concentration	0.144 mg/L	1)
	(8) Winter DIP concentration	0.017 mg/L	2)
	(9) Winter DIN/DIP ratio	16	Redfield ratio
II	(10) Annual maximum chlorophyll-*a* concentration	20 µg/L	3)
	(11) Annual mean chlorophyll-*a* concentration	5µg/L	4)
	(12) Red tide (diatom sp.)	1 event/ year	
	(13) Red tide (dinoflagellate sp.)	1 event/ year	
III	(14) Annual minimum DO	6.0 mg/L	Fisheries water quality standard
	(15) Abnormal fish-kill	1 event/ year	
	(16) COD	3.0 mg/L	Environmental water quality standard Type B
IV	(17) Red tide (*Noctiluca* sp.)	3 events/3 year	
	(18) Shellfish poisoning	1 event/ year	

1) Set based on the relationship between winter TN and DIN
2) Set based on the relationship between winter TP and DIP
3) Upper threshold of medium eutrophication based on Bricker *et al.* (2003)
4) Lower threshold of medium eutrophication based on Bricker *et al.* (2003)

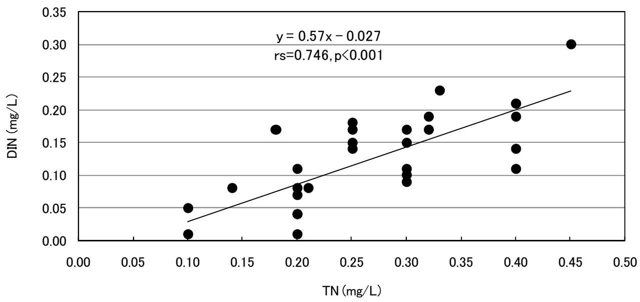


Fig. 3.1 Relationship between winter TN and DIN in Toyama Bay

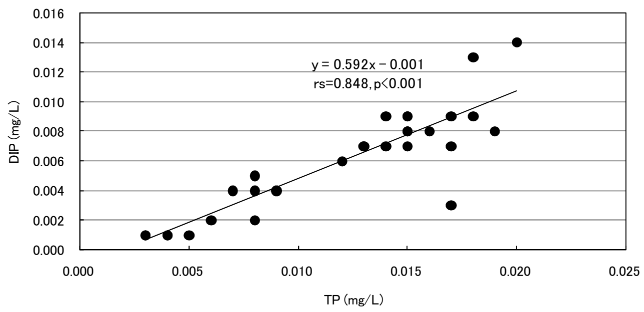


Fig. 3.2 Relationship between winter TP and DIP in Toyama Bay

Table 3.3 Classification of eutrophication levels by chlorophyll-*a* concentration

Hypereutrophic	> 60 μg/L
High	> 20, ≤ 60 μg/L
Medium	> 5, ≤ 20 μg/L
Low	> 0, ≤ 5 μg/L

Bricker *et al.* (2003)

3.2 Setting of classification criteria

The eutrophication status was classified according to the 'status' and 'trend' of the assessment values. Three types of 'identification tools' (comparison, occurrence and trend) were used and combined to determine the 'status' and 'trend' of the assessment values.

With the 'comparison' tool, the mean value of the recent three years (2005-2007) in each survey station was compared with the reference values listed in Table 3.2. However, assessment was not conducted when data availability was limited to less than three years within the five-year period from 2005-2009. A survey station in a sub-area was classified as 'high' when the three-year mean value there was above the reference value; and 'low' when it was below the reference value. The status of the assessment parameter was classified as 'High' when more than 50% of the survey stations in a sub-area were classified as 'high'; and 'Low' if less than 50% of the survey stations in a sub-area were classified as 'Low'. Since a healthy marine environment is usually associated with high DO concentration, the status of DO was rated as 'low' when the mean value was above the reference value; and 'high' when the mean value was below the reference value.

The 'occurrence' tool was applied for the following assessment parameters: '(12) red tide (diatom sp.)', '(13) red tide (dinoflagellate sp.), '(15) abnormal fish-kill' and '(18) shellfish poisoning'. For these parameters, the status was rated as 'high' when one or more incidents occurred in the entire sub-area in the recent three years; and 'Low' if no incidents occurred. Although *Noctiluca* species are dinoflagellates, red tide of *Noctiluca* species was not included under '(13) Red tide (dinoflagellate)', but instead assessed separately under category IV '(17)

Red tide (*Noctiluca* sp.)'. Red tide of *Noctiluca* sp. is known to occur not only by eutrophication but also when *Noctiluca* sp. is physically aggregated by conversion of oceanographic currents. In other words, there will be a risk of misinterpreting the eutrophication status of '(17) Red tide (*Noctiluca* sp.)' if the criterion of 'three events in three years" is applied. Thus, a different criterion was applied here: the status of '(17) Red tide (*Noctiluca* sp.)' was rated as 'High' when three or more incidents occurred in the recent three years, and 'Low' if less than three incidents occurred.

The 'trend' tool was used to analyze yearly increasing or decreasing trends of the assessment parameters. The increasing or decreasing trends were analyzed by using the non-parameteric method of Mann-Kendall. Calculation was conducted with MAKESENS (Salmi *et al.*, 2002). With a significance level at 5%, the results of the trend were indicated by three colored lines: significant increasing trend (red), significant decreasing trend (blue) and no significant trend (black). For maintaining the set significance level, trend analysis was not conducted for the survey stations with data of less than five years. In such a case, their values were indicated in the graph with dotted lines. The most dominant trend among the survey stations was considered to represent the trend of the respective assessment parameters.

Table 3.4 shows the combination of identification tools applied for each assessment parameter. For most parameters, assessments were conducted by applying either the 'comparison' or 'occurrence' tool with the 'trend' tool, and were classified into one of the following six categories: HI, HN, HD, LI, LN or LD (see Fig.3.3). Some parameters were assessed only with the 'trend' tool, and were classified into one of the following three categories: I, N or D (see Fig.3.4).

The status of each assessment category was classified by a combination of 'comparison or occurrence' tools (H or L) and 'trend' tool (I, N or D) by selecting major results of the assessment parameters in the category.

Table 3.4 Identification tools applied to the assessment parameters of Toyama Bay Case Study

Category	Assessment parameter	Assessment value	Identification tool			Remarks
			Comparison	Occurrence	Trend	
I	(1) TN input from river	Annual mean			✓	
	(2) TP input from river	Annual mean			✓	
	(3) TN input from sewage treatment plant	Annual mean				
	(4) TP input from sewage treatment plant	Annual mean				
	(5) TN concentration	Annual mean	✓		✓	
	(6) TP concentration	Annual mean	✓		✓	
	(7) Winter DIN concentration.	Winter mean	✓		✓	
	(8) Winter DIP concentration	Winter mean	✓		✓	
	(9) Winter DIN/DIP ratio	Winter mean	✓		✓	

II	(10) Chlorophyll-*a* concentration	Annual max.	✓		✓	
	(11) Chlorophyll-*a* concentration	Annual mean	✓		✓	
	(12) Red tide (diatom sp.)	Annual no. of events		✓	✓	
	(13) Red tide (dinoflagellate sp.)	Annual no. of events		✓	✓	
III	(14) DO	Annual min.	✓		✓	
	(15) Abnormal fish-kill	Annual no. of incidents		✓	✓	
	(16) COD	Annual mean	✓			
IV	(17) Red tide (*Noctiluca* sp.)	Annual no. of events		✓		
	(18) Shellfish poisoning	Annual no. of incidents		✓		

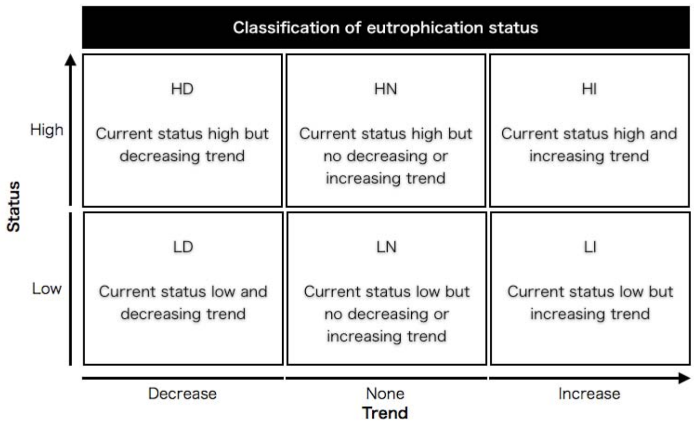


Fig. 3.3 Six classification categories stipulated in the Common Procedures (for 'status' and 'trend')

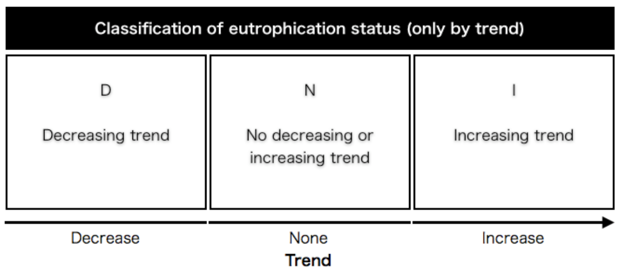


Fig. 3.4 Three classification categories stipulated in the Common Procedures (for 'trend' only)

4. Results

4.1 Sub-area A (Coastal Area)

Assessment results of Category I parameters

(1) TN input from river

There are five Class-A rivers flowing into Sub-area A: the Oyabe River, the Show River, the Jinzu River, the Joganji River and the Kurobe River. TN input of these five rivers per day was between 25.2-39.5 t/day. Input from the Jinzu River dominated among the five, contributing to 54-75% of all. The second biggest source was the Oyabe River: 16-34%. Increasing trends were identified with the Jinzu Rivers while no trends were identified with other four rivers. Since total TN inputs from all the rivers showed no trends, the trend of TN inputs from rivers in Sub-area A was classified as 'No trend.'

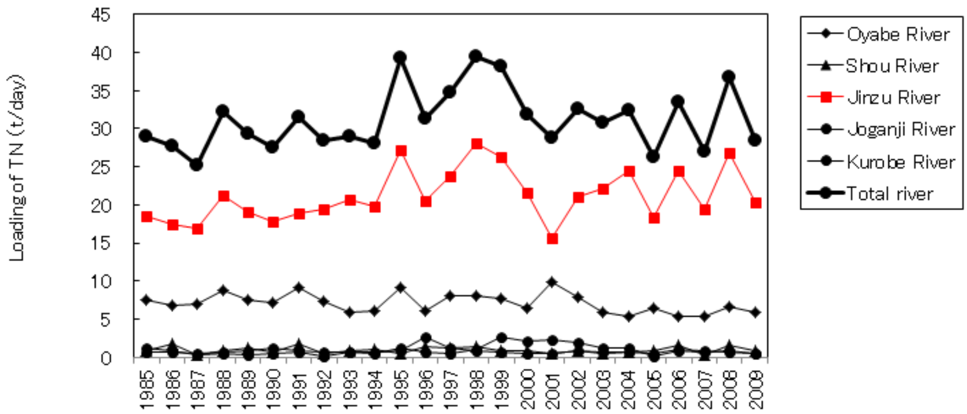


Fig. 4.1 TN input from the rivers in Sub-area A

(2) TP input from river

TP input from Class-A rivers into Sub-area A was between 0.69-2.75 t/day. The Jinzu River contributed most between 1985 and 1994. The largest input from the Jinzu River was 2.3 ton/day in 1992, however, the amount decreased by 0.3 t/day in 2007. As of 2009, TP input from the Jinzu River and the Oyabe River contributed to 50% and 42% of all respectively. Decreasing trend was identified with the Jinzu River while no trends were identified with other four rivers. Since the total input from all the rivers showed decreasing trend, the trend of TP input from rivers in Sub-area A was classified as 'Decreasing trend.'

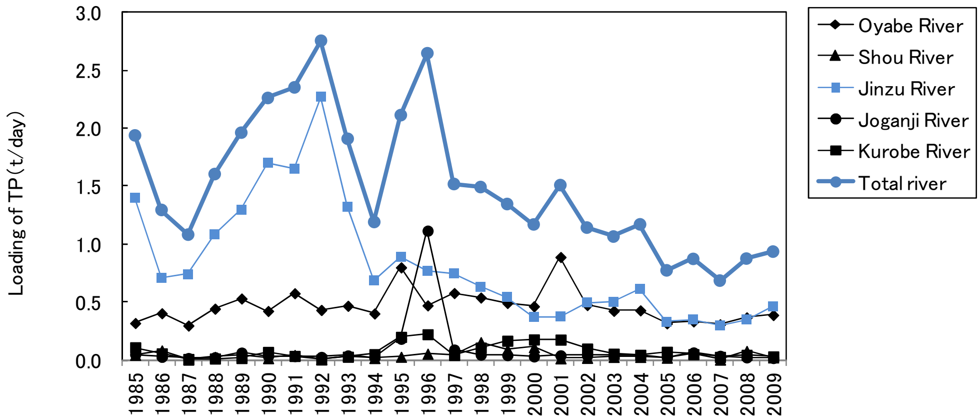


Fig. 4.2 TP input from the rivers in Sub-area A

(3) TN input from sewage treatment plant

TN is directly input into Sub-area A from five sewage treatment plants: the Jinzu River left-bank Sewage Treatment Plant, Hamakurosaki Sewage Treatment Plant, Fushiki Sewage Treatment Plant, Uozu-city Sewage Treatment Plant, and Namerikawa-city Sewage Treatment Plant. Unfortunately, there was no data until 2009 to identify trend of annual TN input from sewage treatment plants. However, according to compiled statistics in 2004, TN input to Toyama Bay from sewage treatment plants contributed to 8% of total nitrogen input including from rivers (Toyama Prefecture, 2008). Therefore, the amount of TN input from sewage treatment plants was considered smaller than that from rivers.

(4) TP input from sewage treatment plant

Same as TN input, there was no data for annual direct TP input to Sub-area A from sewage treatment plants until 2009. According to compiled statistics in 2004, TP input to Toyama Bay from sewage treatment plants occupied 16% of total phosphorus including from rivers (Toyama Prefecture, 2008). Therefore, the amount of TP input from this type of plants was considered small, comparing with that from rivers.

(5) TN concentration

There are nine survey stations in Sub-area A, and data were available from 1997 to 2009. The annual mean of TN concentration didn't show any trend at all nine stations. The mean TN concentration of the recent three years ranged between 0.16-0.26 mg/L, and all nine stations were below the reference value (0.3 mg/). Therefore, the status and trend of TN in Sub-area A was classified as 'Low eutrophication status and No trend.'

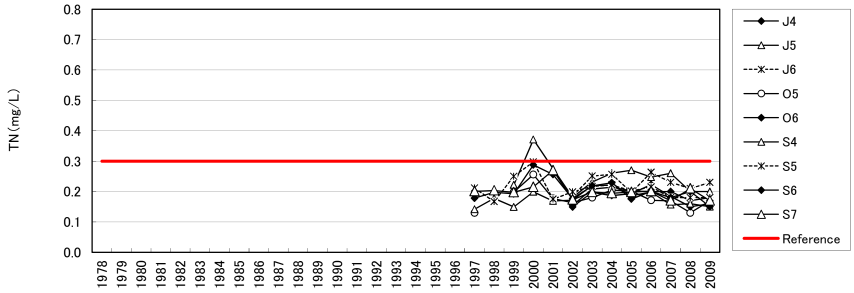


Fig. 4.3 TN concentration in Sub-area A

(6) TP concentration

The annual mean of TP concentration showed decreasing trend at three stations, but no trend at six stations. The mean TP concentration of the recent three years ranged between 0.010-0.014 mg/L, and all nine stations were below the reference value (0.03 mg/L). Therefore, the status and trend of TP in Sub-area A was classified as 'Low eutrophication status and decreasing trend.'

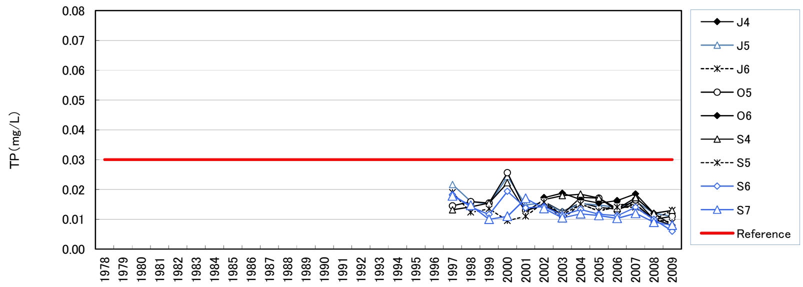


Fig. 4.4 TP concentration in Sub-area A

(7) Winter DIN concentration

Winter DIN concentration didn't show any trend at all four stations. The mean winter DIN concentration of the recent three years ranged between 0.08-0.17 mg/L. One station (J5) was above the reference value (0.144 mg/L) while the other three stations were below the reference value. Therefore, the status and trend of winter DIN concentration in Sub-area A was classified as 'Low eutrophication status and No trend.'

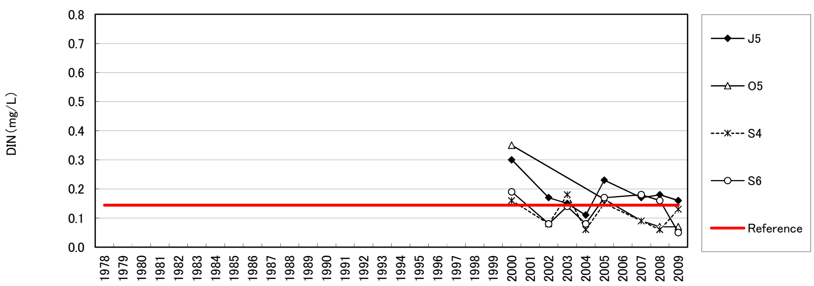


Fig. 4.5 Winter DIN concentration in Sub-area A

(8) Winter DIP concentration

Winter DIP concentration didn't show any trend at all four stations. The mean winter DIP concentration of the recent three years ranged between 0.007-0.008 mg/L, and all stations were below the reference value (0.017 mg/L). Therefore, the status and trend of winter DIN concentration in Sub-area A was classified as 'Low eutrophication status and No trend.'

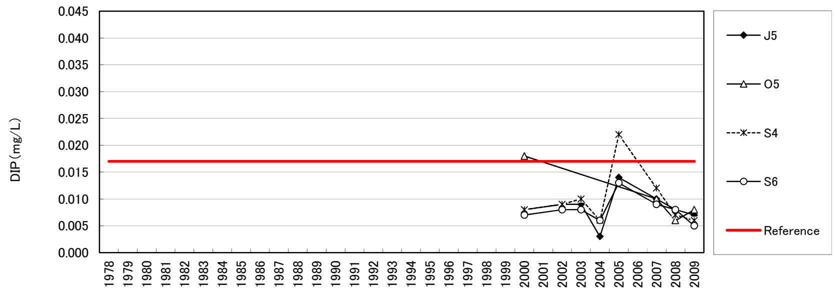


Fig. 4.6 Winter DIP concentration in Sub-area A

(9) Winter DIN/DIP ratio

Winter DIN/DIP ratio didn't show any trend at all four stations. The mean winter DIN/DIP ratio of the recent three years ranged between 22 and 46, and all stations were above the reference value of 16. Therefore, the status and trend of winter DIN/DIP ratio in Sub-area A was classified as 'High eutrophication status and No trend.' However, both winter DIN and DIP concentrations were below the reference values respectively, therefore, the classification result of winter DIN/DIP ratio was not reflected in the overall result of Category I.

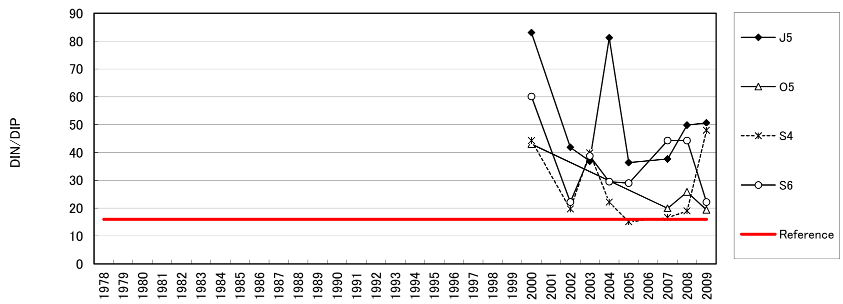


Fig. 4.7 Winter DIN/DIP ratio in Sub-area A

Assessment results of Category II parameters

(10) Annual maximum chlorophyll-*a* concentration

There was no trend in the annual maximum chlorophyll-*a* concentration at all the stations (S4, S6 and J5). The annual maximum chlorophyll-*a* concentration of the recent three years ranged between 15.0-22.3 μg/L, and one station (S6) was above the reference value (20μg/L) while the other three stations were below the reference value Therefore, the status and trend of annual maximum chlorophyll-*a* concentration in Sub-area A was classified as 'Low eutrophication status and No trend.'

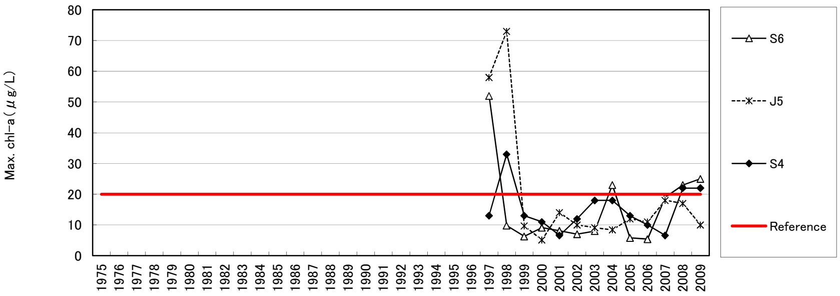


Fig. 4.8 Annual maximum chlorophyll-*a* concentration in Sub-area A

(11) Annual mean chlorophyll-*a* concentration

There were no trends in the annual mean chlorophyll-*a* concentration at all stations. The annual mean chlorophyll-*a* concentration of the recent three years ranged between 6.0-8.0 μg/L, and all stations were above the reference value (5 μg/L). Therefore, the annual mean chlorophyll-*a* concentration in Sub-area A was classified as 'High eutrophication status and No trend.'

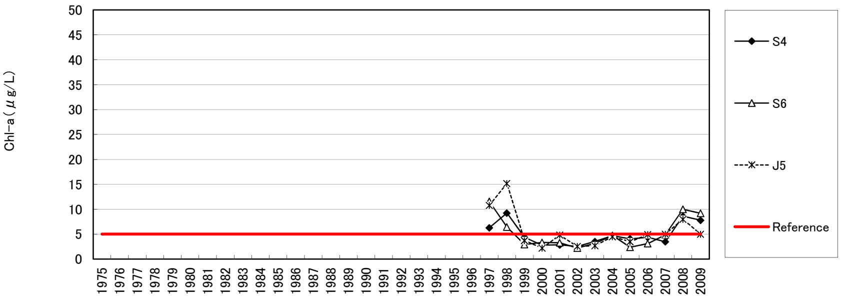


Fig. 4.9 Annual mean chlorophyll-*a* concentration in Sub-area A

(12) Red tide (diatom sp.)

The number of diatom red tide in Sub-area A ranged between 1-13 events/year from 1967-1999, however, there were no events after 2000, except in 2002 and 2003. The number of diatom red tide events decreased, and there were no events in the recent three years. Therefore, the status and trend of diatom red tide in Sub-area A was classified as 'Low eutrophication status and Decreasing trend.'

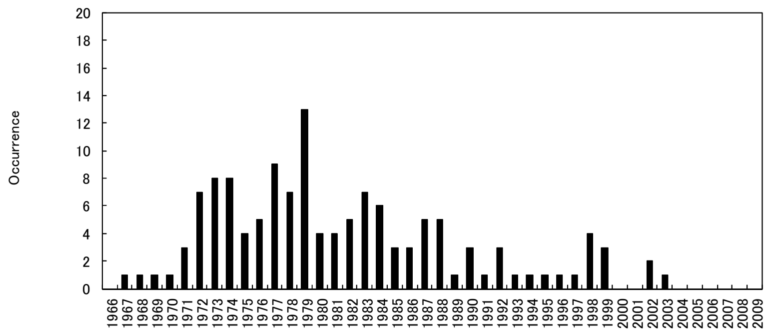


Fig. 4.10 Number of diatom red tide in Sub-area A

(13) Red tide (dinoflagellate sp.)

There was only one event of dinoflagellate red tide in 1970 in Sub-area A, and no trend was identified. Therefore, the status and trend of dinoflagellate red tide in Sub-area A was classified as 'Low eutrophication status and No trend.'

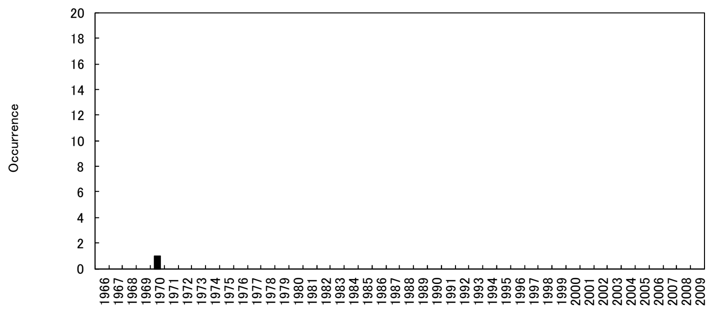


Fig. 4.11 Number of dinoflagellate red tide in Sub-area A

Assessment results of Category III parameters

(14) Dissolved oxygen (DO)

Within nine stations, two stations (S6 and S7) showed decreasing trend in the annual minimum DO concentration. The other seven stations didn't show any trend. The mean DO of the recent three years ranged between 6.8-7.4 mg/L, and all stations were above the reference value (6.0 mg/L). Following the setting of classification criteria (See 3-2), DO was classified in an opposite way of other parameters. Therefore, the status and trend of DO in Sub-area A was classified as 'Low eutrophication status and No trend.'

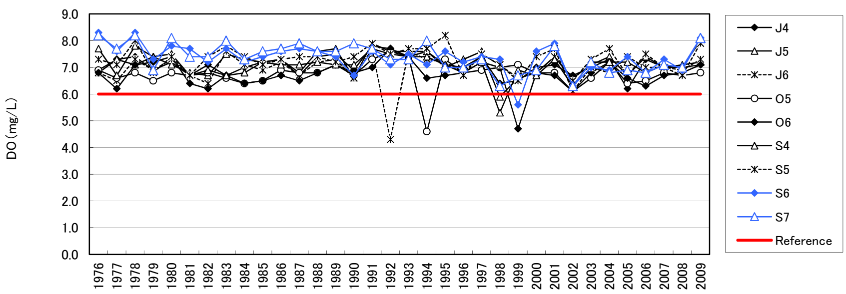


Fig. 4.12 DO concentration in Sub-area A

(15) Abnormal fish kill

Incidents of abnormal fish kill were not confirmed. Therefore, its status and trend in Sub-area A was classified as 'Low eutrophication status and No trend.'

(16) Chemical oxygen demand (COD)

Annual mean COD concentration didn't show any trend at all nine stations. The mean COD of the recent three years ranged between 1.7-1.8 mg/L, and all stations were below the reference value (3.0 mg/L). Therefore, the status and trend of COD in Sub-area A was classified as 'Low eutrophication status and No trend.'

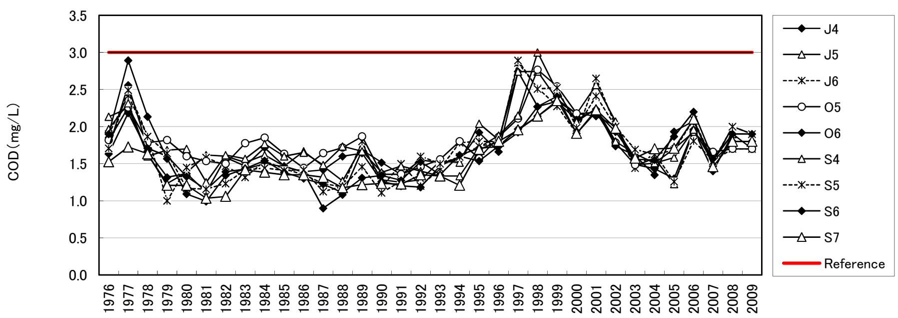


Fig. 4.13 COD concentration in Sub-area A

Assessment results of Category IV parameters

(17) Red tide (*Noctiluca* sp.)

From 1966 to 2009, *Noctiluca* red tide occurred in fourteen years at a frequency of 1-3 times per year. No trend was identified. Within the recent three years, only one *Noctiluca* red tide was confirmed in 2007. Overall, the status and trend of *Noctiluca* red tide Sub-area A was classified as 'Low eutrophication status and No trend.'

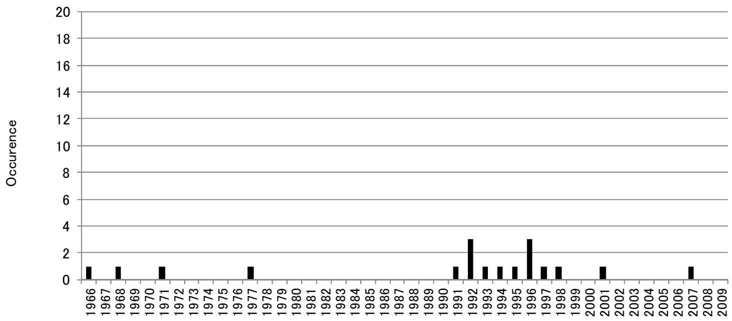


Fig. 4.14 Number of *Noctiluca* red tide in Sub-area A

(18) Shellfish poisoning

Incidents of shellfish poisoning were not confirmed. Therefore, its status and trend in Sub-area A was classified as 'Low eutrophication status and No trend.'

Assessment results of each assessment category

Table 4.1 Assessment results of each assessment category in Sub-area A (Coastal Area)

Categories	Assessment parameters	Comparison	Occurrence	Trend	Parameter identification	Category identification
I	①Riverine input of TN	×	×	N	N	LN
	②Riverine input of TP	×	×	D	D	
	③Sewage plant input of TN	×	×	×	-	
	④Sewage plant input of TP	×	×	×	-	
	⑤TN concentration	L	×	N	LN	
	⑥TP concentration	L	×	D	LD	
	⑦Winter DIN concentration	L	×	N	LN	
	⑧Winter DIP concentration	L	×	N	LN	
	⑨Winter DIN/DIP ratio	H	×	N	HN*	
II	⑩Annual maximum of chlorophyll-*a*	L	×	N	LN	LN
	⑪Annual mean of chlorophyll-*a*	H	×	N	HN	
	⑫Red tide events (diatom sp.)	×	L	D	LD	
	⑬Red tide events (dinoflagellate sp.)	×	L	N	LN	
III	⑭Dissolved oxygen (DO)	L	×	N	LN	LN
	⑮Fish kill accidents	×	L	N	LN	
	⑯Chemical oxygen demand (COD)	L	×	N	LN	
IV	⑰Red tide events (*Noctiluca* sp.)	×	L	N	LN	LN
	⑱Shell fish poisoning incidents	×	L	N	LN	

*Parameter identification of the winter DIN/DIP ratio was not used for category identification, because winter DIN concentration and winter DIP concentration were lower than reference concentrations.

Assessment results of Sub-area A (Coastal Area)

Toyama Bay is a semi-enclosed bay, located in the center of the eastern part of NOWPAP area, and five Class-A rivers flow into the bay. The biggest is the Jinzu River, originated in Gifu Prefecture and runs through Toyama City with the population of 4.2 million.

Category I (degree of nutrient enrichment) parameters: TN input from all of the Class-A rivers didn't show any trend. However, TN input from the Jinzu River showed increasing trends. Because of its size and location (the biggest and flowing into the closed-off section of the bay), the Jinzu River has significant influence over the Toyama Bay. Thus, it is required to address TN input from this river in order to prevent the bay from eutrophication. On the other hand, TP input from all of the Class-A rivers showed decreasing trend. Almost all of the mean concentrations of TN, TP, winter DIN and winter DIP of the recent three years were below each reference value, and there was no trend.

Category II (direct effects of nutrient enrichment) parameters: The annual maximum of Chlorophyll-a concentrations of recent three years in most stations were below the reference value, however, the annual mean of Chlorophyll-a concentrations in all stations were above the reference values, and there was no trend. The number of diatom red tide showed decreasing trend, and there were no events in recent years. Also, there were no dinoflagellate red tides in the recent three years.

Category III (indirect effects of nutrient enrichment) parameters: DO in most stations satisfied the reference value, however, some stations showed decreasing trends. COD in all stations satisfied the reference value, and all stations didn't show any trend.

Category IV (other possible effects of nutrient enrichment) parameters: There was only one *Nuctiluca* red tide in 2007. No shellfish poisoning incidents were confirmed.

In Sub-area A, all categories were classified as 'Low eutrophication status and No trend'. However, among Category I parameters, it is suggested to reduce TN input because T/P ratio was higher then the reference value. Among Category III parameters, annual mean Chl-a showed high eutrophication status. Therefore, it is required to improve the status by reducing nutrient enrichment.

Table 4.2 Reasons behind classification of each assessment category in Sub-area A (Coastal Area)

	Reason	Classification
I Degree of nutrient enrichment	- TN input from river: No trend, but increasing trend in the Jinzu River - TP inputs from river: Decreasing trend - TN and TP input from sewage treatment plant: Comparing with input from river, both are smaller - TN concentration: Low concentration, and no increasing/decreasing trend - TP concentration: Low concentration, and no increasing/decreasing trend - Winter DIN and DIP concentration: Low concentration in some stations, but no increasing/decreasing trend - Winter DIN/DIP ratio: High ratio, but no increasing/decreasing trend	LN
II Direct effects of nutrient enrichment	- Annual mean of chlorophyll-*a*: Hihger concentrations than the reference values, and no trend - Annual maximum and mean of chlorophyll-*a*: Lower concentrations than the reference values, and no trend - Diatom red tide: Decreasing trend, and no events in the recent three years. - Dinoflagellate red tide: No trend, and no events in the recent three years	LN
III Indirect effects of nutrient enrichment	- DO: Higher concentration than the reference value, but decreasing trends in some stations - COD: Lower concentration than the reference value, but increasing trends in some stations	LN
IV Other possible effects of nutrient enrichment	- *Noctiluca* red tide: Low frequency throughout the assessment period (1966-2009) - Shellfish poisoning: None	LN

4.2 Sub-area B (Intermediate Area)

Work in progress

4.3 Sub-area C (Offshore Area)

Work in progress

5. Review and Validation of assessment results of Toyama Bay

Table 4.7 shows all of the results of Sub-area A, B and C in every Category.

Work in progress.

Table 4.7 Assessment results of Toyama Bay by assessment category and sub-read

Category	Sub-area			Comment on category classification
	A	B	C	
I Degree of nutrient enrichment	LN	LN	LN	All sub-areas showed Low in 'comparison and occurrence' and No in 'trend.'
II Direct effects of nutrient enrichment	LN	LN	LN	All sub-areas showed Low in 'comparison and occurrence' and No in 'trend.'
III Indirect effects of nutrient enrichment	LN	LN	LI	All sub-areas showed Low in 'comparison and occurrence.' Sub-area A showed increasing, and Sub-areas B and C showed No in 'trend.'
IV Other possible effects of nutrient enrichment	LN	LN	LN	All sub-areas showed low in 'comparison and occurrence' and No in 'trend.'

6. Conclusion and recommendation

Work in progress.

References

Bricker, S. B., J. G. Ferreira and T. Simas (2003) An integrated methodology for assessment of estuarine trophic status. Ecological Modelling, 169, 39-60.

Salmi, T., Määttä, A., Antika, P., Ruoho-Airola, T. and Amnell, T. (2002) Detecting trends of annual values of atmospheric pollutions by the Mann-Kendall test and Sen's slope estimates -The Excel template application MAKESENS-. Finnish Meteorological Institute, pp. 35, Helsinki.

Toyama Prefecture (2008) Water and Environment Plan in Toyama Prefecture, Clean Water Plan, p106, Civic Affairs, Environment and Culture Department, Environmental Conservation Division, Toyama Prefecture.

Toyama Bay Water Quality Preservation Research Committee (2001) Bulletin of the FY2000. Toyama Bay Water Quality Preservation Research Committee – the pollution of water in Toyama Bay. pp. 3-37-3-43, Civic Affairs, Environment and Culture Department, Toyama Prefecture.

Assessment of eutrophication status including evaluation of land based sources of nutrients.
Peter the Great Bay refined case study

Pavel Tishchenko, POI, FEB RUS tpavel@poi.dvo.ru
Vladimir Zvalinsky, POI, FEB RUS viz@poi.dvo.ru

Table of Contents

I. Executive Summary

Using available data about river runoff and waste waters inputs into PGB, the annual nutrients loading of PGB was assessed. For assessment of eutrophication status of PGB we used following criteria: a) it was set an almost zero nutrient concentrations in photic layer with thick 50 m as reference condition; b) We accept threshold value of DO as 76 μM which corresponds hypoxia conditions. Using Redfield ratios in organic matter and DO_{th}= 76 μM, threshold values of DIN and DIP were calculated. This approach of assessment of eutrophication status and literature data biological degradation of Amursky Bay (Sub-area **A** of PGB) suggest that Sub-area **A** has current eutrophication status as "**High**" and "**Increase**". Most part of Sub-area **B** is considered that it has eutrophication status as a "Low" with non-detectable trend. At present time, most part of Sub-area **C** has a "Low" eutrophication status with non-detectable trend.

II. Introduction

There are many definitions of eutrophication which are extensively discussed in publications (Nixon, 1995; Andersen et al., 2006). Nixon gave own definition of eutrophication: "Eutrophication (noun) – an increasing in the rate of supply of organic matter to an ecosystem". He stressed that this definition is short and simple. He emphasized that eutrophication is process of change in the trophic status on an ecosystem, it is not a trophic status. The cause of the eutrophication may be an increase in the input of inorganic nutrients, a decrease in the turbidity of the water, a change in the hydraulic residence time of the water, a decline in grazing pressure, etc. A variety of other changes may be associated with eutrophication, for example, reducing of biodiversity, hypoxia, fish kills. Nixon's view emphasizes that eutrophication is rather a fundamental change in the energetic base that may propagate through the system in various ways and produce a variety of changes. In further he wrote: "However, I do suggest that all of us, scientists, regulators, politicians, and even the activists need to consider coastal marine eutrophication and oligotrophication as the fundamental ecological processes they are. They are not simple 'pollution problems' but major ecological changes that must be viewed through the macroscope." (Nixon, 2009). In practical sense, Nixon's definition gives clear distinguishes between phenomena (eutrophication), causes (depth penetration of PAR, nutrient enrichment, grazing pressure, residence time of water) and consequences (hypoxia, fish kills, turbidity) (Nixon, 2009). Anderson's definition of eutrophication stressed another reasons and consequences of this phenomenon (Andersen et al., 2006). This definition is: "the enrichment of water by nutrients, especially nitrogen and/or phosphorus and organic matter, causing an increased growth of algae and higher forms of plant life to produce an unacceptable deviation in structure, function and stability of organisms present in the water and to the quality of water concerned, compared to reference conditions" (Andersen et al., 2006).

At present time scientific community recognized that eutrophication is a widespread phenomenon of the world affecting on ecosystems of coastal and deep waters mostly via forming of "excess" biomass that results in catastrophic changes of biodiversity and forming of dead zones (hypoxia and anoxia) (Duarte, 2009). The formation of dead zones has been exacerbated by the increase in primary production and consequent worldwide coastal eutrophication fueled by riverine runoff of fertilizers and the burning of fossil fuels. Enhanced primary production results in an accumulation of particulate organic matter, which encourages microbial activity and the consumption of dissolved oxygen in bottom waters. Dead zones in the coastal oceans have spread exponentially since the 1960s and have serious consequences for ecosystem functioning (Diaz, Rosenberg, 2008).

We assume that eutrophication in local sites of the world is linked with each other via global changes (global warming, burning of fossil fuel, increasing population, urbanization and etc.) and common mechanisms of its development. Therefore sharing information about eutrophic status of different sites of NOWPAP member states produces new knowledge which permits to make decisions in mitigation of expanding eutrophication.

II.1. Historical Review

There are two organizations which carry out environmental monitoring on Peter the Great Bay (PGB) and keep information about this. These are:

1) Federal State Budgetary Institution Primorskoe Administration for Hydrometeorology and Environmental Monitoring (FSBIPAHEM) was established in 1937. Main goal of the organization is environmental monitoring of atmosphere, hydrosphere and soils.

2) Far Eastern Regional Hydrometeorological Research Institute (FERHRI) was established in 1950. Main goals are development of methods of monitoring systems, modeling for forecasting of environmental changes, carrying out of marine observations.

Both organizations are under umbrella of ROSHYDROMET (FEDERAL SERVICE ON HYDROMETEOROLOGY AND MONITORING OF ENVIRONMENT).

Actually, FSBIPAHEM started monitoring of chemical pollutants of coastal Primorye environment in late 1960s years. First quarter reports of row chemical pollutants data was published in 1968. ROSHYDROMET is under Russian Government. FERHRI and FSBIPAHEM merged together about in 1971 and started ecological monitoring of PGB. In 1980 these organizations were split and they are existing separately again. However they continue ecological monitoring of PGB together. Scheme of monitoring stations is demonstrated on Fig.1 (Lishavskaya et al., 2010).

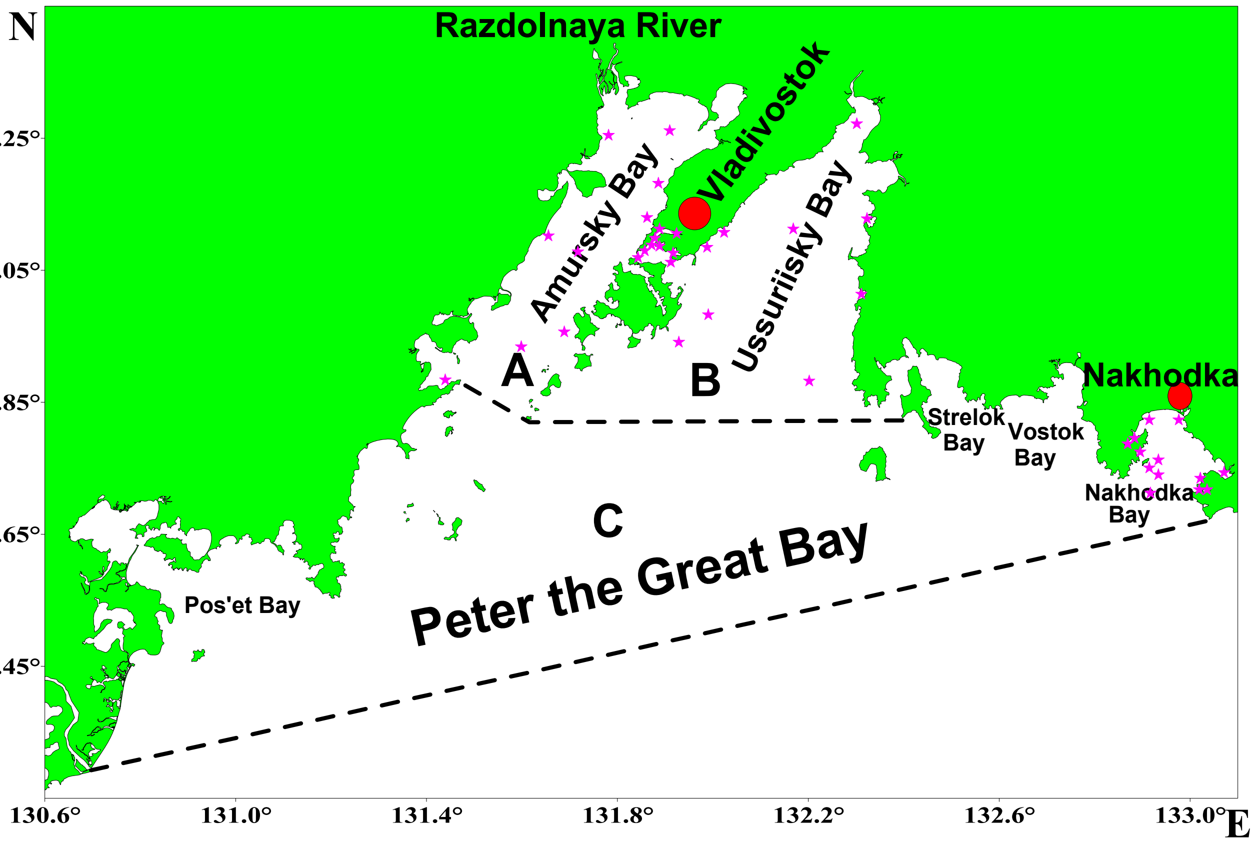


Fig. 1. Scheme of monitoring stations in PGB for ecological observations carried out by FSBIPAHEM/FERHRI during more than 40 years (from 1971 to present time).

Analyses were carried out on following parameters: dissolved oxygen, pH, nitrite, nitrate, ammonium, total nitrogen, phosphates, total phosphorous, silicates, oil hydrocarbons, trace metals

(Pb, Cu, Zn, Ni, Cd), pesticides, phenols and detergents. It was planed that each ten days sampling and analyzing should be carried out in warm period of year (from April to November) according to scheme presented on Fig.1. However due to rejecting of budget in late 80-th years this monitoring program was reduced. There are quarter reports of row data from 1968 to 1984 and annual reports from 1985 up to present time. Also there are annual reviews about chemical pollution of coastal marine environment, which published by FSBIPAHEM and FERHRI from 1968 to present time. An additional problem in reconstruction of historical data regarding to eutrophication of Peter the Great Bay is that, row data of annual reports of these observations and reviews were unavailable in the open access publications at the Soviet time (up to 1991). From 1991 to present time annual reports and reviews of FSBIPAHEM are available but after payment only. Reviews of these annual reports lead to conclusions (Lishavskaya et al., 2010) that Zolotoy Rog Bay is heavily contaminated area that agree with previously investigations (Tkalin et al., 1993; Tkalin et al., 1996; Belan et al., 2007). Amursky Bay and Ussurijsky Bay are characterized as moderate and weak contaminated areas respectively (Lishavskaya et al., 2010). Reviews of annual reports of FSBIPAHEM are partly including into annual reports of the State Oceanographic Institute (SOI) which are available in open access publications (Korshenko et al., 2006; Korshenko et al., 2008a; Korshenko et al., 2008b; Korshenko et al., 2009a; Korshenko et al., 2009b). Annual reviews of FSBIPAHEM are partly including into annual reviews of Goshydromet (Review, 2009; Review, 2010; Review, 2011; Review, 2012). Annual reports of SOI and Reviews of Goshydromet give general information only about contaminations and ecological state of PGB. There is no more detail information than those in publications of the Annual reports of FSBIPAHEM.

There are scientific organizations which carry out ecological investigations of the PGB. These are:

1. Pacific Scientific Research Fisheries Center (TINRO-Centre) was established in 1925;
2. Far Eastern Federal University (FEFU) was established in 1899;
3. Pacific Geographical Institute Far Eastern Branch of Russian Academy of Sciences (PGI) was established in 1971;
4. A.V. Zhirmunsky Institute of Marine Biology Far Eastern Branch of Russian Academy of Sciences (IMB) was established in 1970
5. V.I.Il`ichev Pacific Oceanological Institute Far Eastern Branch of Russian Academy of Sciences (POI) was established in 1973.

Some institutes contain monitoring centers/laboratory inside itself. These are Harmful Algal Monitoring Center established in 2007 (IBM FEB RAS), Pollution Monitoring Regional Activity Center formed in 1999 (PGI FEB RAS). However main goal of these five organizations is scientific research. These organizations published some books which are very important for undeserving of how ecosystem of PGB is going.

II.1.1. Early oceanography study of PGB

Geographical descriptions, first oceanographic measurements (depths, currents, tidal currents), climate of PGB and adjacent basins were given in the second half of the 19-th century by Russian officers of the Russian Fleet. Review of publications concerning this period investigation of PGB recently was given by Khristoforova (2012). In 1925 outstanding Russian scientist, professor K.M. Derugin formed Pacific Scientific Fisheries Station (TONS) which later became TINRO-CENTER. Review of main stages of oceanographic studies carried out by TINRO-Center and their results obtained since 1925 till 2005 was given by Khen and Moroz (2005). Most important of publication of early period is hydrological essay about Amursky Bay and estuary Suyphun (Razdolnaya) River (Gomoyunov, 1927). The zoobenthos and planktonic studies including PGB area are carried out by TINRO-Center since 1925 till present day 2005. Reviews of these studies were given elsewhere (Nadtochy and Koblikov, 2005; Dolganova, 2005; Nadtochy, Galysheva, 2012). Professor K.M. Derugin organized hydrochemical observations in PGB (Amursky Bay and Ussuriisky Bay) from

1931 till 1935. Observations were implemented on hydrological parameters (temperature, salinity, depth) and following hydrochemical parameters: dissolved oxygen, pH, total alkalinity, nitrite, nitrate, phosphates, and silicates. Voronkov considered and discussed of these observations (1941a; 1941b). He noted that seasonal variation of dissolved oxygen concentration, with minimum in bottom waters in late summer-beginning September. Minimal concentration was about 68 % from saturation. Phosphate concentrations in PGB vary at summer within 0.04 – 0.08 and 0.14 – 0.35 μmol/l in surface and near bottom waters (100 m), respectively. Surface waters of PGB had no nitrate as a rule. However at depths 40 m concentrations of nitrate ions may exceed 10 μmol/l. Nitrite concentrations revealed high variability. Maximal concentrations of nitrite (within 0.03 – 0.17 μmol/l) in PGB corresponded near bottom waters in October 1934. For surface waters concentrations of silicates reached up to 29 μmol/l in the northern part of Amursky Bay that was explained by influence of Razdolnaya River. In the western part of the PGB maximal silicate concentrations revealed in near bottom waters (36 μmol/l) (Voronkov, 1941a). Also it was found that studied hydrochemical parameters demonstrated strong daily variability in the PGB, that is explained by wind-induced current system (Voronkov, 1941b). Very extensive seasonal observations on meteorological, hydrological and hydrochemical parameters in Amursky Bay and Ussuriisky Bay were implemented by FERHRI during 1959-1961 years. Hydrological observations contain temperature, salinity, depth, transparency, water color, waves, tidal currents, currents and ice distribution. Following hydrochemical parameters were measured: dissolved oxygen, pH, total alkalinity, nitrite, phosphates, and silicates. Detail description of this study was given by Lastovetsky and Veshcheva (1964). It is should be noted that minimum concentration of dissolved oxygen was observed in bottom waters of Amursky Bay at August 1961 and was 2.04 ml/l or 40% from saturation by air. This minimum of oxygen content corresponds maximum in phosphates and silicates concentrations, 1.26 and 125 μmol/l, respectively.

II.1.2. Monitoring of contaminations of PGB

One of the main goals of the FSBIPAHEM and FERHRI activity is monitoring of quality water of PGB. List observing parameters is following: dissolved oxygen, pH, nitrite, nitrate, ammonium, total nitrogen, phosphates, total phosphorous, silicates, oil hydrocarbons, trace metals (Pb, Cu, Zn, Ni, Cd), pesticides, phenols and detergents (Lishavskaya et al., 2010). It should be to say that above noted contaminants have different sources and differently impact on marine ecosystem. In this paragraph we shortly review publications which focused on such contaminants as trace metals, pesticides, phenols and detergents and oil hydrocarbons. This is important for understanding general ecological situation with PGB. Most extensive observations of contamination of PGB were carried out during 80th -90th years of last century by Tkalin with colleagues from FERHRI (Tkalin et al., 1990; Tkalin et al., 1993; Tkalin, 1995; Tkalin, 1996; Tkalin et al., 1997; Tkalin, 1998; Tkalin et al., 1998; Tkalin, et al., 2000). These investigations with others (Anikiev, 1987; Polyakov and Botsul, 2004; Shulkin, 2004; Naumov, 2006; Kovekovdova et al., 2012) demonstrated that waters and sediments of Zolotoj Rog Bay and Nakhodka Bay were chronically contaminated by trace metals, persistent organic pollutants and oil hydrocarbons. The main source of this pollution was activity of ports in Zolotoj Rog Bay and Nakhodka Bay and industrial waste waters. Amursky Bay and Ussurijsky Bay are characterized as moderate and weak contaminated areas respectively. These conclusions were supported by recent investigation (Lishavskaya et al., 2010). Impacts of trace metals contaminations and persistent organic pollutants on biota of PGB were extensively discussed elsewhere (Khristoforova et al, 1993; Shulkin and Kavun, 1995; Vaschenko, 2000; Shulkin et al., 2003; Zhadan, 2005; Lutaenko, Vaschenko, 2008; Lukyanova et al., 2009). Many authors noted that waste waters generated by industry in Primorye region was reduced since 1990 till present time (Fig. 2) (Shulkin and Semykina 2012; Lukyanova et al., 2012). Nevertheless some regions of PGB are still contaminated.

We suggest that there are three directions in studying of eutrophication of PGB in the past which can be used in Screening Procedure. These are: 1) an unacceptable deviation in trophic structure of PGB; 2) land based sources of nutrients; 3) seasonal hypoxia of bottom waters and related nutrients concentrations. These investigations can be used for detection of eutrophication symptoms.

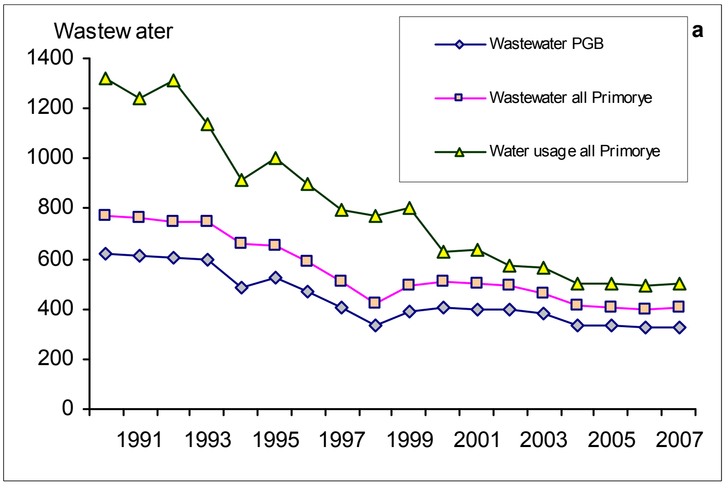


Fig. 2. The water usage and waste water discharge (10^6 t/y) within Peter the Great Bay watershed and all Primorye region (10^6 t/y) during 1991-2007 years. Reprinted with permission from Shulkin and Semykina (2012).

III. Screening Procedure

There are three directions in study of PGB which carried out in the past and can be use for detection of eutrophication symptoms.

III.1. Trophic structure of PGB and its variability

The investigations of benthic communities in Peter the Great Bay were conducted from 1925 to the early 2000s. During long time distribution and variability of benthic community in Peter the Great Bay were analyzed in TINRO-center (Nadtochy at al., 2005a, 2005b; Nadtochy, Galysheva, 2012). In general, the total biomass varied from 4 to 7260 g/m² (mean 360 ± 38 g/m²). The maximum value of the total biomass of 7260 g/m² is fixed in the inner part of the Ussuriisky Bay. In all these areas bivalves dominated. The major taxonomic groups of macrobenthos in Peter the Great Bay, playing a major role in the formation of its total biomass (86 %), are bivalve molluscs, polychaetes and holothurians, to a lesser extent – barnacles, and higher plants, sea stars, sea urchins and phoronid. Comparing to 30 years old data, the biomass of macrobenthos in the Amursky Bay (sub-area A) became almost in 4 times higher (in average 430 g/m^2 in 2003 and 118 g/m^2 in 1970s) due to greater abundance of bivalves and cirripedias. It became almost twice higher in the central and eastern parts of Ussuriisky Bay (sub-area B) caused by abundance of holothurians and foraminifers (not noted here earlier) in the central part, and by bivalves and sponges – in its eastern parts. Joint investigations of FERHRI and IMB FEB RAS (Belan, 2003; Belan et al., 2003; Belan, Moshchenko, 2005; Belan, Belan, 2006; Moschchenko, Belan, 2008; Boyarova, Lukyanova, 2012) in northern part of Amursky Bay (sub-area A) allowed to get data on species composition, structure and quantitative distribution of macrozoobenthos in 2000s years. Trophic structure of macrozoobenthos changed: in the 1930s, swallowing detritophages prevailed in the community, whereas in the 1970s, collecting detritophages began to dominate (Klimova, 1971, 1976). However, judging by cited publications, up to the middle of the 1970s, a cardinal transformation of bottom fauna structure was not registered. Maximal changes in composition and structure of the Amursky Bay bottom fauna occurred within the period from the 1970s to the 1980s (Tkalin et al., 1993; Belan, 2003). Amursky Bay is characterized by a high content of organic matter in the environment and with the clear transformation of benthic biocenoses occupying vast areas in the bay (Belan, 2003; Belan and Belan, 2006).

In this period, and eutrophication-tolerant animals which early observed occasionally, became common species such as Polychaeta, Bivalvia and Amphipoda had maximal abundance (Moschenko and Belan, 2008). The peak of technogenic impact on PGB falls at the 1960s-1980s (Petrenko, 2003). Therefore change in species structure of benthos in the bay could be in many respects connected with processes of chronic pollution and eutrophication (Tkalin et al., 1993; Belan, 2003; Moschenko and Belan, 2008). Moschenko and Belan assume that eutrophication and variation of granulometric composition of sediments are the most possible important reasons for macrozoobenthos changes in the Amursky Bay (2008). Galysheva noted (2009) that in Peter the Great Bay the processes of community transformation that lead to the simplification of species structure and the predominance of species tolerant to organic pollution were recorded in the areas subjected to the most intensive inflow and increase of organic matter content. Thus, the predominance of the polychaetes *Tharyx pacifica* and *Dipolydora cardalia*, which are tolerant to organic contamination, was observed in benthic biocenoses in the area of the Tumen River estuary and in the basin near Furungelma Island.

Long-term observations of the community of Japanese Scallop and its epibionts in the Amursky Bay documented that during 1982-1993s the mean age of scallops in the settlement increased and the rate of linear growth of the mollusks dropped (Silina, Ovsyannikova, 1995). The most noticeable changes occurred in the species composition and quantitative distribution of cirriped barnacles. Less tolerant epibionts were gradually replaced by species highly resistant to silting and organic pollution. The Polychaetes appeared the most tolerant to pollution (Silina, Ovsyannikova, 1995). Dramatically changes of bentic flora in Amursky Bay were found (Levenets, Skriptsova, 2008). The total species number of macrophytes in 2005 decreased 1.5 times as compared to record of 1970 – 1980s. The most pronounced qualitative and quantitative changes of the flora were observed in the zones subjected to an anthropogenic press and the direct impact of the Razdolnaya River drain. It was found that the algal thickets with domination of kelps and sargassum have reduced, and extensive thickets of sea grasses have disappeared from these sites. The reduction of the species number, biomass decrease, change of dominants in plant communities along with an increased importance of green algae testify to a human-induced transformation of vegetation towards its degradation (Levenets, Skriptsova, 2008). Biological investigations (Silina, Ovsyannikova, 1995; Levenets, Skriptsova, 2008; Moshchenko, Belan, 2008) strongly suggest that trend of increasing eutrophication is occurred in sub-area **A**. We did not find any data which may clearly suggest about any trend of eutrophication in Sub-areas **B** and **C**.

The first data on the phytoplankton of the PGB and adjacent areas were reported in the 1920s-1930s. Reviews of these investigations were published somewhere (Konovalova et al., 1989; Stonik and Orlova, 1998; Stonik and Orlova, 2002). Konovalova (1972) was the first who carried out year-round study of the species composition and dynamic of the phytoplankton in Amursky Bay. Microalgal community of PGB is dominated by one species, *S. constatum*, which accounted for about 70-90 % of the total density of phytoplankton as a rule (Konovalova, 1972; Konovalova et al., 1989; Stonik and Selina, 1995; Stonik and Orlova, 1998; Stonik and Orlova, 2002; Shevchenko et al., 2004; Morozova and Orlova, 2005; Orlova et al., 2009). Microalgal bloom is characterized three peaks spring, summer and autumn (Stonik and Selina, 1995; Shevchenko et al., 2004). The maximal peak of phytoplankton density reveals at August-beginning September in Amursky Bay (Stonik and Orlova, 1998). The overall cell numbers of phytoplankton were 0.01 to 31.1 million cells/liter and biomass 0.3 to 29 g/m^3 (Stonik and Orlova, 1998). Distributions of phytoplankton in PGB permits to make conclusion that this area is high productive and waters characterized as eutrophic and extremely eutrophic (Stonik and Selina, 1995; Stonik and Orlova, 1998, 2002). In comparison with the late 1960s and early 1970s, the species richness of phytoplankton increased markedly and greater number of bloom-forming species was recorded. It is mean that eutrophication of PGB becomes stronger with time (Orlova et al., 2009). New toxic microalgal species were appeared with time in PGB (Orlova et al., 1996; Orlova, 2012). Zooplankton aboundance had two seasonal peaks in Amursky Bay: the first driven by mass development of cold-water copepods occurred usually in June, and the second caused by warm-water copepods was observed in the southern part of the bay in September but in the northern part in October. Total zooplankton biomass had lesser seasonal variability in the range 500-1600 mg/m^3 (Nadtochy, 2012).

III.2. Land based sources of nutrients

There are two main inputs of nutrients into PGB. These are waste waters from Vladivostok + other small towns and villages and riverine fluxes. Loads of nutrients and organic matter into Amursky Bay by waste waters and Razdolnaya River were intensively studied (Gavrilevsky et al., 1998; Ogorodnikova, 2001; Nigmatulina, 2005; POMRAC, 2006; POMRAC, 2009; CEARAC, 2011; Mikhailik et al., 2011; Zvalinsky et al., 2012). Gavrilevsky et al. (1998), Ogorodnikova (2001) and Nigmatulina (2005) made estimations of nutrient loads into Amursky Bay using Municipal Data on total annual volume of waste water inflowing into Amursky Bay and concentrations of pollutants. For estimations nutrients loads by Razdolnaya they used annual discharge of the River and concentrations pollutants measured by Prymorsky Center on Hydrometeorology and Environmental Monitoring. Mikhailik et al. (2011) estimated daily fluxes of pollutants supplied into Amursky Bay by Razdolnaya River. Some results were summarized in Table 1 (CEARAC, 2011).

Table 1. Annual loads (T/year) of nutrients, COD, SS into Amursky Bay by river runoff and waste waters of Vladivostok

Nutrients, COD, SS	DIN	N-tot	DIP	P-tot	COD	DISi	SS	BOD_5
River runoff	1800	4200	120	450	36560	17040	117840	37800$^{***)}$
Waste-water	700	1150$^{**)}$	100	140$^{**)}$	8000$^{****)}$	nd$^{*)}$	2156$^{***)}$	1733$^{***)}$

$^{*)}$nd means no data; $^{**)}$ N-tot and P-tot values were calculated assuming that organic forms of nitrogen and phosphorus are 40 and 30 % from total its contents, respectively (Henze, 2006); $^{***)}$ (Gavrilevsky et al., 1998); $^{****)}$ POMRAC, 2006.

More than 70% supplied by nutrients causes by loading of Razdolnaya River. There are available data of water quality trends of Razdolnaya River (POMRAC, 2009). Review of data by POMRAC clearly demonstrates trends in increasing concentrations of phosphates and ammonium with time in Razdolnaya River. Enrichment of Amursky Bay by nutrients, suspended substances and organic matter causes eutrophication of the bay as it is considered by many scientists. These works were recently reviewed (Lutaenko, Vaschenko, 2008). Killed fishes event and recently discovered hypoxia of bottom waters (Tishchenko et al., 2008; Tishchenko et al., 2011a, 2011b) are consequences of eutrophication of Amursky Bay. Estimations of nutrient loads into Ussuriisky Bay (sub-area **B**) and open part of PGB (sub-area **C**) are given in Tables 2 and 3, respectively. Due to monsoon climate the heavy rains, water discharge may increase some of the warm period, and a large amount of nutrients and suspended matter are supplied into surface layer of Amursky Bay by Razdolnaya River during high water periods. In 2008, such eutrophication pulses occurred on June 2 and July 19 (Fig. 3; Mikhailik et al., 2011)

Table 2. Annual loads (T/year) of nutrients, COD, SS into Sub-area **B** (Ussuriisky Bay) from river runoff and waste waters of Vladivostok

Nutrients, COD, SS	DIN	N-tot	DIP	P-tot	COD	DISi	SS
River runoff	178	400	24.3	90	7550***)	4400	7300***)
Waste-water	950	1600**)	130	185**)	10000	nd*)	nd*)

*)nd means no data; **) N-tot and P-tot values were calculated assuming that organic forms of nitrogen and phosphorus are 40 and 30 % from total its contents, respectively (Henze, 2006); ***) (POMRAC, 2006).

Table 3. Annual loads (T/year) of nutrients, COD_{Cr}, SS into Sub-area **C** from river runoff and waste waters

Nutrients, COD, SS	DIN	N-tot	DIP	P-tot
River runoff	250**)	500	11**)	40
Waste-water	450	750*)	100	160*)

*) N-tot and P-tot values were calculated assuming that organic forms of nitrogen and phosphorus are 40 and 30 % from total its contents, respectively (Ecological… 2000); **) POMRAC (2009).

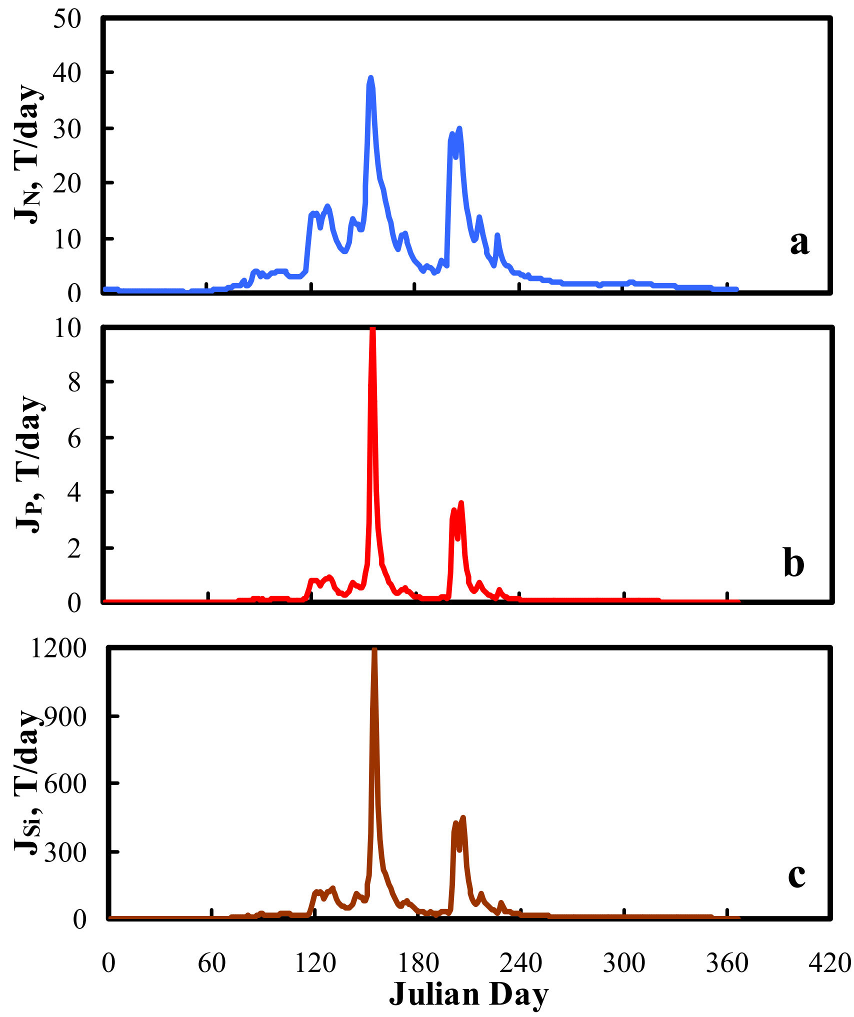


Fig. 3. Fluxes of nutrients (a – DIN; b – DIP; c – DISi) loaded into Amursky Bay by Razdolnaya River as function of Julian Days (Mikhailik et al., 2011).

III.3. Seasonal hypoxia of bottom waters and related nutrients concentrations

According to Anderson's definition of eutrophication (Anderson et al., 2006) the nutrients concentrations are immediately following as variable indicators for assessment of trophic status of PGB regarding to some reference state. However, excepting few recent publications (Tishchenko et al., 2008; Tishchenko et al., 2011a, 2011b; Semkin et al., 2012; Zvalinsky et al., 2012), the distributions of nutrients in PGB were rather studied as geographical or/and oceanographic descriptions than ecological problems of PGB (Voronkov, 1941a, 1941b; Lastovetsky and Veshcheva, 1964; Podorvanova et al., 1989; Rachkov, 2002; Luchin et al., 2005, 2007; Rachkov, 2006; Zuenko, 2008). It is necessary to note that nutrients from land-sources load by means of fresh-waters inflow into photic layer of PGB. However, excepting winter time (Tishchenko et al., 2011a), there were no observations of high nutrients concentrations in surface layer. Vice versa, higher concentrations of nutrients were observed in bottom waters of PGB (Voronkov, 1941a; Lastovetsky and Veshcheva, 1964; Podorvanova et al., 1989; Rachkov, 2002; Rachkov, 2006; Tishchenko et al., 2011a, 2011b; Semkin et al., 2012). This feature can be explained by existence of biological pump which convert inorganic nutrients into organic matter (phytoplankton) then after settling of phytoplankton on the bottom, the organic matter releases nutrients into seawater by mineralization process (microbial destruction). Many scientists observed low dissolved oxygen concentrations near bottom in summer time (Voronkov, 1941a; Lastovetsky and Veshcheva, 1964; Redkovskaya, 1980; Rodionov, 1984; Podorvanova et al., 1989; Rachkov, 2002; Rachkov, 2006; Tishchenko et al., 2011a, b; Semkin et al., 2012; Fig.4).

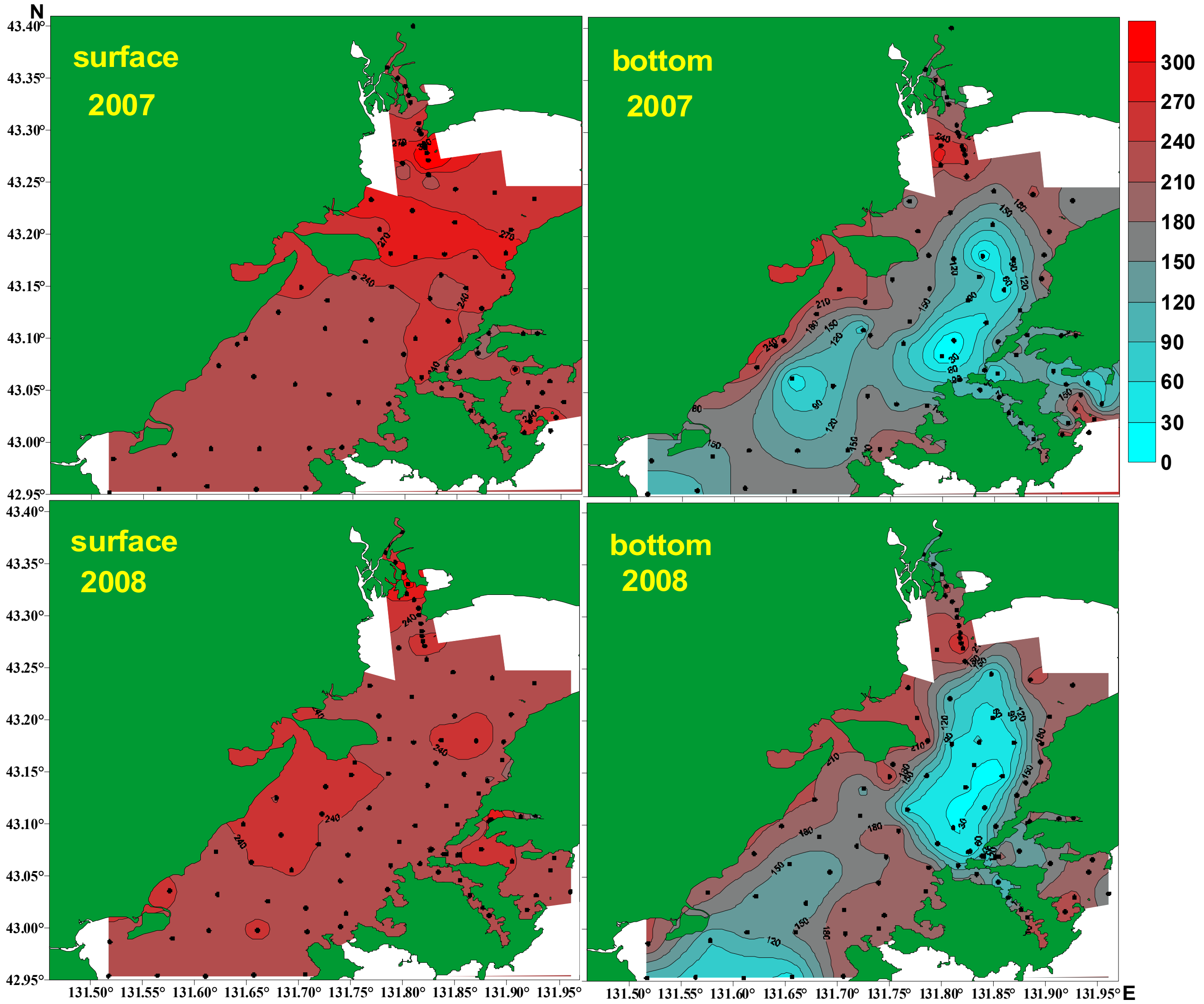


Fig. 4. Distribution of oxygen concentration (μmol/kg) in Amursky Bay. August, 2007 (upper panel). August, 2008 (bottom panel).

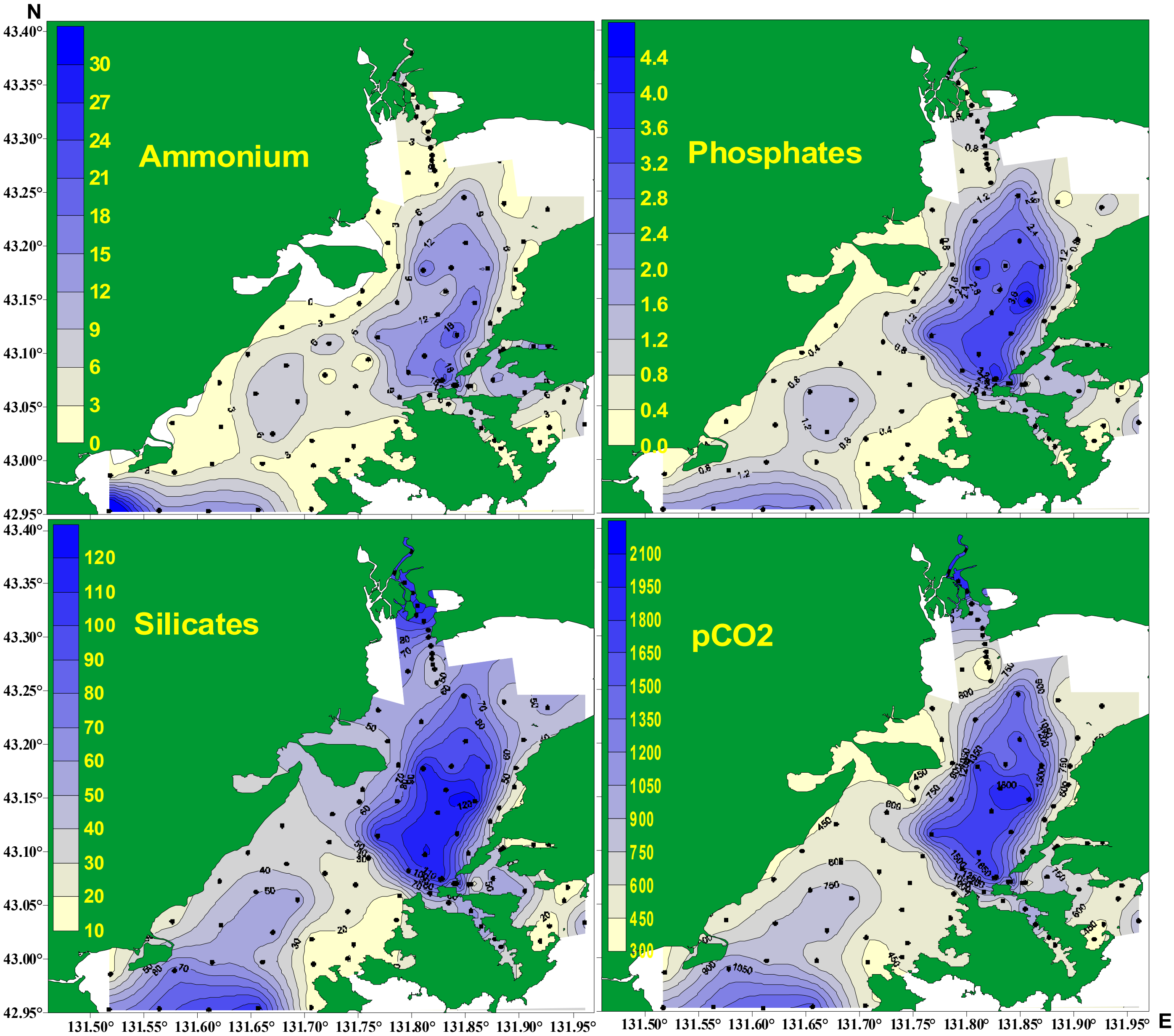


Fig.5. Distribution of ammonium, Phosphates, Silicates (umol/kg) and CO2 partial (uatm) in the bottom water of the Amursky Bay. August, 2008.

However most of researchers did not link together causes of observed low oxygen concentrations with causes of observed high nutrients concentrations (phosphates, silicates, ammonium). In recent publications (Tishchenko et al., 2008; Tishchenko et al., 2011a, b; Semkin et al., 2012) hypoxia of bottom waters and high nutrients concentrations of phosphates, silicates and ammonium in Amursky and Ussuriisky Bays were considered as consequence of eutrophication and working of biological pump which supplies nutrients from photic layer into bottom waters and consumes oxygen from near bottom layer. Figures 4 and 5 demonstrate that there are similar shapes of spatial distributions in chemical anomalies (ammonium, phosphates, silicates and CO_2 partial pressure) and oxygen concentrations in the bottom waters of the Amursky Bay during August 2008. Similar shapes prove that these are the result of one process that governs hydrochemical features observed in the bottom waters of the bay during August. This process is a microbiological degradation of the “excess” phytoplankton, the main part of which is diatoms. Phylogenic studies show that the microalgae population in the area of the Razdolnaya River mouth and the adjacent waters of Amursky bay is dominated in population density by diatoms and cryptophytes (64% and 27%, respectively) and in biomass by diatoms (94%) (Stonik et al., 2009). Rate of oxygen consumption was directly measured by Water Quality Monitor (Fig. 6).

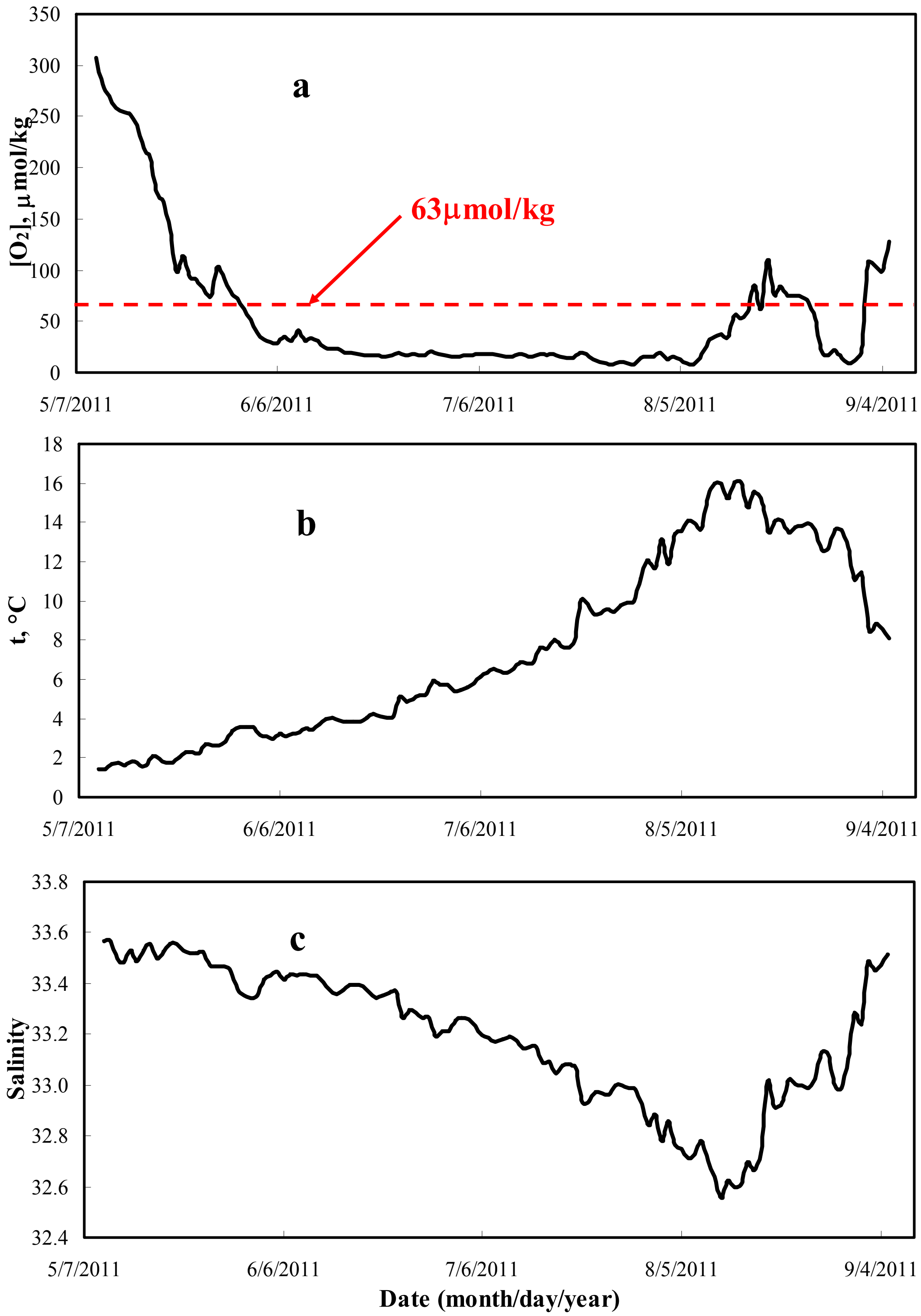


Fig. 6. Temporal variability of hydrological parameters near bottom layer of the Amursky Bay (43°10.881' N; 131°49.893' E) was logged by Water Quality Monitor (Wet Lab firm) during warm period in 2011. Red line corresponds to hypoxia condition. (Tishchenko P.P. et al., 2013 in press).

Our data of oxygen concentration in hypoxia area suggest that detected hypoxia in the Amursky Bay has seasonal character (Fig. 7).

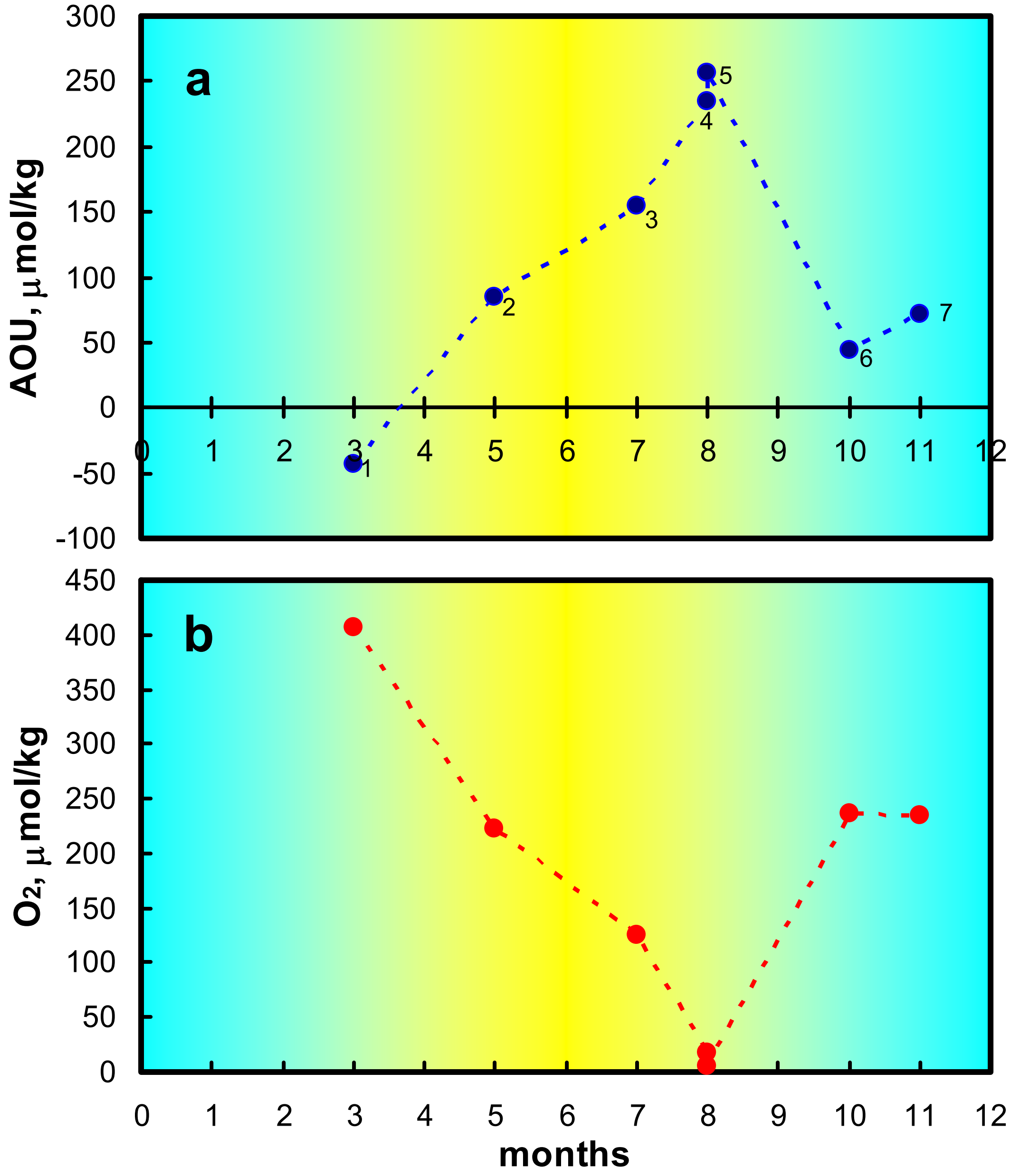


Fig.7. Seasonal variability of Apparent Oxygen Utilization (a) and Oxygen Concentration (b) in near-bottom waters in the hypoxic area of the Amursky Bay. Using Data: 1 – March 04, 2008; 2 – May 23, 2008; 3 - July 08, 2008; 4 – August 20, 2007; 5 – August 25, 2008; 6 – October 15, 2006; 7 – November 01, 2006.

In contrast to Amursky Bay, the Ussuriisky Bay is much less studied. Recently we carried out comprehensive hydrochemical study of this bay. Seasonal distributions of dissolved oxygen concentrations in the bottom waters are given on Fig. 8. Lowest concentration of dissolved oxygen was 68 uM, that is close to hypoxic conditions. It was detected in the bottom waters at August, 2011. Nevertheless dissolved oxygen concentrations in the bottom waters of the Ussuriisky Bay are generally higher than those in the Amursky Bay. Vice versa is in distributions of the nutrient concentrations. We did not find some symptoms of significant eutrophication of the Ussuriisky Bay.

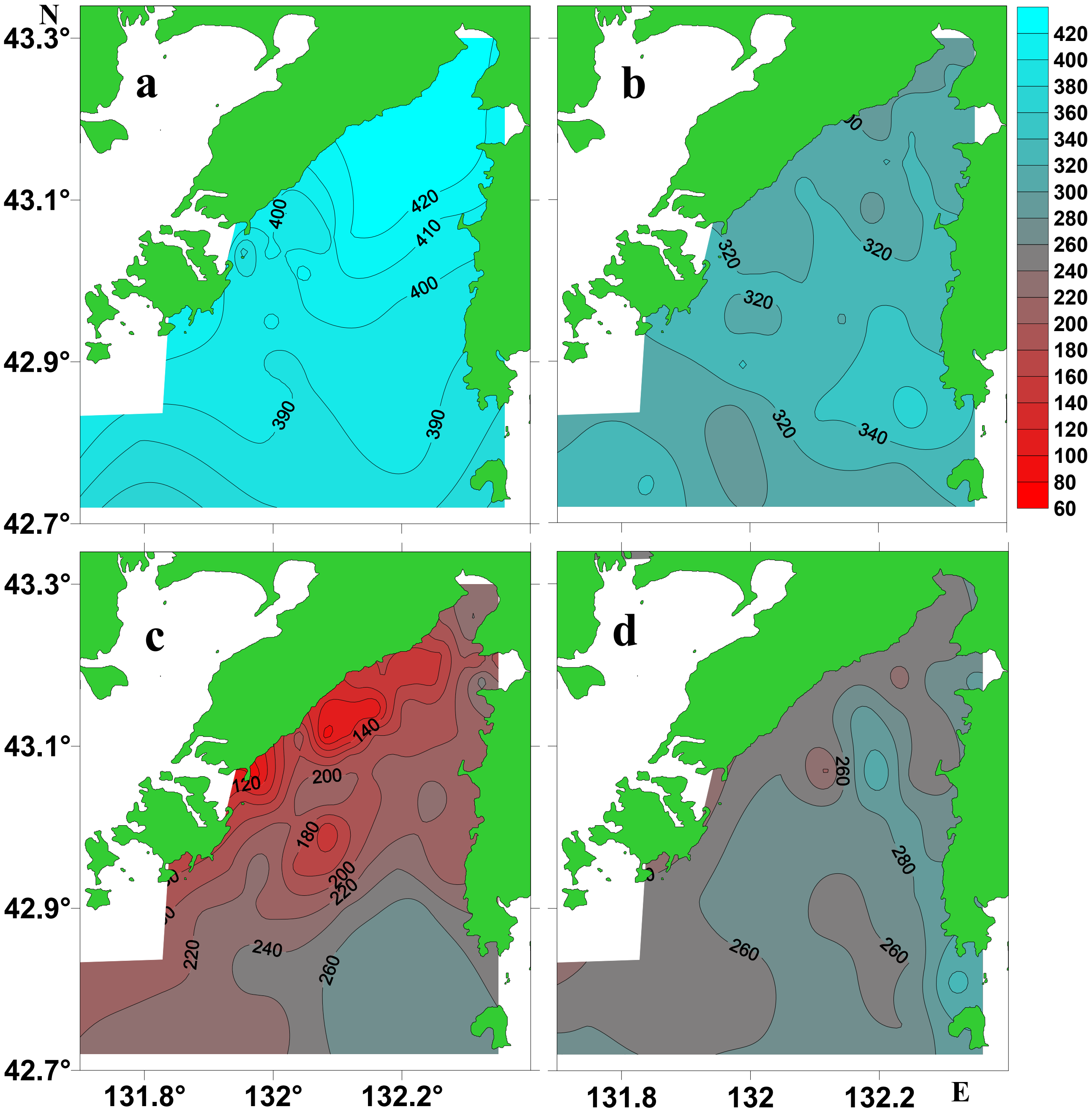


Fig. 8. Seasonal distributions of dissolved oxygen concentration (µmol/kg) in the bottom waters of the Ussuriisky Bay. a – February, 2010; b – May, 2011; c – August, 2011; d – October, 2011.

IV. Comprehensive Procedure

The objective of this comprehensive procedure is assessment of eutrophic status of Peter the Great Bay with aiming to improve management and healthy of coastal environment of area where symptoms of eutrophication were detected.

IV.1. Peculiarities of Peter the Great Bay

Peter the Great Bay (PGB) is situated in a northwestern part of NOWPAP region (Fig. 9). From open sea, border of the bay is line connecting two points. One is mouth of Tumannaya River (western side), another one is Povorotniy Cape (eastern side). Distance between these points is about 200 km. Distance of the coastal line around bay is about 1500 km. Total area of PGB is about 9500 км^2. The bay contains about 500 км^3 of water. Muravjev-Amursky peninsula and group of islands (Russky Island, Popov Island, Rejnike Island and smaller others) divide PGB on two sub-areas – Amursky Bay (western part) and Ussuriisky Bay (eastern part). Besides, there are more four small bays within PGB. They are Posjet Bay, Strelok Bay, Vostok Bay and Nakhodka Bay (Fig. 9). Northern part of the bay is shallow. The depths of the bay smoothly increase in southward and reach maximum (120 – 150 m). There is steep continental slope off PGB, where depths sharply change from 200 to 2000 m within width 6 – 15 km. PGB is partly covered by ice in winter season. Ice formation usually starts at the end November. The northern part of Amursky Bay is covered by consolidated sea-ice during late December – beginning March. There is non-consolidated ice in southern part of Amursky Bay and a most part of Ussuriisky Bay during winter season. Due to sea-ice formation and brine rejection dense waters are forming on the shelf of PGB. Deep convection and renewal of bottom waters through brine rejection had occurred sometimes in NOWPAP region (Talley et al., 2003). Due to upwelling the Intermediate Waters of the NOWPAP Sea comes up on the shelf of PGB at autumn season (Zhabin et al., 1993).

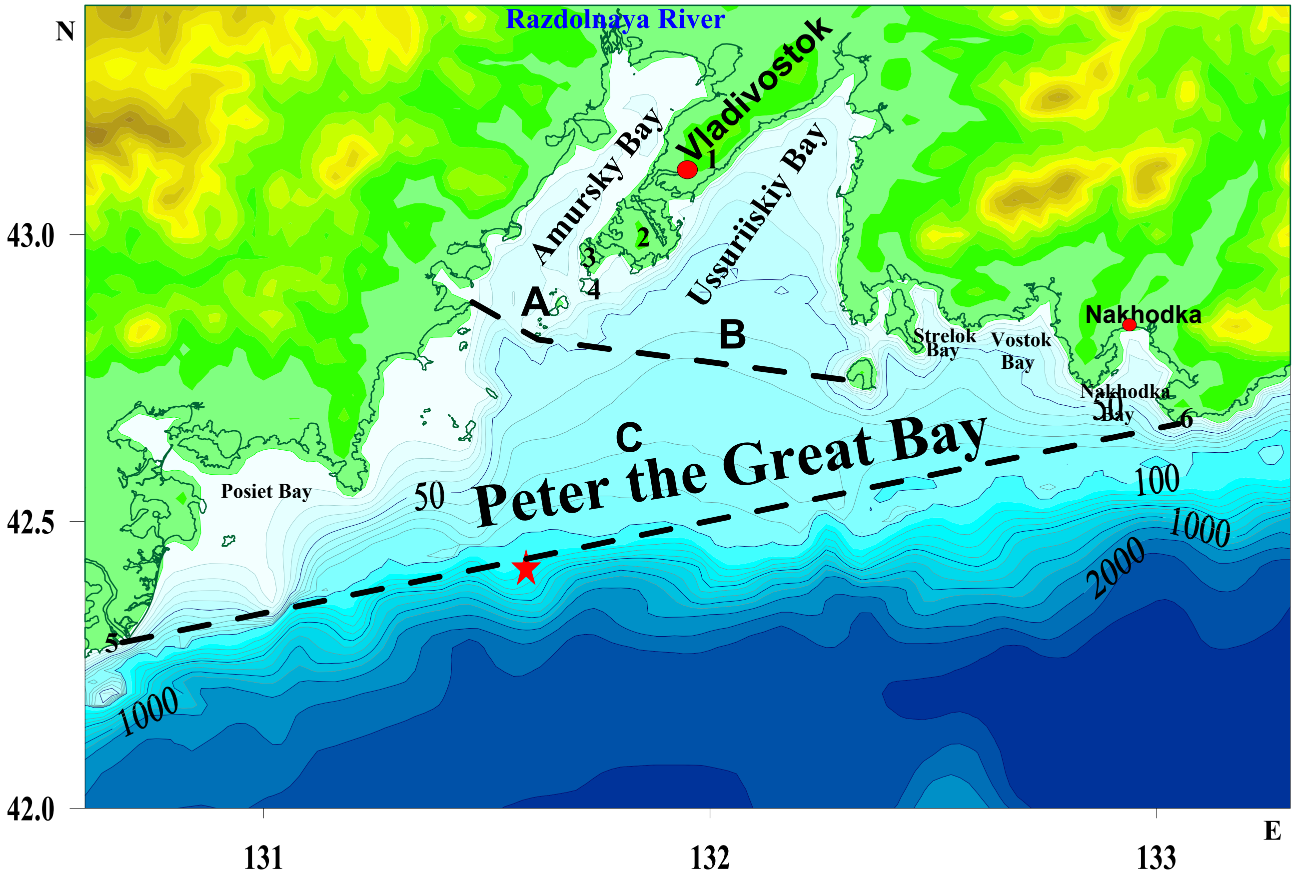


Figure 9. Peter the Great Bay and its sub-areas: **A** - Amursky Bay; **B** - Ussuriysky Bay ; **C** - South part of The Peter the Great Bay. 1 – Muravejev-Amursky Peninsula; 2 – Russky Island; 3 – Popov Island; 4 – Rejnike Island; 5 – Mouse Tumannaya River; 6 – Povorotnij Cape. Star notes site of reference station.

Some rivers inflow into PGB. Largest one is Razdolnaya River which inflows into northern part of Amursky Bay. Average annual runoff of Razdolnaya River is about 2.46 m^3. Smaller rivers – Artemovka, Shkotovka, Sukhodol inflow into Ussuriisky Bay. Annual runoffs of Artemovka River, Shkotovka River, Sukhodol River and Petrovka River are 0.29, 0.22, 0.14 and 0.1 km^3, respectively. Partizanskaya River inflows into Nakhodka Bay, its annual runoff is 1.32 km^3. Total annual river runoff into PGB varies within 2.1 - 8.2 km^3, and its average value is about 4.72 km^3. Due to monsoon climate, the main part of river runoff (70-90%) is occurred in during April – September.

Vladivostok is largest city in Primorye and it situated on a coast of Amursky Bay and Ussuriisky Bay. Its population is about 630,000 peoples. Smaller cities – Nakodka and Slavyanka are situated in Nakhodka Bay and Slavyansky Bay, respectively. Main anthropogenic pressure on PGB is caused by inputs of Razdolnaya River and waste waters of Vladivostok city. Summation of peculiarities of PGB is given by sketch (Lobanov et al., 2009; Fig. 10).

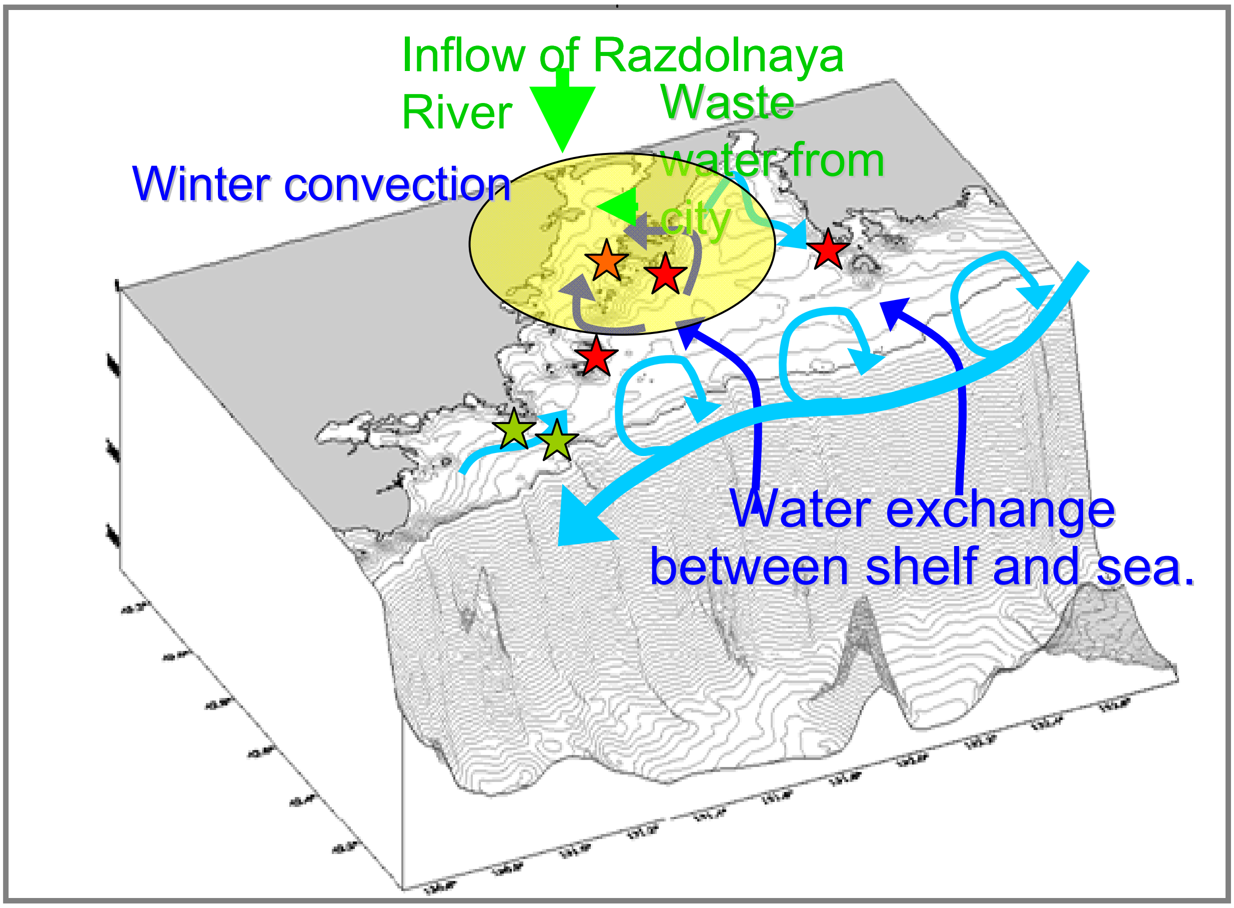


Figure 10. Sketch of main peculiarities of Peter the Great Bay: a) Inputs waters enrichment by nutrients via Razolnaya River inflow and waste waters of Vladivostok-city (yellow ring); b) sea-ice formation and winter convection mostly occur in yellow ring; c) There is water exchange between shelf and NOWPAP area through steep continental slope.

IV.2. Collection of relevant information

From our historical review is following that there are only two organizations which carry out environmental monitoring on Peter the Great Bay (PGB) and keep information about this. These are Federal State Budgetary Institution Primorskoe Administration for Hydrometeorology and Environmental Monitoring (FSBIPAHEM) and Far Eastern Regional Hydrometeorological

Research Institute (FERHRI). However row data of annual reports and reviews produced by these organizations were unavailable in the open access publications at the Soviet time (up to 1991). From 1991 to present time annual reports and reviews of FSBIPAHEM are available after payment only. On these reason for getting relevant information we used open accessed publications such as monographs:

Anikiev V.V. (1987) Short-scale of geochemical processes and pollution of ocean. Moscow. Nauka. 192 p. (POI, Rus.).

Condition of Marine Ecosystems Influenced by the River Flow. Ed. L.M. Gramm-Osipov. Vladivostok, Dalnauka, 2005, 260 p. (POI, collective monograph, Rus.).

Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok, Far Eastern Federal University Press, 2012, 438 p. (FEFU, collective monograph, Rus.).

Current state and tendencies of changes of environment of Peter the Great Bay of Japan Sea. Eds. V.B. Lobanov, A.C. Astakhov. Moscow. GEOS, 2008, 460 p. (POI, collective monograph, Rus.).

Ecological Studies and the state of the Ecosystem of Amursky Bay and the Estuarine Zone of the Razdolnaya River (Sea of Japan). Eds. K.A. Lutaenko and M.A. Vaschenko. Vladivostok, Dalnauka, 2008, V. 1, 301 p. (IMB, collective monograph, Rus.).

Ecological Studies and the state of the Ecosystem of Amursky Bay and the Estuarine Zone of the Razdolnaya River (Sea of Japan). Eds. K.A. Lutaenko and M.A. Vaschenko. Vladivostok, Dalnauka, 2009, V. 2, 331 p. (IMB, collective monograph, Rus.).

Konovalova G.V., Orlova T.Yu., Pautova L.A. Atlas of phytoplankton of the Japan Sea // L.: Nauka, 1989. 160 p. (IMB, Rus.).

Naumov. Y.A. Anthropogenez and ecological condition of geosystem marine-coastal zone of Peter the Great Bay the Sea of Japan. Vladivostok. Dalnauka, 2006. 300 p. (FEFU, Rus.).

Ogorodnikova A.A. Ecological and economical estimations of impacts of land-sources pollutants on the environment and bioresources of Peter the Great Bay. TINRO-Center, 2001. 193 p. (TINRO-Center, Rus.)

Podorvanova, N.F., T.S. Ivashinnikova, V.C. Petrenko, L.S. Khomichuk. 1989: Main features of hydrochemistry of Peter the Great Bay (Japan Sea). Vladivostok: DVO AN SSSR DVGU, 114 p. (FEFU, Rus.).

Response of Marine Biota to Environmental and Climatic Changes. Ed. A.V. Adrianov. Vladivostok, Dalnauka, 2007, V. 2, 331 p. (IMB, collective monograph, Rus.).

Shulkin V.M. Trace metals in ecosystems on the marine shelf. Vladivostok. Dalnauka, 2004, 279 p. (PGI, Rus.).

Tkalin A.V., Klimova V.L., Shapovalov E.N. et al., Some of regional consequences of anthropogenic impacts on marine environment. Ed. A.V. Tkalin. Leningrad. Hydrometeoizdat, 1990, 107 p. (FERHRI, collective monograph, Rus.).

Zuenko Yu.I. Fisheries Oceanography of the Japan Sea. Vladivostok. TINRO-Center, 2008, 228 p. (TINRO-Center, Rus.).

These above cited monographs provide us information relevant to the eutrophication assessment of the PGB such as: a) marine flora/fauna; b) pollutant sources (e.g. municipal, industrial, agricultural wastewater, marine aquaculture); c) supplementary information (e.g. oceanography, meteorology, catchment area population, wastewater management, coastal recreation).

For the eutrophication assessment of the PGB we used data-set collected by Pacific Oceanological Institute during 1999 to 2011, which include hydrochemical observations. Aim of the hydrological surveys carried out by POI was rather establish of hydrochemical status of the PGB then control of water quality. Usually measurements were carried out for surface and bottom horizons on following parameters: CTD – conductivity (salinity), temperature, depth using probe; salinity (salinometer), dissolved oxygen, nutrients (as rule as ammonium. nitrite, nitrate, phosphate, silicate), pH, Total Alkalinity, Humic Substances, Chlorophyll *a*, disk Secchi depth. At all, during 1999 to 2010 more than 2660 samples were analyzed (Fig.11). However obtained data are quite non-uniform with time and space (Fig. 11, 12).

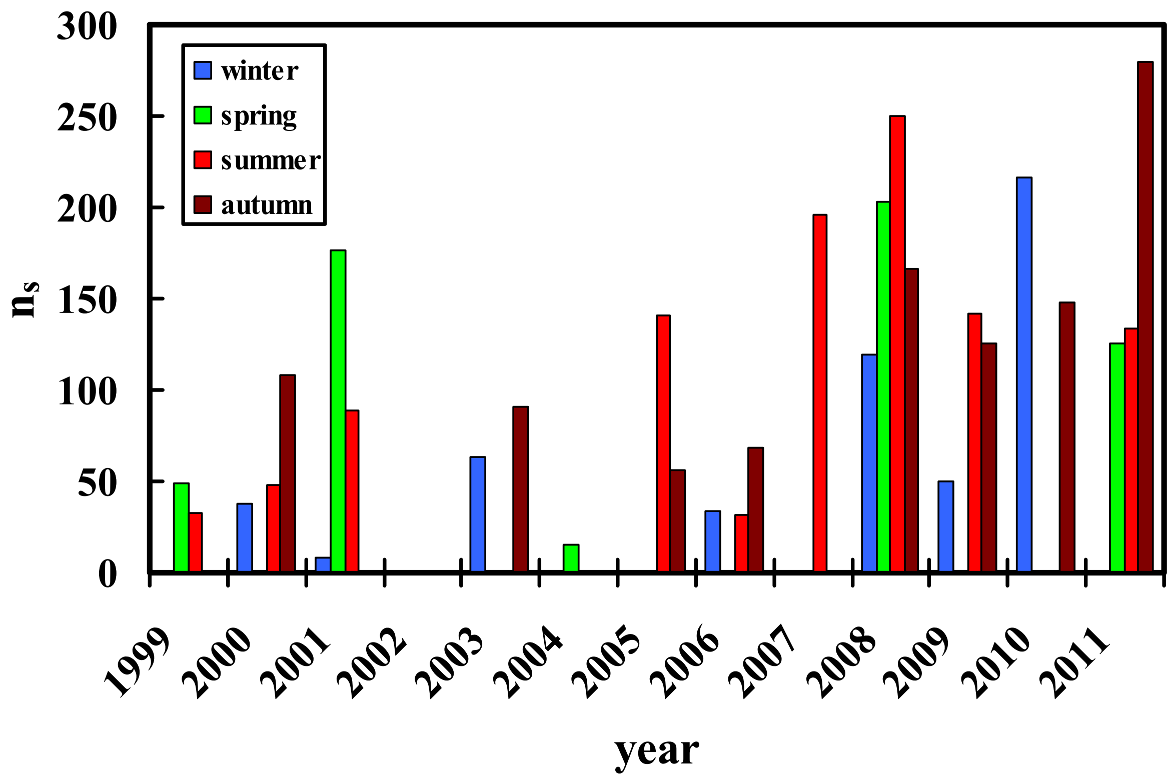


Figure 11. A level of study of Peter the Great Bay. Number of samples used for assessment parameters of eutrophication status of PGB.

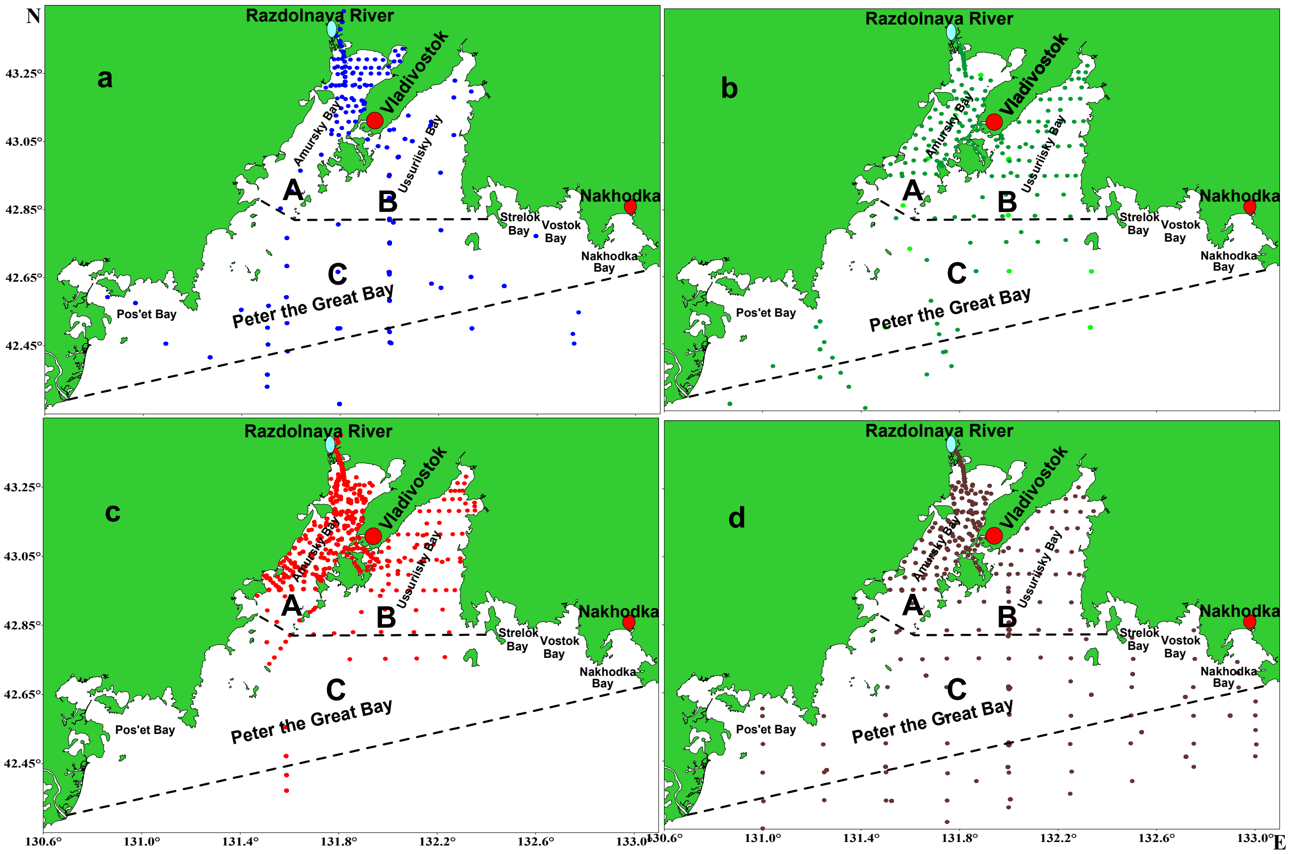


Figure 12. Distribution of hydrochemical stations which were implemented during 1999 – 2011 in Peter the Great Bay. a – Winter; b – Spring; c –Summer; d – Autumn. Points are locations of stations.

IV.3. Categorization and selection of assessment parameters

Selection of assessment parameters should be immediately follows from definition of eutrophication. According to Nixon's definition of eutrophication (Nixon, 2009) we have to measure allokhtonous and autokhtonous fluxes of organic matter in ecosystem. Using only these basic data we can conclusion about rate of supply of organic matter to an ecosystem. Another words rate of supplying of organic matter is balance of different fluxes of organic matter inside and crossborders of ecosystem. There are available data about allokhtonic fluxes caused by river runoff as rule. However there are no information about the export organic matter which caused by existence of current system or living organisms as rule. There are scarce data about the primary production for two reasons. One is that measurement of the primary production is not still ordinary observation. Another reason is that the primary production reveals considerable fluctuations from day to day at one station and site to site for different stations. Such strong spatial and temporal variability is caused by occasional observation of stage of the succession of primary production at given time in given place. In practical sense, Nixon's definition gives clear distinguishes between phenomena (eutrophication), causes (depth penetration of PAR, nutrient enrichment, grazing pressure, residence time of water) and consequences (hypoxia, fish kills, turbidity) (Nixon, 2009). Nevertheless, we prefer Anderson's definition of eutrophication (Andersen et al., 2006) in choice of assessment parameters in estimation of eutrophication status of the PGB. This definition is: "the enrichment of water by nutrients, especially nitrogen and/or phosphorus and organic matter, causing an increased growth of algae and higher forms of plant life to produce an unacceptable deviation in structure, function and stability of organisms present in the water and to the quality of water concerned, compared to reference conditions" (Andersen et al., 2006). According to this definition and recommendation of NOWPAP we accept assessment parameters, which are presented in Table

4. There are three categories of the parameters. First category (I) is concentrations of nutrients which presumably directly demonstrate enrichment of ecosystem by nutrients. Category II is chlorophyll concentration which is indirect parameter of primary production. Third category is oxygen concentration which may shows hypoxia or anoxia as consequence of eutrophication.

Table 4. Assessment and categorization parameters and methods of their measurements

Assessment parameters	Methods
Category I parameters used in this case study	
Nutrients DIN, DIP, DISi, TN, TP	Methods of Sea Water Analysis // Eds. K.Grasshoff, K. Kremling, M. Ehrhardt. Viley-VCH: Weinheim, New York, 1999.
Category II parameters used in this case study	
Chlorophyll	Standart oceanological methods (UNESCO, 1966; Koblenz-Mishke, 1983)
Category III parameters used in this case study	
Dissolved oxygen at bottom layer, Transparency	Winkler method (Carpenter, 1965)

IV.4. Preparation of assessment data sets

Values of each assessment parameters have been measured using commonly accepted methods (Methods…, 1999; UNESCO, 1966; Koblenz-Mishke, 1983; Carpenter, 1965**)**. Data set includes values of NH_4, NO_2, NO_3, PO_4, H_2SiO_3, Chlorophyll *a*, oxygen concentrations and transparency (depth of disk Secci) along following information: date, time, location (Latitude, Longitude), depth (pressure), in situ temperature, salinity, pH, Total Alkalinity. All measurements were carried out by same scientific group and were crossed checked. Therefore assessment parameters have reliable values. Data of assessment parameters were collected into Excel-file for each survey. Obtained dataset was sorting for each Sub-area of Peter the Great Bay.

IV.5. Division of assessment area into sub-area

PGB reveals strong spatial and seasonal variability of all parameters of ecosystem that causes uncertainty of natural character in eutrophication assessment. These peculiarities provide necessity to divide this area on several sub-areas. Due to natural peculiarities and real distribution of anthropogenic pressure on PGB, its area can be divided on three sub-areas. These are Amursky Bay (**A**), Ussuriisky Bay (**B**) and South part of PGB (**C**) (Fig. 9).

Sub-area **A**. Amursky Bay is semiclosed basin (Fig. 13). It is located in the northwestern part of PGB. Its average width is about 15 km, and its length is about 70 km. Depth of Amursky Bay varies from 0 up to 53 m (average depth is about 15 m). Square of the bay is about 1000 km^2, volume – 15 km^3 [http://pacificinfo.ru/data/cdrom/3/]. Razdolnaya River inflows into northern part of Amursky Bay. Average discharge is about 76 m^3/c. Smaller rivers – Shmidtovka, Amba, Barabashevka and Narva play insignificant role in ecosystem of the bay. Total annual river-runoff into Sub-area **A** is about 3.26 km^3. We consider Amursky Bay as estuarine basin, because river water propagates up to Yankovsky Peninsula, when Razdolnaya River has high water. At normal condition, when discharge of Razdolnaya River is about 76 m^3/c, area of mixing river and sea waters is situated between mouse Razdolnaya River and Peschanij Peninsula and depends from direction and strength of wind. About half of bay is covered by consolidated ice in winter season (from middle December to middle March). Other outer half has non-consolidated ice in winter. It is partly caused by work of icebreaker. Largest city of Primorye district is Vladivostok which is located on eastern coast of Amursky Bay. There are small towns on coast of the bay. They are Trudovoe, Uglovoe, Tavrichanka, Volno-Nadezhdenskoe, and Slavyanka.

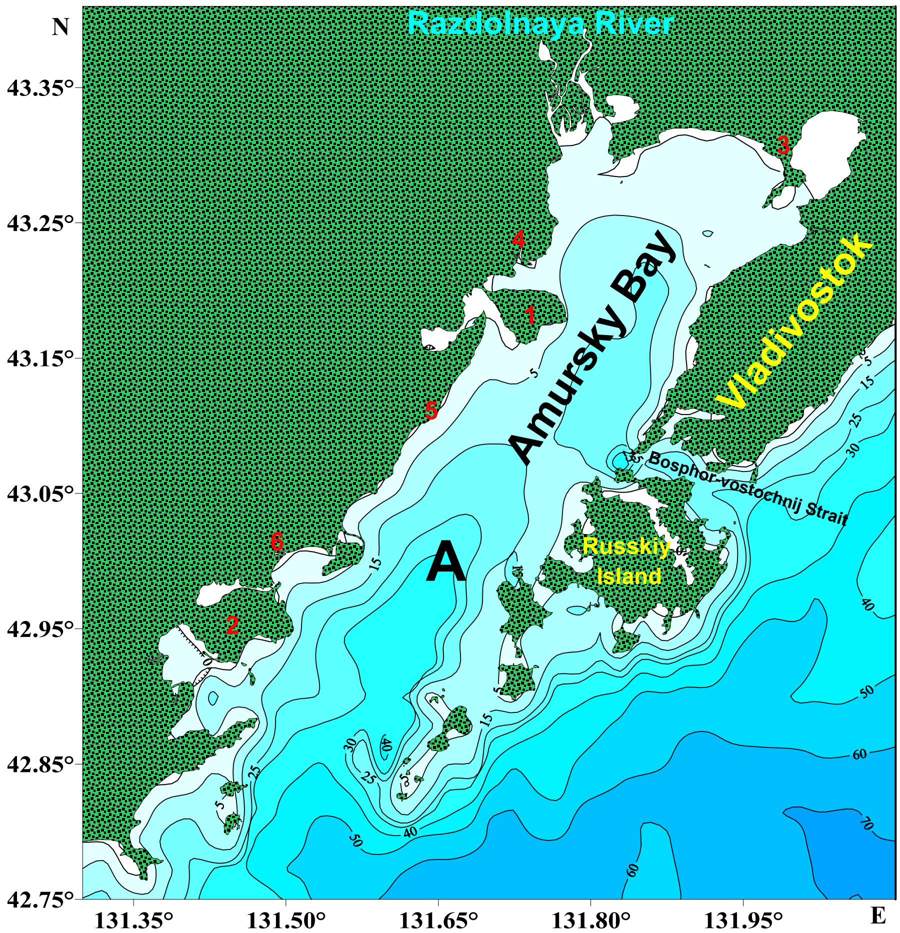


Figure 13. Amursky Bay – Sub-area **A**. It is semi-closed estuarine basin. 1 – Peschanij Peninsula; 2 – Yankovsky Peninsula; 3 – Shmidtovka River; 4 – Amba – River; 5 – Barabashevka River; 6 – Narva River.

There are two main inputs of nutrients into Amursky Bay: a) It is part of waste waters from Vladivostok city (about 55%) + other small towns. These waste waters are from about 300,000 peoples and they almost untreated input into Amursky Bay (Fig. 4); b) It load from Razdolnaya River. This load include waste waters from, Sujfunkhe City (China), Ussuriisk City and small villages which total population is about 150,000 and diffusive sources from agriculture fields which are in valley of the River (Fig. 14). According to Municipal Data, the total annual volume of waste water inflowing into Amursky Bay is about 40-50*10^6 m^3. Summarized characteristics of the waste waters are given in Table 5.

Table 5. Annual waste waters load into Amursky Bay (m^3/year) and concentrations of nutrients, BOD_5, SS in waste waters.

Nutrients, BOD, SS References	V 10^6 m^3/y	BOD_5 mg/l	DIN Mg/l	N-tot	DIP mg/l	P-tot	DISi	SS
Qualifying…, 1988	54	100-650*	18-45	nd$^{*)}$	5-8	nd$^{*)}$	nd$^{*)}$	100-350
Ecological…, 2000	47	nd$^{*)}$	16.6	27.7$^{**)}$	2.1	3$^{**)}$	nd$^{*)}$	nd$^{*)}$
Gavrilevsky et al., 1998	55	32.6	4.2	7$^{**)}$	1.9	2.7$^{**)}$	nd$^{*)}$	39.2

$^{*)}$nd means no data; $^{**)}$ N-tot and P-tot values were calculated assuming that organic forms of nitrogen and phosphorus are 40 and 30 % from total its contents, respectively (Henze et al, 1992**)**.

Annual loads of nutrients, suspended solids and COD_{Cr} into Amursky Bay supplied by Razdolnaya River were published somewhere (Mikhailik et al., 2011). Annual loads (T/year) of nutrients, COD_{Cr}, SS into Amursky Bay from river runoff and waste waters of Vladivostok are given in Table 1.

More than 70% supplied by nutrients causes by loading of Razdolnaya River. Enrichment of Amursky Bay by nutrients, suspended substances and organic matter causes eutrophication of the bay as it is considered many scientists. These works were recently reviewed (Lutaenko, Vaschenko, 2008). Killed fishes event and recently discovered OMZ (Fig. 4, Tishchenko et al., 2008) are consequences of eutrophication of Amursky Bay.

Sub-area **B**. Ussuriysky Bay is open basin (Fig. 14). It is located in the northeastern part of PGB. Square of the bay is about 2100 km^2. Depth varies from 0 up to 75 m (average depth is about 35 m) [http://pacificinfo.ru/data/cdrom/3/]. We also include Golden Horn Bay into Sub-area **B**. There are small rivers which inflow into Ussuriisky Bay. These are Artemovka, Shkotovka, Sukhodol, and Petrovka. Total annual river-runoff to the bay is about 1.3 km^3. Hydrochemical characteristics of waters of these rivers are presented in Table 6.

Table 6. Annual loads (T/year) of nutrients, COD_{Cr}, SS into Ussuriisky Bay from river runoff.

Nutrients, COD, SS	Runoff km^3/y	DIN	N-tot	DIP	P-tot	COD_{Cr}	DISi	SS
Artemovka River	0.29	100	380	20	59	4350	1600	2700
Shkotovka (0,65)	0.22	35	134	2	15	1500	1400	2200
Sukhodol	0.14	25	91	1.3	10.3	1000	900	1400
Petrovka	0.10	18	64	1.0	7	700	500	1000
Total	0.75	178	669	24.3	91	7550	4400	7300

During winter season ice formation is occurred in Sub-area **B**. However, it does not form consolidated ice because basin is open and strong winds, intensive water exchange between the bay and the Sea are unfavorable conditions for forming of consolidated ice. Around Ussuriisky Bay 400,000 peoples live. Vladivostok is situated on western coast of Usseriisky Bay. There are small towns on the coast of the bay. They are Artem, Shkotovo, Petrovka, Bolshoy Kamen. There are two main inputs of nutrients into Ussuriisky Bay: a) It is part of waste waters from Vladivostok city (about 45%) + other small towns; b) It is load from river runoff. These waste waters are from about 400,000 peoples and they almost untreated input into Ussuriisky Bay. Using Municipal Data about concentrations of nutrients and annual volume of waste waters we estimated annual loads of nutrients into Ussuriisky Bay and presented in Table 2. These estimations assume that waters of Golden Horn Bay inflow into Ussuriisky Bay. Knowledge about nutrient concentrations and water discharges of main rivers inflowing into the bay permits to estimate annual loads of nutrients by river runoff which presented in table 2.

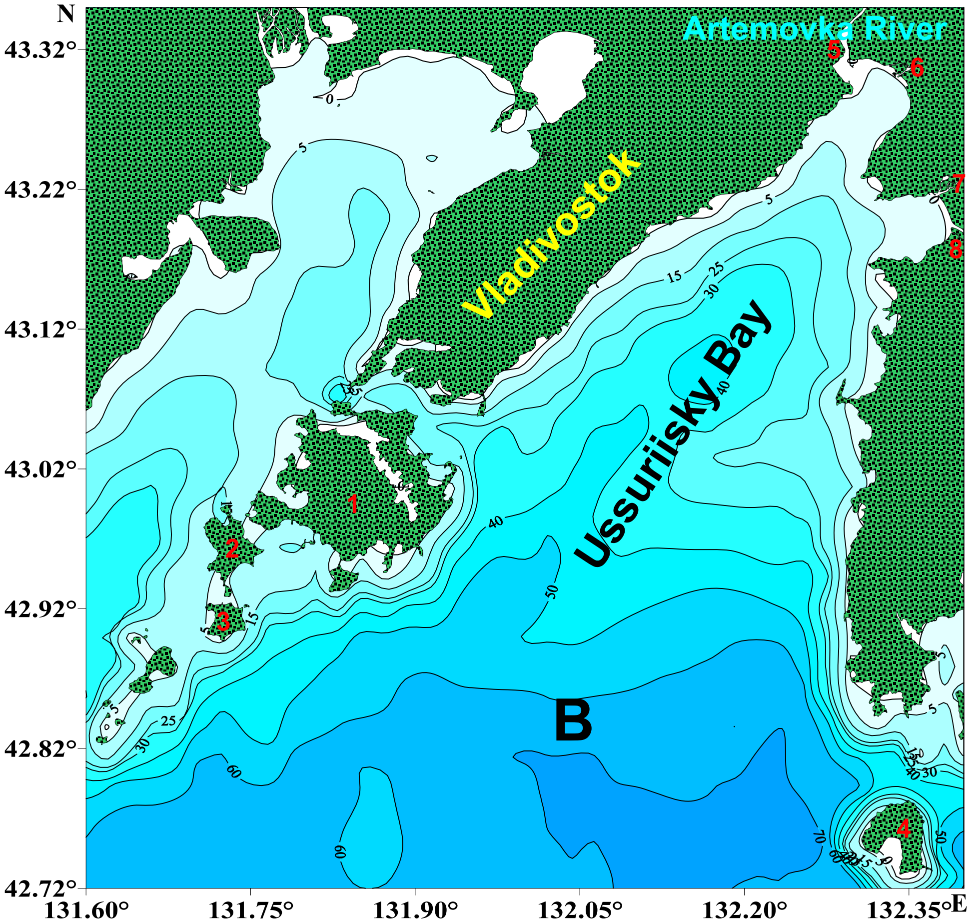


Figure 14. Ussurijsky Bay – Sub-area **B**. It is open basin. 1 – Russky Island; 2 – Popov Island; 3 – Rejnike Island; 4 – Putyatina Island; 5 – Artemovka River; 6 – Shkotovka River; 7 – Sukhodol River; 8 – Petrovka River.

We have to emphasize that the Golden Horn Bay is actually inner harbor of Vladivostok. This bay is suffering under high anthropogenic pressure, due to inputs of untreated waste waters high concentrations of nitrate, phosphate and low oxygen were observed in the past (Tkalin et al., 1993). Nevertheless we included Golden Horn Bay into Sub-area **B** which is presumably expected less anthropogenic impact. The main reason of this including is existence of current system at present time. Industrial waters which are originally seawaters from Ussuriisky Bay strongly flush Golden Horn Bay at present. Power Station of the Vladivostok (TEC-2) takes seawater from Ussuriisky Bay for cooling and then, after Power Station warm seawaters are disposed into Golden Horn Bay. Surface waters from the Harbor mostly flow into Ussurijsky Bay. Probably, clean of Harbor by means of dredging of bottom and flushing of water masses by means of existent current system result in elevating of oxygen concentration with time (Luchin et al., 2007**)**. Main feature of Ussuriisky Bay is high dynamic circulations and water exchange between Ussuriisky Bay and open part of Peter the Great Bay. Winds play is a governing role in appearance of high dynamic waters of Ussuriisky Bay (Zuenko, 2008).

Sub-area **C**. It is south part of PGB. Its square is about 6400 km^2. Depth varies from 0 up to 150 m (average depth is about 70 m). There are four bays. One of them is Posyet Bay which is situated in southwestern part of PGB. Another bays are Vostok Bay, Strelok Bay and Nakhodka Bay. They are in eastern part of PGB (Fig. 9). In this sub-area, biggest town is Nakhodka with population about 180,000. Total population around this sub-area is about 200,000. There are small rivers which inflow in this sub-area. Biggest one is Partizanskaya which average discharge is 37

m^3/c. Total annual river runoff is about 1.2 km^3. We do not include Tumannaya River in our consideration because we do not know how much water of this river comes into PGB. Our estimations of nutrient loads into Sub-area **C** are presented in Table 3.

Most distinct feature of this sub-area is intensive exchange between shelf waters of the bay and deep waters of the Sea by downwelling and upwelling processes along steep slope. These processes are poor understood at present time. However they have a significant effect on assimilation capacity of the PGB.

Summation of loads of the nutrients into the PGB and each of its Sub-area as well are listed in Table 7. Thus, according to Table 7 we can conclude that anthropogenic pressure is highest for Sub-area **A** (Amursky Bay) and lowest for sub-area **C**.

Table 7. Annual loads of nutrients and specific loads (per square) into PGB and each its sub-area from river runoff and waste waters.

Nutrients	DIN	TN	DIP	TP
	Sub-area A Amursky Bay (S=1000 km^2)			
River runoff, t/y	1800	4200	120	450
Vladivostok, t/y	700	1150	100	140
Total, t/y	2500	5350	220	590
Load per square, $t/km^2/y$	2.5	5.35	0.22	0.59
	Sub-area B Ussuriisky Bay (S=2100 km^2)			
River runoff, t/y	180	400	25	90
Waste waters, t/y	950	1600	130	185
Total, t/y	1130	2000	155	275
Load per square, $t/km^2/y$	0.54	0.95	0.07	0.13
Sub-area C south part of Peter the Great Bay (S=6400 km^2)				
River runoff, t/y	250	500	11	40
Waste waters, t/y	450	750	100	160
Total, t/y	700	1250	111	200
Load per square, $t/km^2/y$	0.11	0.2	0.017	0.031
Peter the Great Bay (S=9500 км^2)				
River runoff, t/y	2230	5100	156	581
Waste waters, t/y	2100	3500	330	485
Total, t/y	4330	8600	486	1066
Load per square, $t/km^2/y$	0.46	0.9	0.05	0.11

IV.6. Setting of assessment criteria

There are numerous methods developed for the quantitative assessment of eutrophication. Recent review of these methods was given by M. Karydis (2009). The classification of ecosystem regarding to trophic levels provides a useful tool for assessing environmental quality and help coastal managers in the making of decision. From Andersen's definition of eutrophication nutrients and chlorophyll concentrations are immediately following as variable indicators for assessment of trophic status of PGB regarding to some reference state. If we formally set "maximum permissible concentration" which accepted in Russia (DIN 680 μM; DIP 1.61 μM; DO 94 μM (POMRAC,

2006) as threshold values and apply these values for assessment eutrophic status for three regions: NW-Pacific; Sea of Okhotsk and NOWPAP Sea, we will get no sense result (Fig. 15). According to Fig. 15a, waters of NW-Pacific, Sea of Okhotsk and NOWPAP area have a bad quality below 50, 100 and 400 m respectively for these areas. However ecosystems of these regions are mostly undergoing by natural processes. So far, in setting of assessment criteria two fundamental problems rise: What is the reference values used for comparison? What are the threshold values characterizing a water body that gets into eutrophic phases? There is approach when unimpacted ecosystems can be used as reference sites for compare variable values related to eutrophication (Karydis, 2009). This approach was criticized by Duarte et al. (2009). They argue that concurrent changes, human-induced and otherwise, lead to shifting baselines imposing dynamic trajectories for reference ecosystem status. Expectation that ecosystems can be returned to an idealized past reference status by virtue of reducing direct human pressures is as likely as the existence of *Neverland* (Duarte et al., 2009).

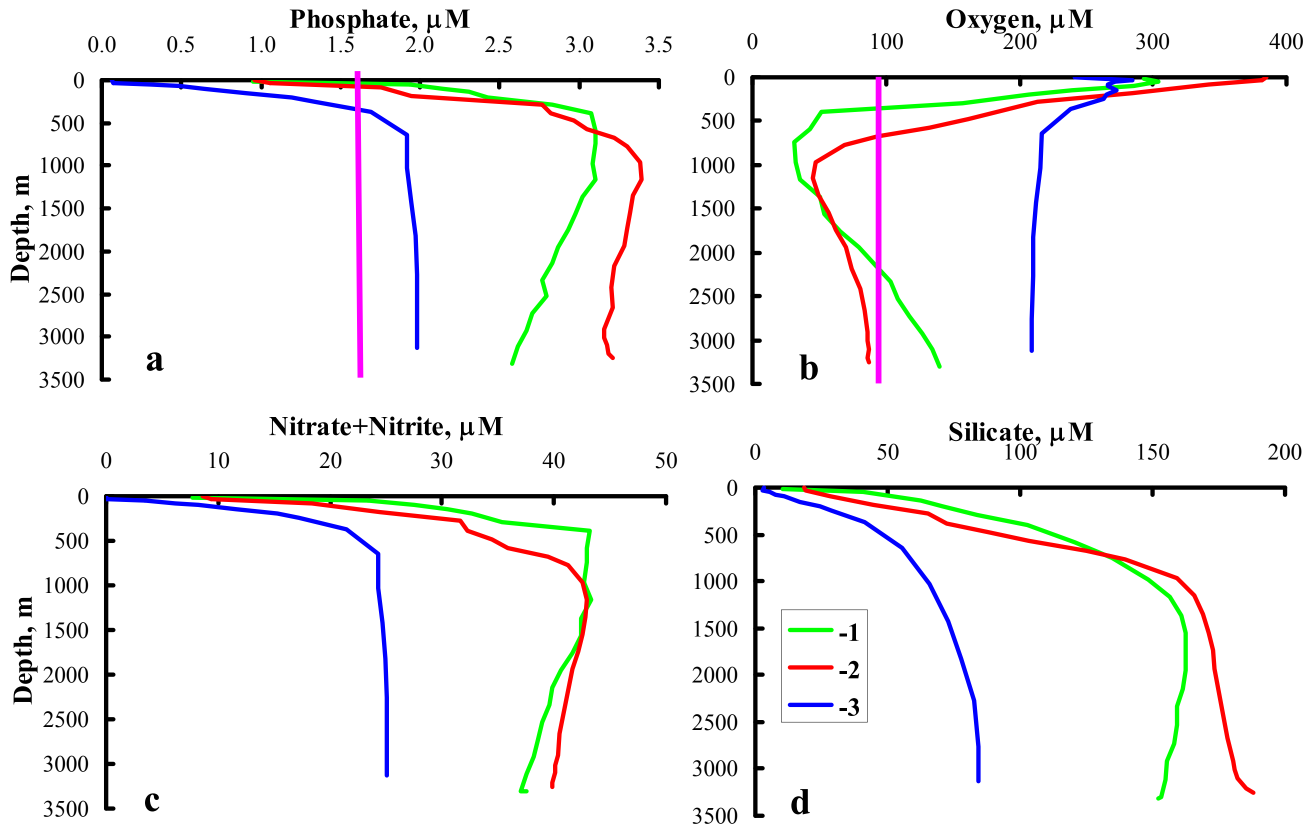


Figure 15. Vertical variations of assessment parameters (DIP -a, DO -b, DIN-c, DINSi-d) in NW-Pacific -**1** **φ=44.49°N, λ= 153.20°E**; Sea of Okhotsk -**2** **φ=47.49°N, λ=147.91°E**, NOWPAP Sea -**3** **φ=43.54°N, λ=139.20° E.** Purple vertical lines correspond "maximum permissible concentration" accepted in Russia.

We use actual properties of body water as "reference" site of which is noted by star (Fig. 9). Vertical profiles of some properties are shown on Fig. 16. It is should be noted that depth of euphotic layer is about 50 m. And DIN and DIP concentrations in this layer are almost zero, and then concentrations of nutrients sharply increase for depths deeper euphotic layer. This increasing of nutrient concentrations with depth has natural character. **We set reference conditions as follow: – there are almost zero nutrient concentrations in layer with thick 50 m.**

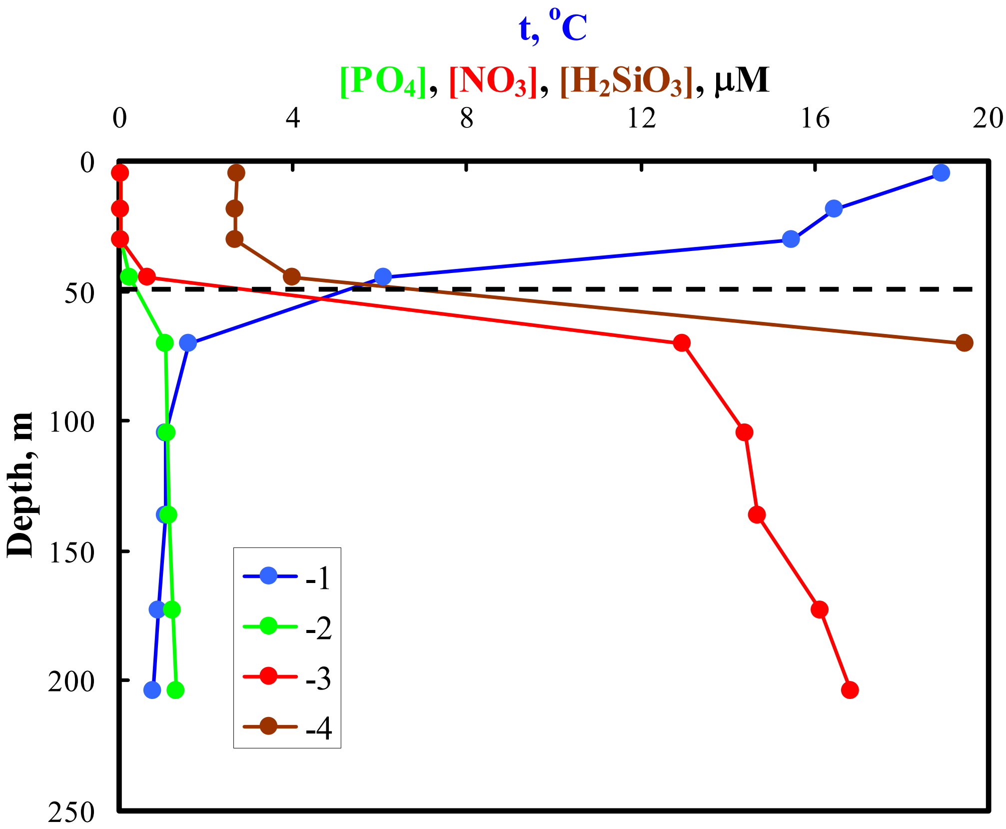


Figure 16. Vertical distribution of **1** - temperature (°C), **2** - PO_4 (µM), **3** - NO_3 (µM), and **4** - H_2SiO_3 (µM) on the station which is accepted as "standard" (42.417° N; 131.588° E, it is noted by star on Fig.1). Data obtained at August 1999 on R/V "Professor Khromov "-36.

The second problem is to set threshed values for nutrients (DIN, DIP, DISi) and Chlorophyll concentrations. We do not know why Russian Government accepted "maximum permissible concentration" for DIN DIP and DO tabled by POMRAC (2006). Hypoxia is one of the common effects of eutrophication in coastal marine ecosystems. Under low-oxygen conditions, the physiological processes and life cycles of biota can be disrupted. Among fishes and invertebrates, different taxonomic groups, body sizes and skeletal types have different oxygen tolerances and thresholds (Levin, 2009). Hypoxia is often defined as a content of DO concentration below 2 mg liter^{-1} (63 µM) O_2 (Diaz, 2001) or 2 ml liter^{-1} (89 µM) (Breitburg et al., 2009). The average value (76 µM) of these noted DO concentrations corresponds with the median lethal oxygen concentration for half of the tested species by Vaquer-Sunyer, Duarte (2008). This oxygen concentration was used as a threshold value for the assessment of the eutrophication status of Peter the Great Bay (NOWPAP CEARAC, 2011) and will be accepted as a definition of hypoxia here. Using supposition that in water initially equilibrated with atmosphere, mineralization of organic matter consumes DO, then we able to calculate thresholds values of nutrients by following equations:

$$DIN_{th}(\mu M) = \frac{(DO_{sat} - DO_{th}) \cdot 16}{138} = \frac{(DO_{sat} - 76) \cdot 16}{138} \quad (1)$$

$$DIP_{th}(\mu M) = \frac{(DO_{sat} - DO_{th})}{138} = \frac{(DO_{sat} - 76)}{138} \quad (2)$$

$$DISi_{th}(\mu M) = \frac{(DO_{sat} - DO_{th}) \cdot 17}{138} = \frac{(DO_{sat} - 76) \cdot 17}{138} \quad (3)$$

Here DIN_{th}, DIP_{th}, $DISi_{th}$ are threshold values of DIN, DIP and DISi, respectively; DO_{th}, DO_{sat} are threshold value and value at saturation conditions of oxygen concentration, respectively. It is assumed that Redfield stoichiometrical relations between oxygen, nitrogen and phosphorus are proved (Redfield, et al., 1963). Atomic ratio between Si:N in diatoms was accepted 1.05 (Brzezinski, 1985) which results "17" in equation (3). Thresholds values of nutrients were calculated by equations (1)-(3) and presented in Table 8. Meaning of these nutrient threshold values is that such content of nutrients in the photic layer is in principle enough for forming of hypoxia in bottom layer for same thickness. We accepted 5 μg/L as threshold value of chlorophyll concentration.

Table 8. Threshold values of nutrient concentrations calculated at summer temperature and salinity correspond those in near bottom waters of Amursky Bay. These values can be use for assessment of eutrophic status of PGB.

t, ^{o}C	S, ‰	DIN_{th}, μM	DIP_{th}, μM	DIS_{th}, μM
20	33	18.3	1.1	19.4

IV.7. Identifying the trend

Coastal waters reveal high biogeochemical dynamic, since they are influenced by both of natural and anthropogenic factors. The monsoon climate of the Primorye Region is the main influencing factor on the seasonal character of all hydrochemical, hydrological and atmospheric coastal environment. For example, a major part of atmospheric precipitations occurs during the summer. Heavy rains may cause occasional flooding and make impulses in supplying of nutrients by river (Fig. 3). Increase of atmospheric temperatures and increased fresh water discharge from rivers result in a strong vertical stratification of the water column during the summer season. The topography of Amursky Bay reveals a depression in its central portion (Fig. 13) which limits horizontal advection and water exchange in the bottom layer. These natural features of the bay cause weak dynamics in the bottom waters during the summer season. Monsoon winds change their phase from southern to western and northwestern, usually during September-October. These winds induce the development of upwelling along Primorye coast and advection of the Sea water onto the shelf of Peter the Great Bay (Zhabin et al., 1993; Zuenko, 2008). Thus, an upwelling and advection of cold open sea water in the bottom layer of the bay occurred at the autumn. All these physical mechanisms influence on rate of nutrient transformations and primary production. Due to highly dynamic variations of nutrients, chlorophyll and oxygen concentrations in space and time on seasonal scale and short-term scale as well, it is seemed very difficult to establish any trends of these parameters on long-term scale. Nevertheless, we try to recognize the trend of assessment parameters for Sub – area **A** in summer season, because this Sub-area is most investigated in the summer time. In this Sub-area we choose local area in the central part of Amursky Bay. It is situated on contrary of Peschanij Peninsula (Fig. 13). We have data of assessment parameters for surface and bottom horizons. It was found that values of parameters for bottom horizons are strongly dependent from depths of basin (Fig.17). For excluding this dependence we calculate values of assessment parameters for certain depth, namely, for 15 m using linear regression as it is shown on Fig.17. Number of stations used in such linear regressions vary within 7 (2001 year) – 22 (2008 year). Values of assessment parameters for surface horizons were simply averaged using data of same stations as for bottom horizons. Obtained such way values of assessment parameters were presented on Fig.18. Graphs on Fig.18 reveal trends in increasing of DIN, DIP, DISi, and decreasing in oxygen concentrations for bottom horizons. However, vice versa is for surface horizons excepting DIN case. This figure demonstrates trend in increasing concentration of Chlorophyll.

Available historical published data demonstrates that the lowest values of DO concentrations obtained in the summer season at the bottom waters of Amursky Bay have been systematically decreasing with time over the last eighty years (Fig. 19).

There are available data of water quality trends of Razdolnaya River (Fig. 20; POMRAC, 2009). Fig. 20 clearly demonstrates trends in increasing concentrations of phosphates and ammonium with time in Razdolnaya River.

Long-term observations of the community of Japanese Scallop and its epibionts in the Amursky Bay documented that from 1982 through 1993 the mean age of scallops in the settlement increased and the rate of linear growth of the mollusks dropped (Silina, Ovsyannoikova, 1995). The most noticeable changes occurred in the species composition and quantitative distribution of cirriped barnacles. Less tolerant epibionts were gradually replaced by species highly resistant to silting and organic pollution. The Polychaetes appeared the most tolerant to pollution (Silina, Ovsyannoikova, 1995). Dramatically changes of bentic flora in Amursky Bay were found (Levenets, Skriptsova, 2008). The total spaces number of macrophytes in 2005 decreased 1.5 times as compared to record of 1970 – 1980s. The most pronounced qualitative and quantitative changes of the flora were observed in the zones subjected to an anthropogenic press and the direct impact of the Razdolnaya River drain. It was found that the algal thickets with domination of kelps and sargases have reduced, and extensive thickets of sea grasses have disappeared from these sites. The reduction of the spaces number, biomass decrease, change of dominants in plant communities along with an increased importance of green algae testify to a human-induced transformation of vegetation towards its degradation (Levenets, Skriptsova, 2008). The investigations of long-term changes of macrozoobenthos in Amursky Bay suggest negative tendency in ecosystem of the bay (Moshchenko, Belan, 2008). Eutrophication and silting of the bay are supposed to be most probable reasons of macrozoobenthos change in the northern part of Amursky Bay in end of the XX-beginning of the XXI centuries, and to be an obstacle for restoration of the bay fauna (Moshchenko, Belan, 2008). Hydrochemical data (Figs. 4, 5), and biological investigations (Silina, Ovsyannoikova, 1995; Levenets, Skriptsova, 2008; Moshchenko, Belan, 2008) strongly suggest that trend of increasing eutrophication is occurred in sub-area **A**. We did not find any data which may clearly suggest about any trend of eutrophication in Sub-areas **B** and **C**.

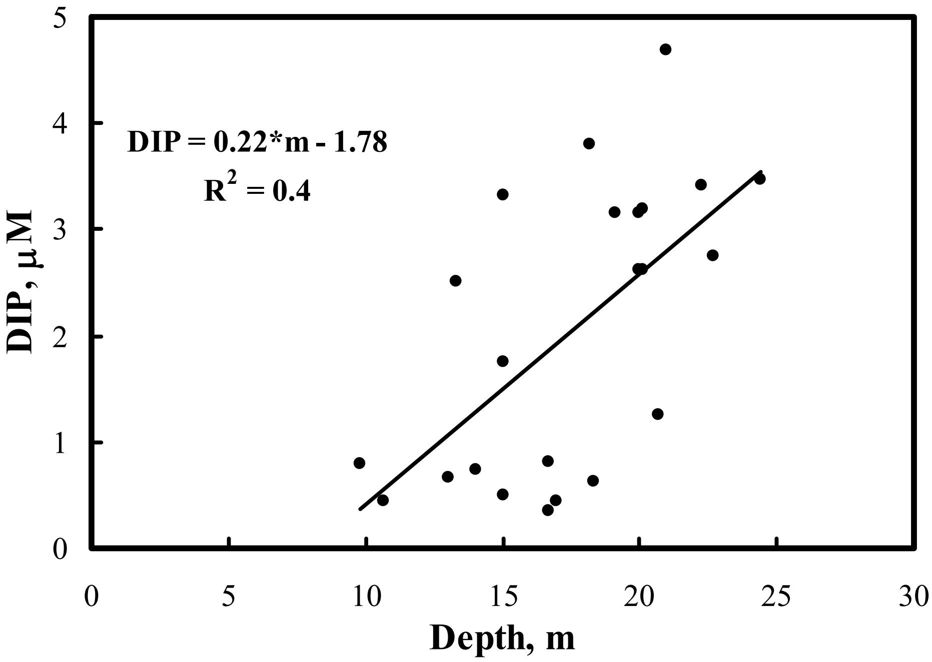


Figure 17. DIP concentrations in bottom layers as function of depth in chosen local area of central part of Amursky Bay which is situated on contrary of Peschanij Peninsula. Data obtained at August, 2008.

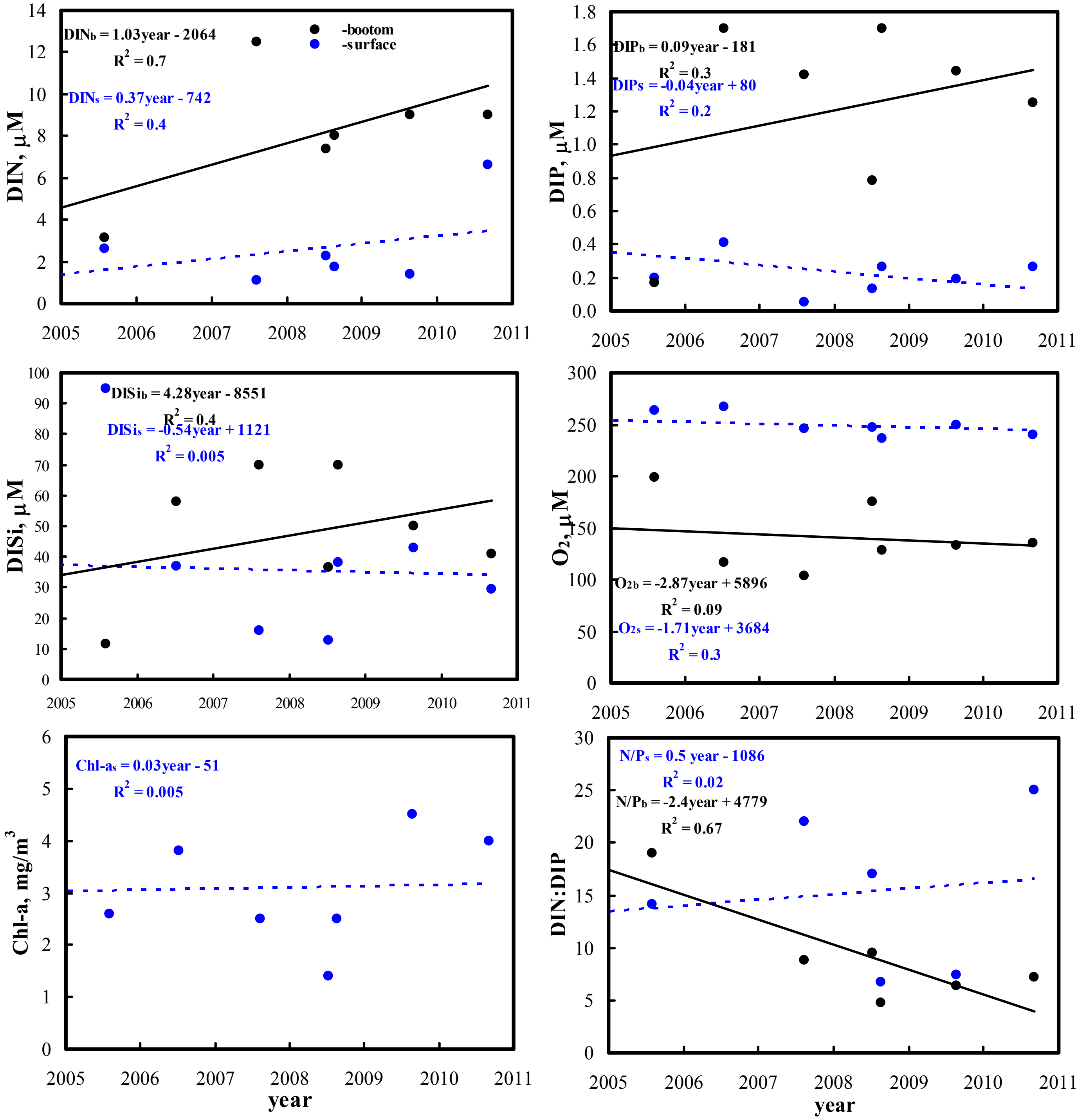


Figure 18. Trends of assessment parameters in the Peter the Great Bay (Sub-area **A**). Solid lines and fill circles correspond to bottom horizon -15 m. Dash lines and open circles correspond to surface horizon.

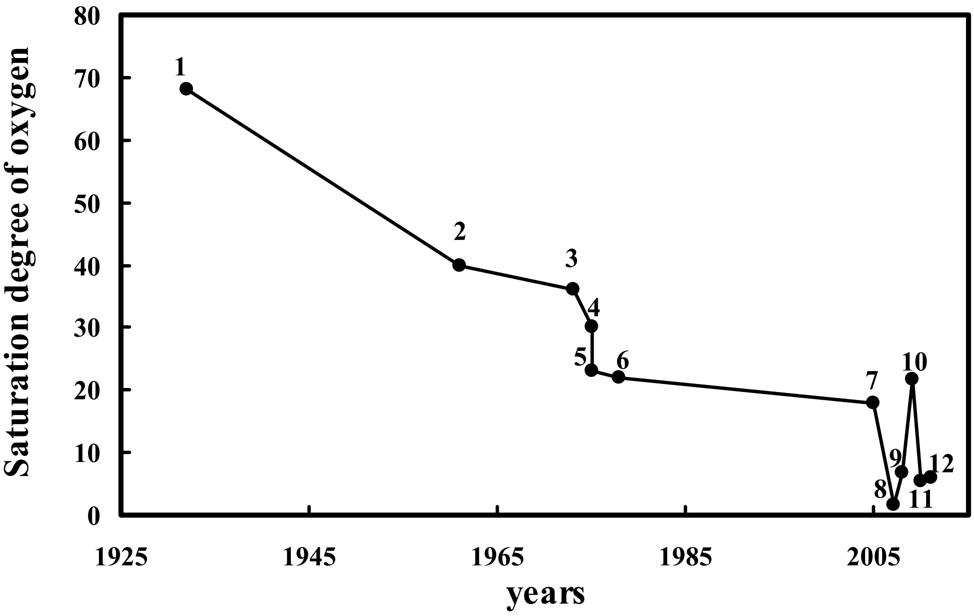


Figure 19. Minimal values of dissolved oxygen concentrations (saturation degree) observed in bottom waters of Amursky Bay in summer season by different investigators (**1** – Voronkov, 1941; **2** – Lastovetsky and Veshcheva, 1964; **3** – , **5** – Redkovskaya, 1980; **4** – Rodionov, 1984; **6** – Podorvanova et al., 1989; **7 – 12** – Hydrochemistry Laboratory of POI).

Figure 20. Trends of the water quality chemical parameters for some Russian rivers within NOWPAP area.

IV.8. Determine the eutrophication status of assessment category (I-IV) by setting assessment category classification criteria

Sub-area **A** (Amursky Bay) was most extensively studied in comparison with sub-areas **B** and **C**. Distributions of DIN, DIP, DISi, DO, Chlorophyll concentrations in surface and near bottom layers are given by Figs. 21 and 22. Red color means that nutrients concentrations exceed threshold values and dissolved oxygen concentrations less threshold value. We have to emphasize that waters which supply nutrients (river waters and waste waters) have lower density than surround seawater and should be revealed in distributions in the surface water. However it is actually observed for Razdolnaya River inputs only. Low concentrations of DIN (about 2 μM), DIP (about 0.1 μM) are observed in surface for most part of Sub-area **A**. Explanation of this feature is in there is biological pump which transforms nutrient concentration into biomass of diatoms. Part of diatoms is grazed by zooplankton. However “excessive” biomass of phytoplankton settles on the bottom. We suggested (Tishchenko et al., 2011) that phytoplankton bloom might be caused by enhanced supply of nutrients into the upper layer by increased discharge of the river on the short-time scale (Fig. 3). At high water phase of Razdolnaya River, its discharge approaches up to 1000 m^3/s at the summer time due to monsoon climate. Under these conditions river waters enriched by suspended matter and nutrients cover major part of the bay area (Fig. 23). Just after settling of suspended matter perfect conditions for phytoplankton bloom are occerred because of a strong stratification of water column, a nutrients enriched surface layer and almost absence of zooplanktons due to fast dynamics of processes. Therefore blooming phytoplankton dies and then sinks on the bottom in a large amount.

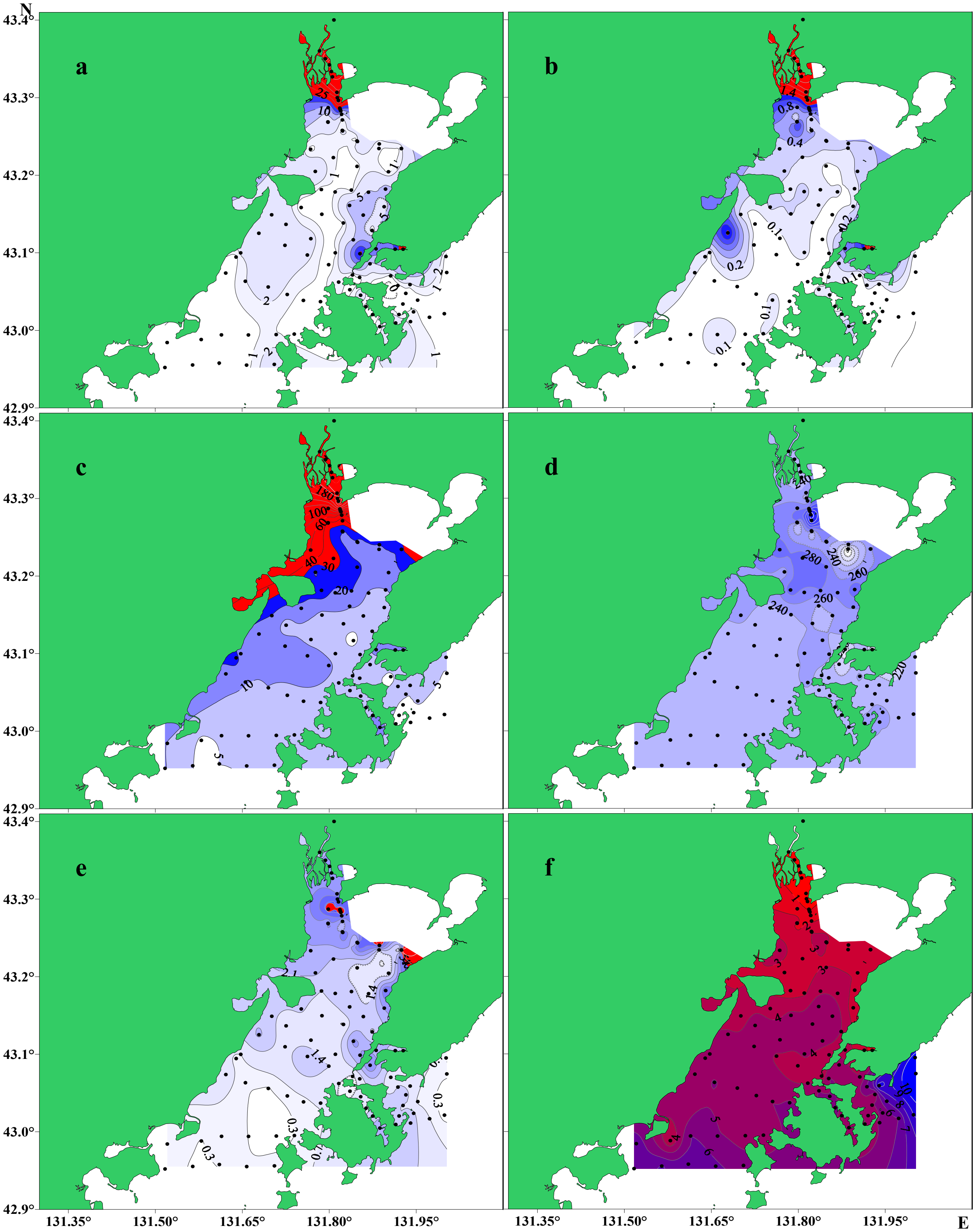


Figure 21. Distribution of **a** - DIN (μM), **b** – DIP (μM), **c** – DISi (μM), **d** – DO (μmol/kg), and **e** – chlorophyll a (μg/L) in surface layer of Amursky Bay. f – Depth of disk Secci (m). Data obtained at August 2007 on R/V "Malakhit". Red color means that nutrients concentrations exceed threshold values.

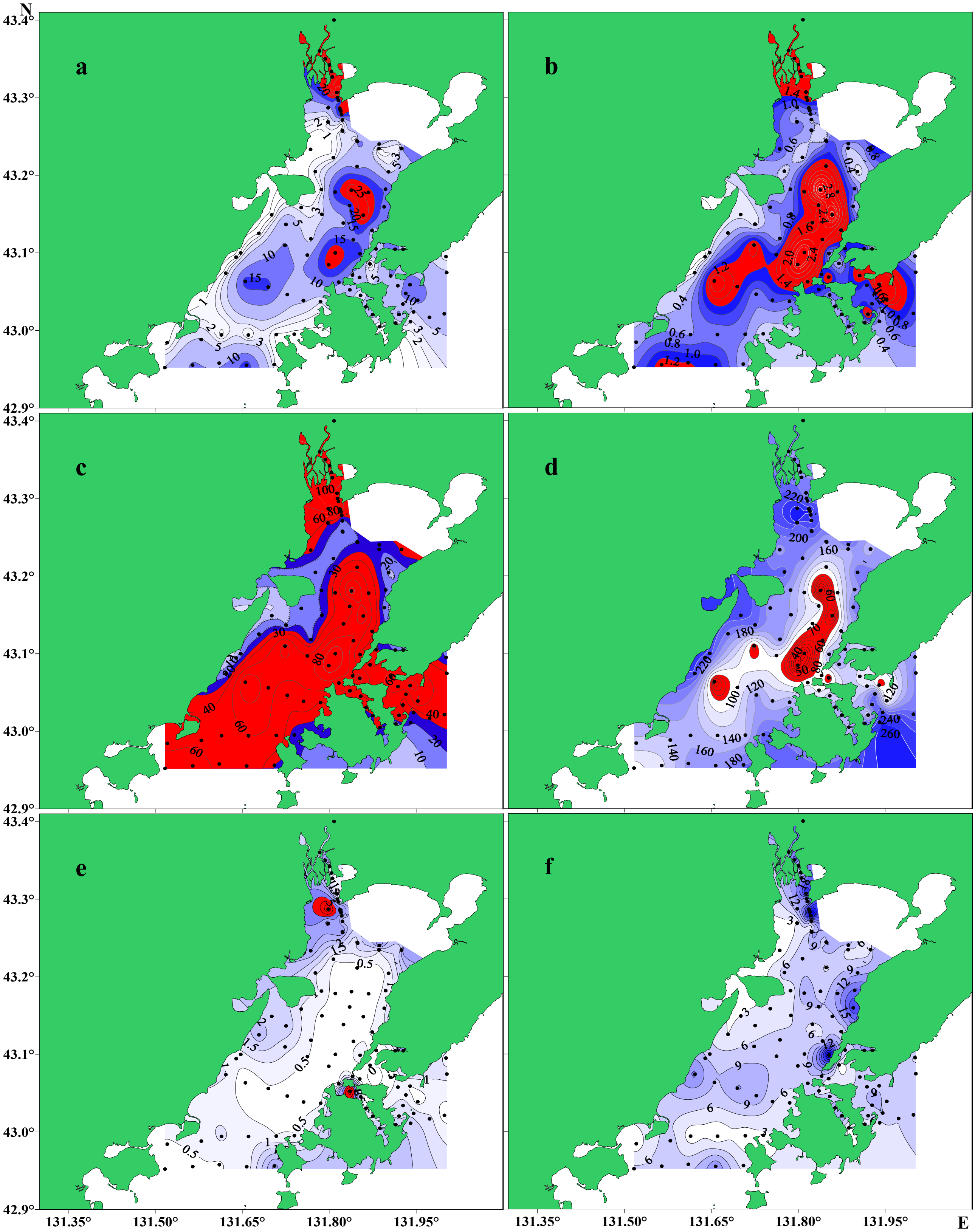


Figure 22. Distribution of **a** - DIN (μM), **b** – DIP (μM), **c** – DISi (μM), **d** – DO (μmol/kg), **e** – chlorophyll a (μg/L), f – atomic ratios of DIN/DIP in near bottom layer of Amursky Bay. Data obtained at August 2007 on R/V "Malakhit". Red color means that nutrients concentrations exceed threshold values and oxygen concentrations less threshold value.

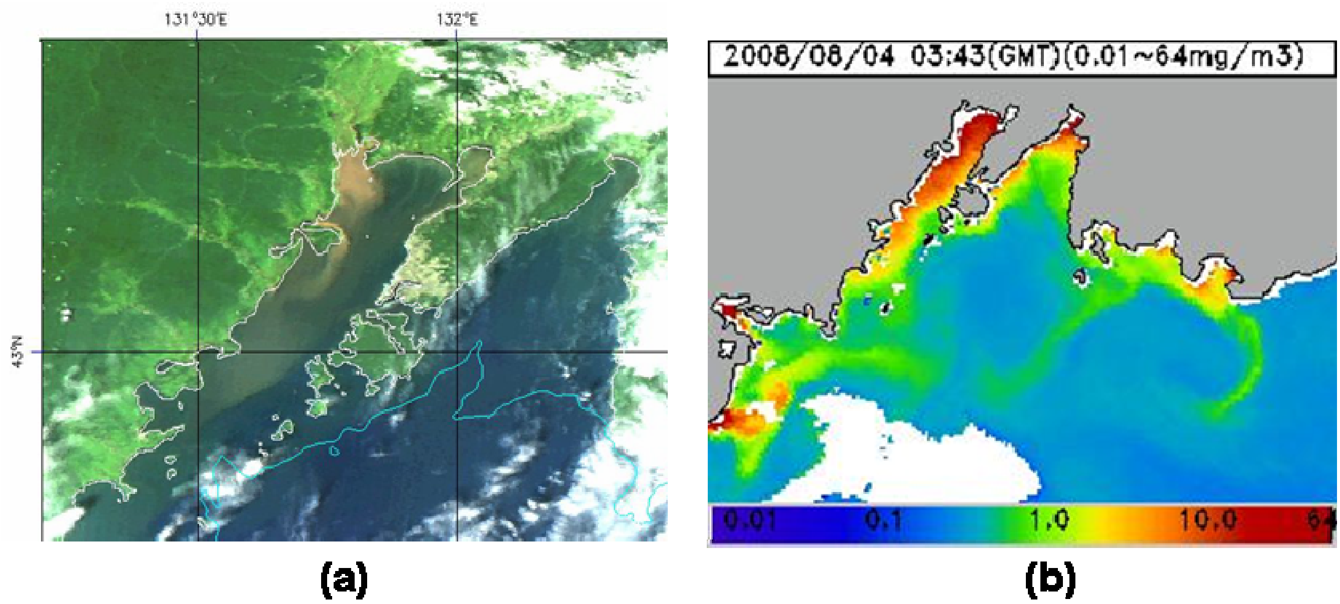


Figure 23. Ocean color satellite images from MODIS showing high content of suspended material from Razdolnaya River (a) and then high Chl-a concentration (b) in the Amursky Bay in Summer period.

Microbiological decay of died diatoms under conditions of light deficiency (at depth more than 15 m) intensively consumes dissolved oxygen and produces phosphates, ammonium, and silicates which we observed on Fig. 22. Direct observations on concentration cells of phytoplankton support that maximum number of bloom events corresponds to July and August months (Fig. 24). Seasonal distributions of DIN, DIP, DISi, DO, Chlorophyll are demonstrated by Figs. 19 – 23. Our data suggest that hypoxia has seasonal character with a peak in the end of summer. Upwelling in the beginning of fall season and its advection across the shelf is the main process which destroys the hypoxia. Ecosystem of Amursky Bay was completely recovered in winter because of intensive ventilation.

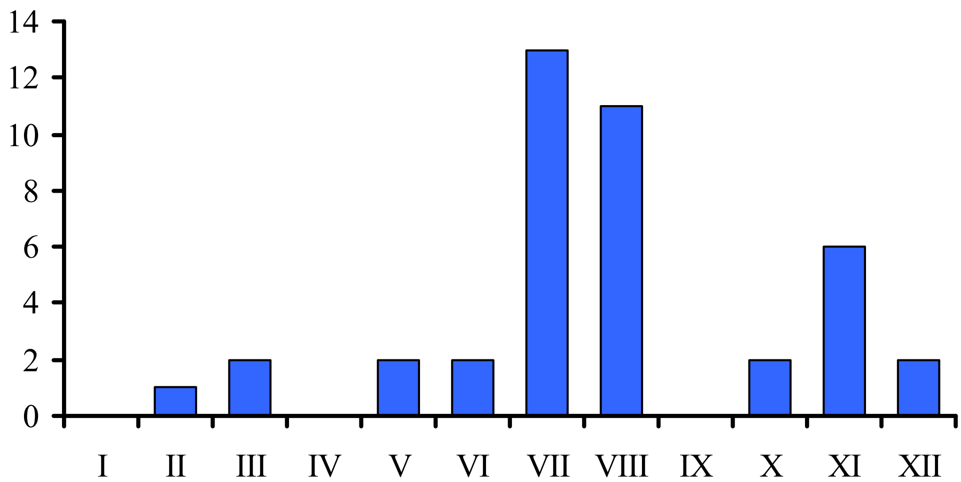


Figure 24. Number of bloom events by month in Amurskyi Bay (1991–2007). Source: Center of Monitoring of HABs & Biotoxins of the Institute of Marine Biology FEB RAS http://www.imb.dvo.ru/misc/toxicalgae/index.htm **(Tatiana ORLOVA, IMB, FEB RUS).**

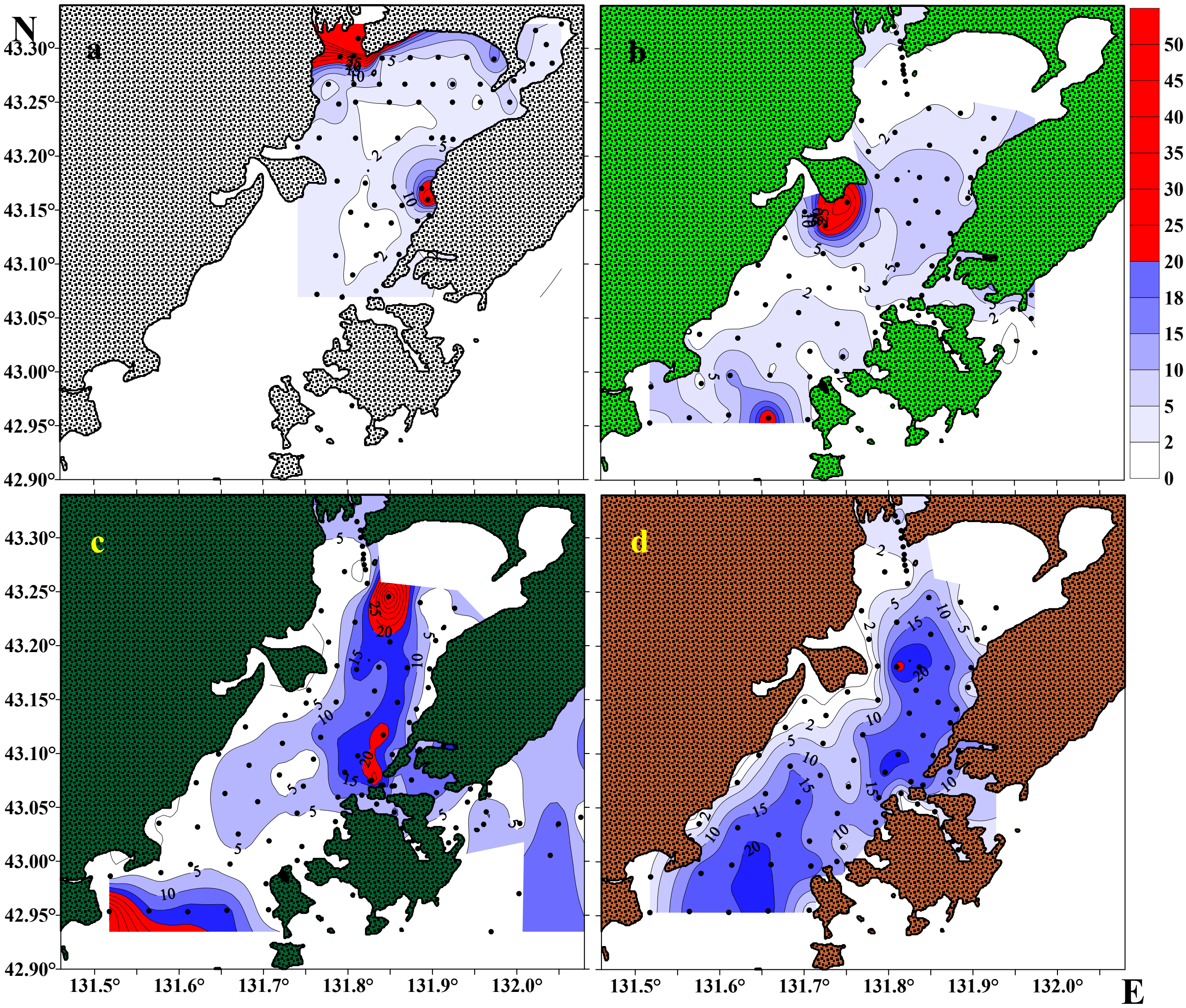


Figure 25. Seasonal distribution of DIN concentration (μM) in bottom waters of Amursky Bay. **a** – Winter, **b** – Spring, **c** – Summer, **d** – Autumn 2008. Red color means concentrations of DIN higher than threshold value.

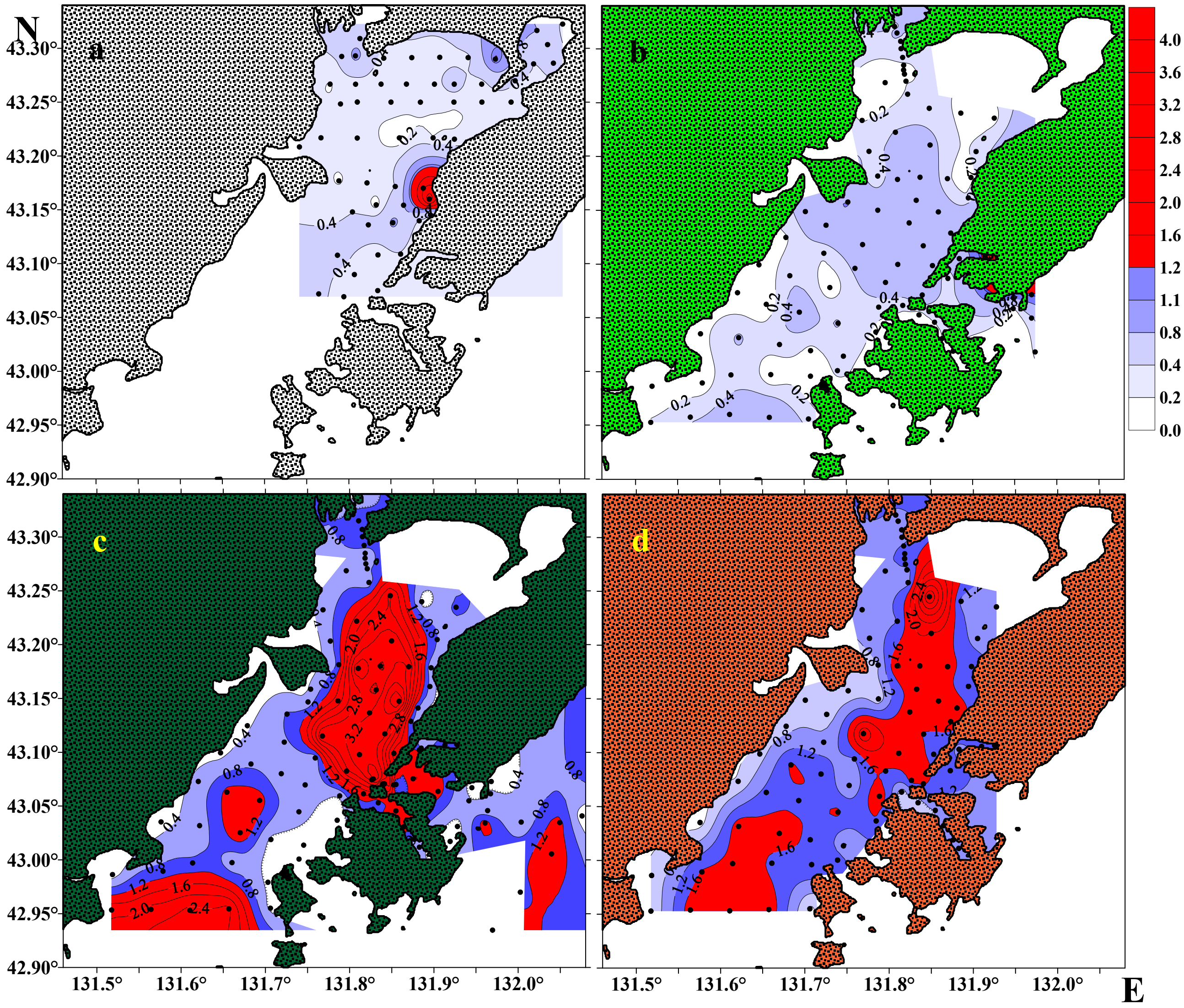


Figure 26. Seasonal distribution of DIP concentration (μM) in bottom waters of Amursky Bay. **a** – Winter, **b** – Spring, **c** – Summer, **d** – Autumn 2008. Red color means concentrations of DIP higher than threshold value.

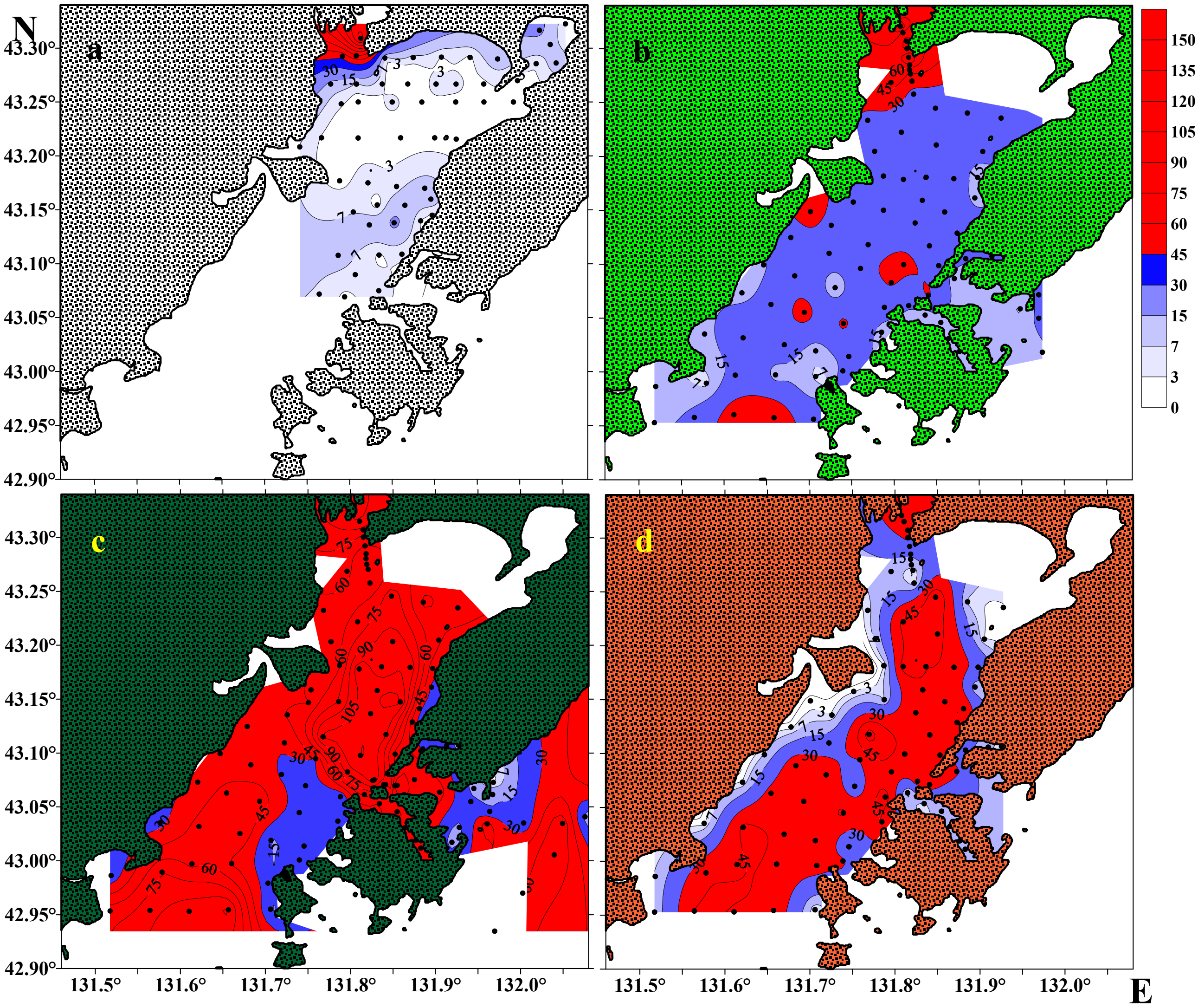


Figure 27. Seasonal distribution of DISi concentration (μM) in bottom waters of Amursky Bay. **a** – Winter, **b** – Spring, **c** – Summer, **d** – Autumn, 2008. Red color means concentrations of DISi higher than threshold value.

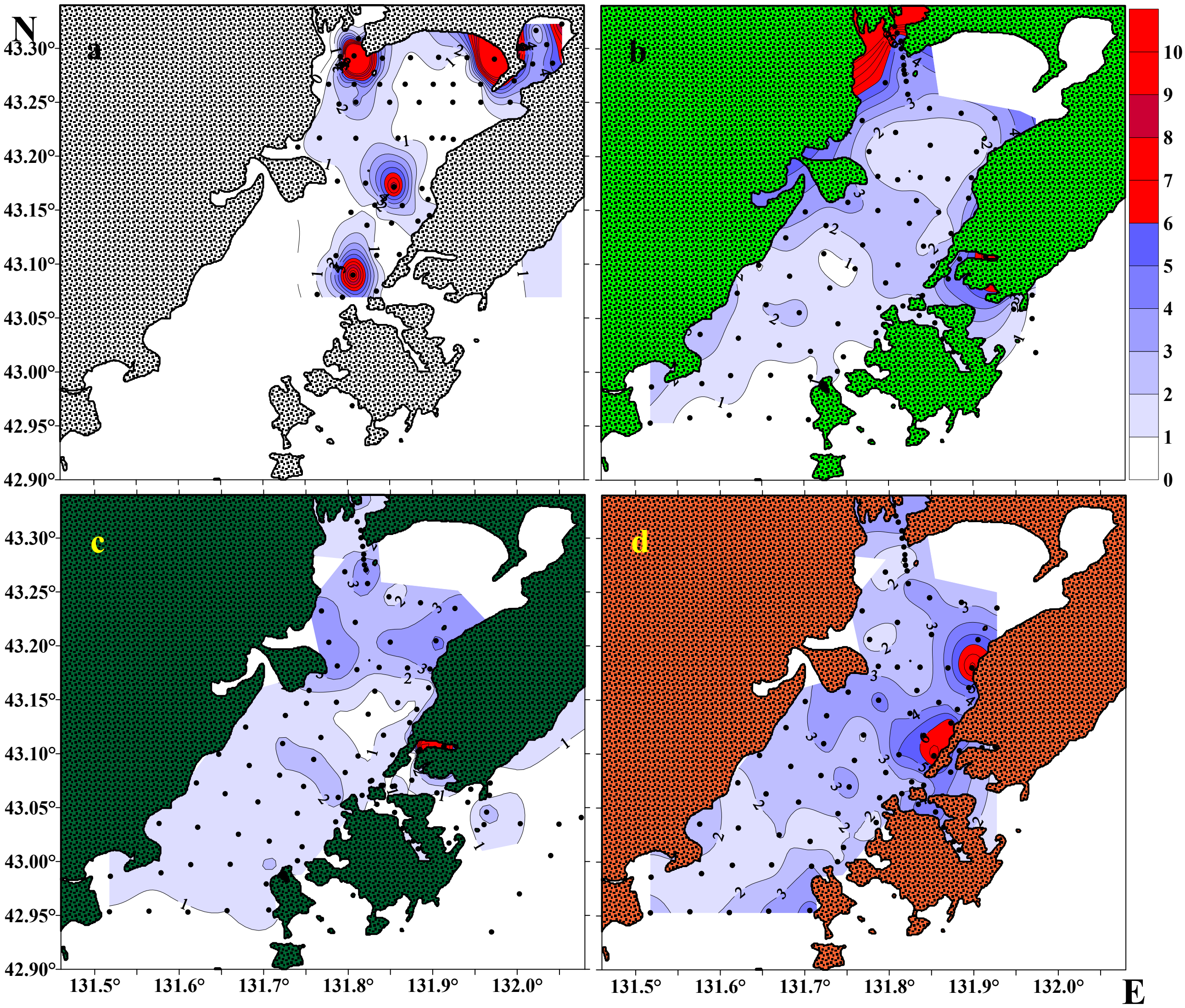


Figure 28. Seasonal distribution of Chlorophyll *a* concentration (mg/m^3) in bottom waters of Amursky Bay. **a** – Winter, **b** – Spring, **c** – Summer, **d** – Autumn, 2008. Red color means concentrations of DISi higher than threshold value.

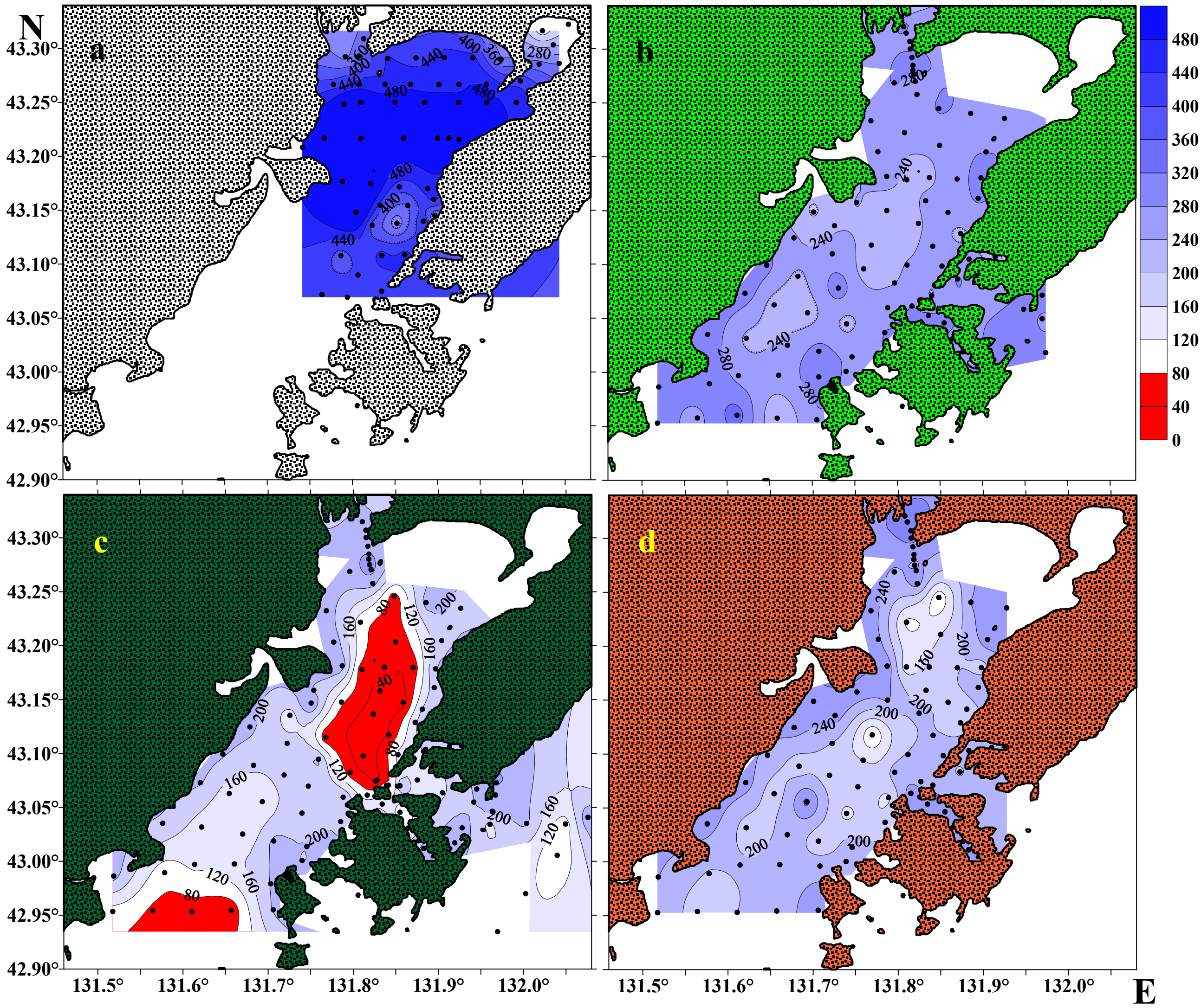


Figure 29. Seasonal distribution of dissolved oxygen concentration (μM) in bottom waters of Amursky Bay. **a** – Winter, **b** – Spring, **c** – Summer, **d** – Autumn, 2008. Red color means concentrations of DO less than threshold value.

Sub-area **B** (Ussuriisky Bay) was recently extensively studied (Semkin et al., 2011). Seasonal distributions nutrients, chlorophyll and dissolved oxygen concentration are presented for surface and bottom waters on Figs. 30-34. During winter season ice formation is occurred in Sub-area **B**. However, it does not form consolidated ice because basin is open and strong winds, intensive water exchange between the bay and the Sea are unfavorable conditions for forming of consolidated ice. Our data suggest that Ussuriisky Bay reveals highest productivity in winter season. Because highest chlorophyll concentration was 11 mg/m^3 which detected in winter (Fig. 33). Simultaneously Sub-area **A** and **B** are extensively studied at end February and September in 2010. In winter time ecological situation was very nice in both sub-areas. There are very low concentrations of DIN, DIP, DISi, and very high concentrations of DO (it was supersaturated regarding to atmosphere) for surface and bottom layers in winter season (Figs. 30-32, 34).

However, situation is quite different for both sub-areas at warm seasons. In contrast with Sub-area **A**, practically there is not any hypoxic region in Ussuriisky Bay, and region where concentrations of DIN exceed threshold values. There are large areas where concentrations DIP and DISi of bottom waters exceed threshold values for summer and autumn seasons (Figs. 31-g,h 32-g,h). Shapes of distributions of DIP and DISi in bottom layer are not coincided to those of oxygen concentrations. Probably high concentrations of nutrients in bottom layer are partly caused by upwelling of the intermediate waters of the Sea which contains high nutrient concentrations. However historical data documents that for summer time there are local sites with low oxygen concentration near bottom which is less than threshold value (Podorvanova et al., 1989). We carried out observations of hydrochemical parameters at August 31 in 2008, 2009. These results are presented on Fig. 35. This figure shows that DIP, and DISi exceed threshold values in bottom layer at 2008, 2009 years. However low DO concentrations in bottom layer are observed in 2008 only. Moreover, in 2009 DO concentrations in bottom layer were higher than ones in surface layer. We explain this finding that in 2009 survey was carried out just after upwelling. We suggest that water from Sub-area **C**, from deep about 100 m comes to Ussuriisky Bay. This water was enriched by oxygen and DIN. This result is very important because demonstrates another source of nutrients in enrichment of Sub-area **B**. This source is natural. It is deep water of Sub-area **C** and even deep water of Sea. Upwelling is mechanism which supplies nutrients on the shelf of Sub-area **B** and Sub-area **A** as well at autumn season. Main feature of Ussuriisky Bay is high dynamic circulations and water exchange between Ussuriisky Bay and open part of Peter the Great Bay. Winds play is a governing role in appearance of high dynamic waters of Ussuriisky Bay (Zuenko, 2008).

Sub-area **C** is open part of PGB. This Sub-area is less studied. Nevertheless, Tables 3 and 7 suggest that this Sub-area has minimal anthropogenic pressure in comparison with sub-areas **A** and **B**.

Table 8 summarizes spans of variations of assessment parameters for different Category. This Table shows variations of nutrients and DO concentrations are minimal for Sub-area **C**. This sub-area reveals maximal Secci disk depth. At present time, ecosystem behavior of most part of Sub-area **C** is close to natural character.

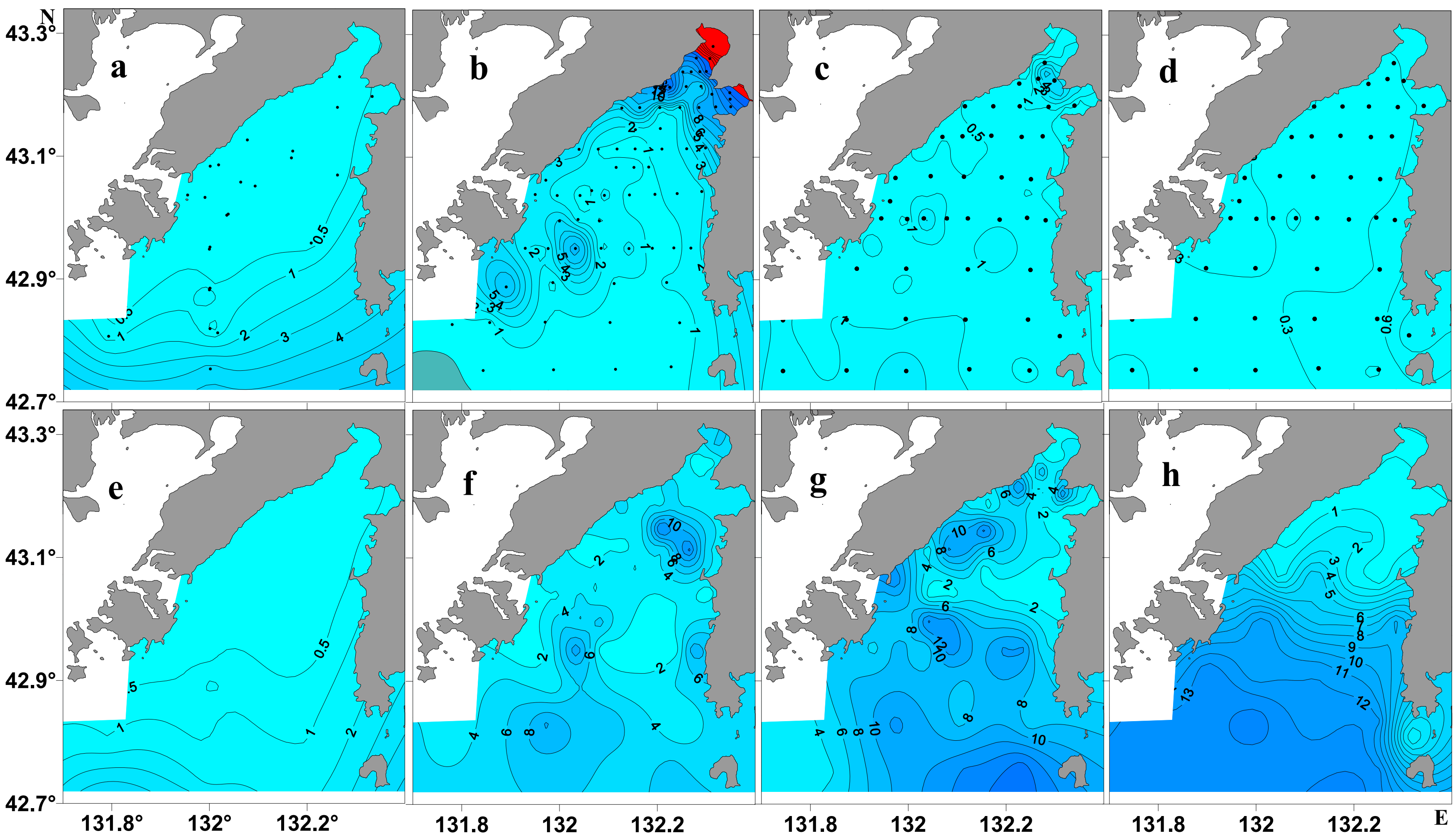


Fig. 30. Seasonal distributions of DIN concentration (μM) in the surface waters (upper penal) and bottom waters (bottom penal) of the Ussuriisky Bay. a, e – February, 2010; b, f – May, 2011; c, g – August, 2011; d, h – October, 2011.

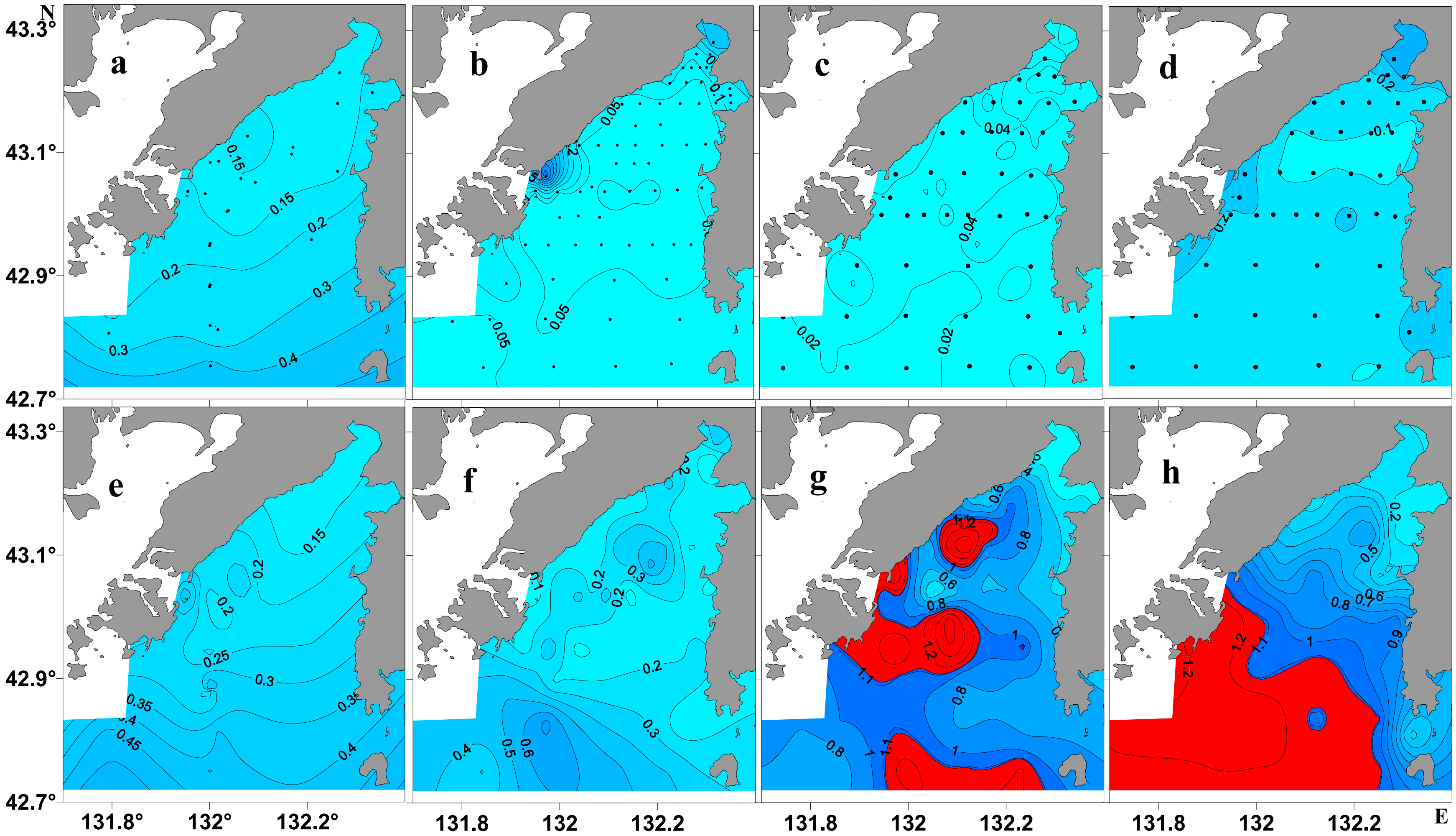


Fig. 31. Seasonal distributions of DIP concentration (µM) in the surface waters (upper penal) and bottom waters (bottom penal) of the Ussuriisky Bay. a, e – February, 2010; b, f – May, 2011; c, g – August, 2011; d, h – October, 2011.

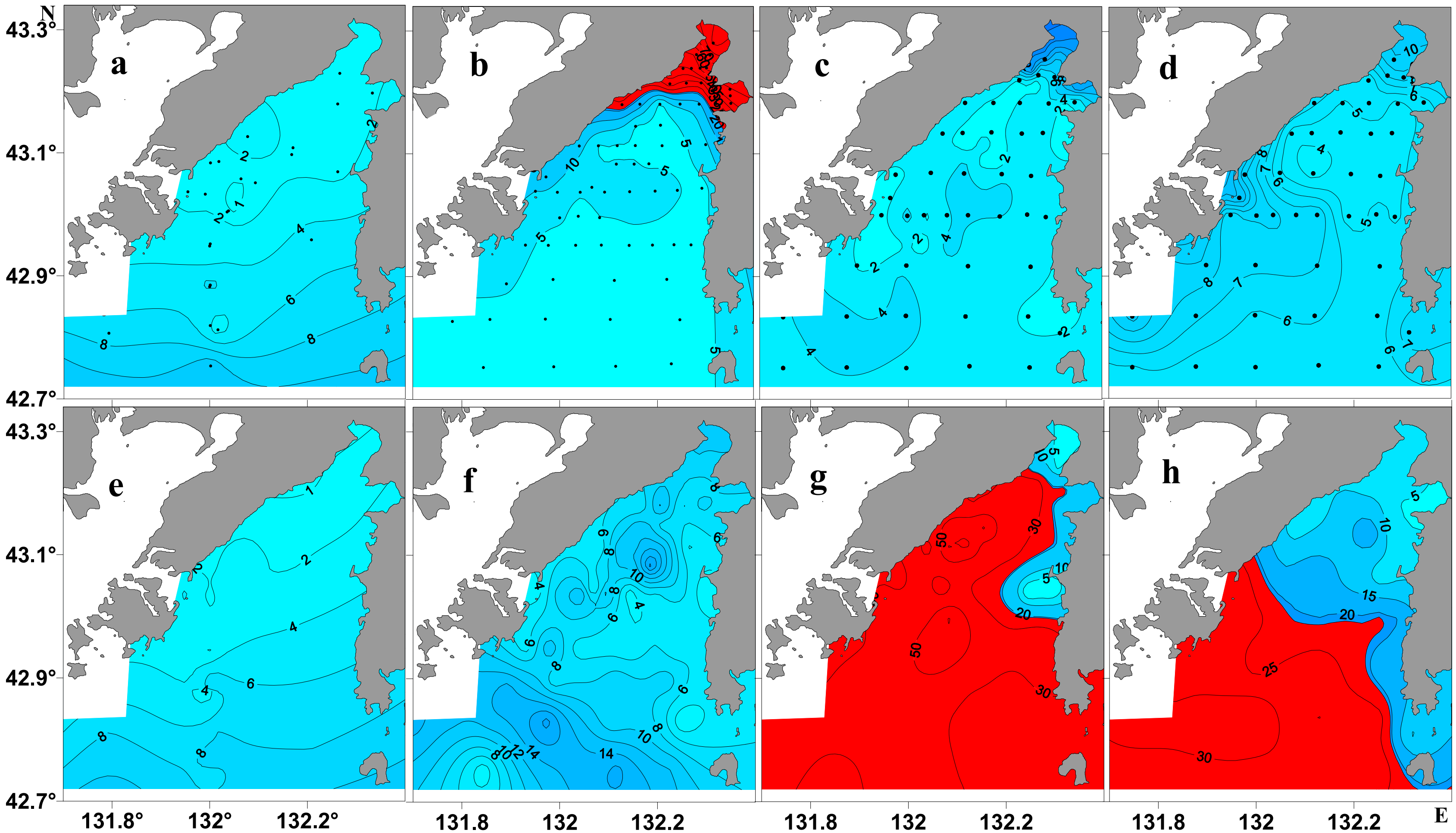


Fig. 32. Seasonal distributions of DISi concentration (μM) in the surface waters (upper penal) and bottom waters (bottom penal) of the Ussuriisky Bay. a, e – February, 2010; b, f – May, 2011; c, g – August, 2011; d, h – October, 2011.

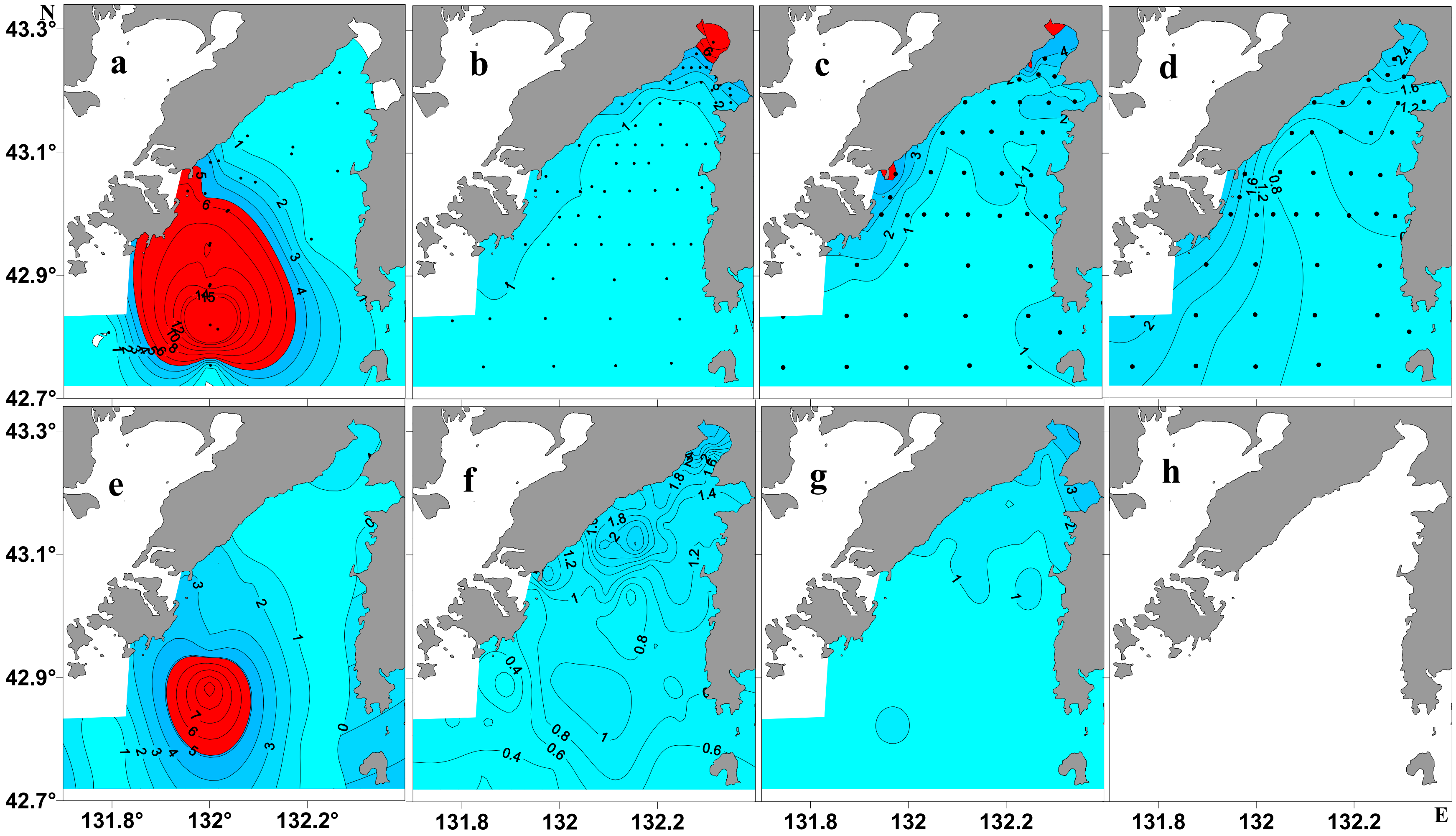


Fig. 33. Seasonal distributions of chlorophyll *a* concentration (mg/m^3) in the surface waters (upper penal) and bottom waters (bottom penal) of the Ussuriisky Bay. a, e – February, 2010; b, f – May, 2011; c, g – August, 2011; d, h – October, 2011.

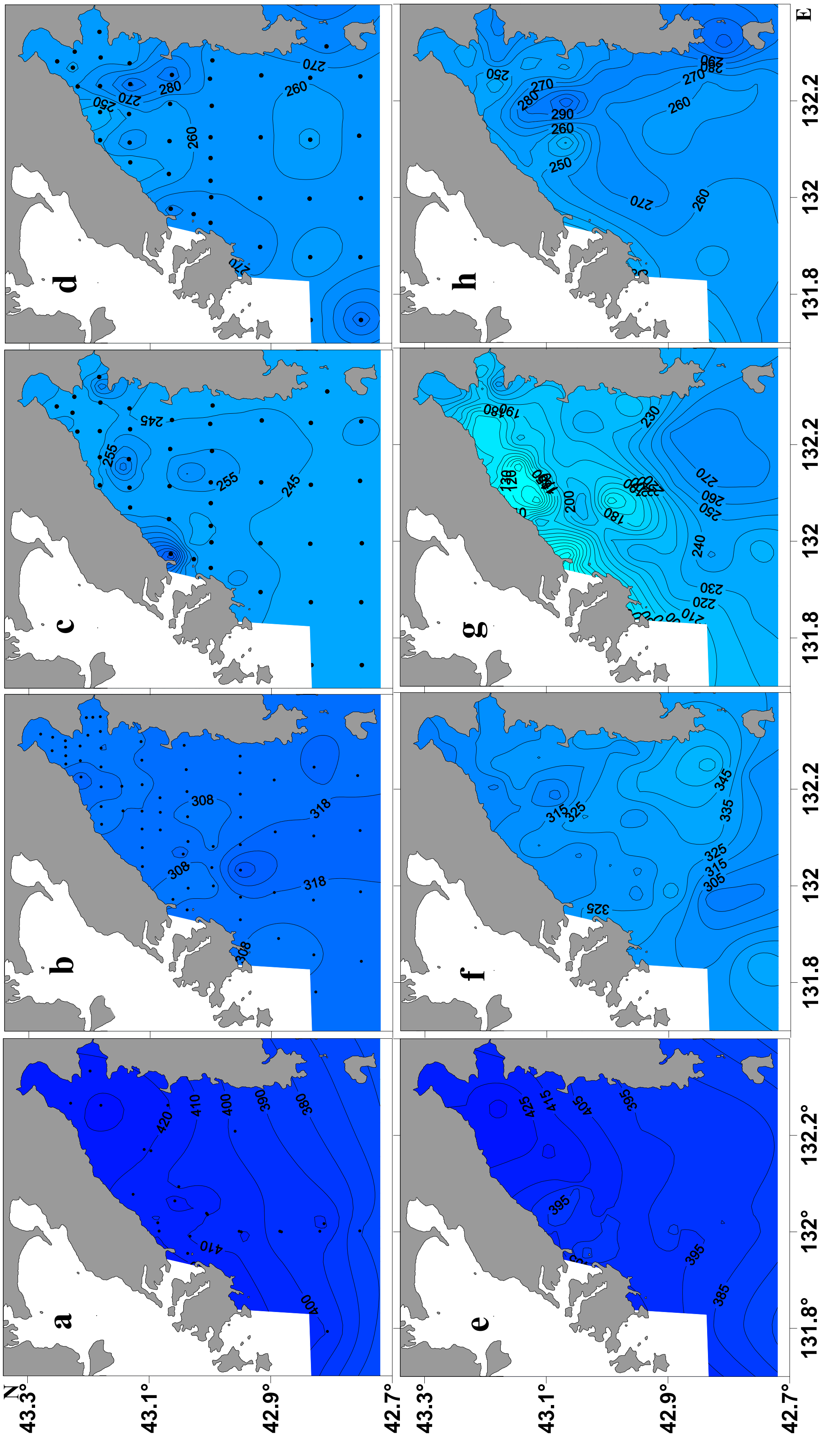


Fig. 34. Seasonal distributions of dissolved oxygen concentration (μM) in the surface waters (upper penal) and bottom waters (bottom penal) of the Ussuriisky Bay. a, e – February, 2010; b, f – May, 2011; c, g – August, 2011; d, h – October, 2011.

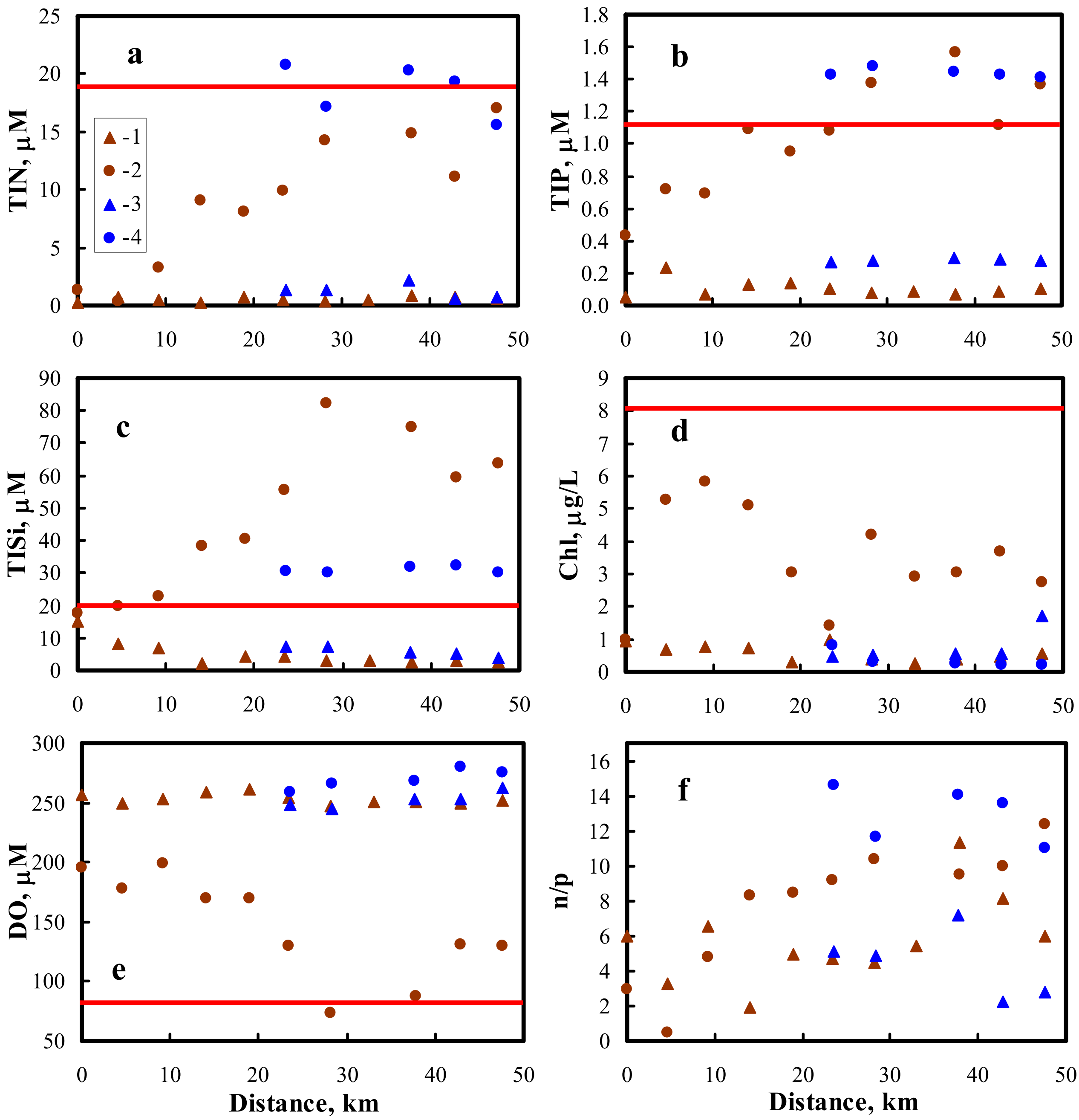


Figure 35. Distributions of a – DIN, b – DIP, c – DISi, d – Chlorophyll a content, e – DO, f – N:P ratios along longitudinal section. **1, 3** – surface horizon, **2, 4** – bottom horizon. Ussuriisky Bay. Red liens correspond threshold values of assessment parameters. 1, 2 – 31 August 2008; 3, 4 – 31 August 2009.

Table 8. Characteristics assessment parameters of different Categories for Sub-areas **A**, **B**, **C**.

Sub-area **A** Amursky Bay								
Category	Assesment parameter	Units	Sub-area **A**		Sub-area **B**		Sub-area **C**	
			TN	TP	TN	TP	TN	TP
I	Total load,	t/y	5350	590	2000	275	1250	200
	Winter, DIN, DIP	uM	4.9	0.4	0.45	0.25	7	0.25
	Winter ratio DIN/DIP	atomic	12.5		1.8		14	
II	Chlorophyll	Mg/m^3	min	max	min	max	min	max
			.02	26	0.2	11	0.05	11
	Red-tide	event	n/d		n/d		n/d	
III	DO bottom	uM	min	max	min	max	min	max
			4.7	600	55	450	240	450
	Fish kill	event	two		n/d		n/d	
	Transparancy	m	min	max	min	max	min	max
			0.5	8	5	20	10	20

IV.9. Results and discussion

IV.9.1 Eutrophication status of PGB. There are three types of nutrient sources for Peter the Great Bay: **a**) Local sources are wastewaters of Vladivostok, Ussuriisk, Nakhodka, Suyfunkhe. Obviously they are caused by urbanization of studied region. These sources have almost constant fluxes during year. **b**) Diffusive sources are agriculture fields, atmospheric precipitations. Nutrients from these sources are loaded into PGB by rivers, coastal runoff and atmospheric precipitation. Fluxes of these sources have distinct seasonal variability due to seasonal atmospheric precipitation. **c**) Deep or/and intermediate waters of the Sea which contain high concentration of nutrients is natural source of nutrients. Fluxes from this source are determined by frequency and intensity of cross-shelf water exchange between deep/intermediate water of the Sea and waters of the PGB. We quantify only two types of nutrient sources (**a**, **b**), which enhance eutrophication of PGB. These types of nutrient sources (wastewaters, river runoff) are associated with fresh water. Therefore we expect high nutrient concentrations in surface layer of PGB. However, high nutrient concentrations are observed in bottom layer (Figs. 5, 22, 25, 26, 27). Explanation of this feature is existence of biological pump which transforms inorganic nutrients into biomass of phytoplankton. Then, “excess” of phytoplankton dies, settles on the bottom and decays releasing inorganic nutrients and consuming dissolved oxygen (Tishchenko et al., 2011a). Therefore high concentrations of nutrients exceeded threshold values are observed in near bottom layer where deficit of light is occurred. Also it is should be noted that maximal square with nutrients concentrations exceeded threshold values correspond DISi. There are two reasons which explain this feature. One is denitrification on interface seawater/sediments:

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + \frac{7314}{63}\cdot O_2 + \frac{97}{63}\cdot H^+ \rightarrow$$
$$106\cdot CO_2 + \frac{160}{63}\cdot NH_4^+ + \frac{424}{63}\cdot N_2 + \frac{7950}{63}\cdot H_2O + H_2PO_4^- . \quad (4)$$

Reaction (4) is result of two consequence microbiological processes:

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138\cdot O_2 \rightarrow$$
$$106\cdot CO_2 + 122\cdot H_2O + 16\cdot HNO_3 + H_3PO_4 . \quad (5)$$

and

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 84.8NO_3^- + 99.8H^+ \rightarrow$$
$$106CO_2 + 148.4H_2O + 16NH_4^+ + 42.4N_2 + H_2PO_4^- . \quad (6)$$

In Eqs. (4) – (6) Redfield stoichiometric ratios were used in “formula” of organic matter. Evidences that mass-balance of mineralization of organic matter corresponding scheme (4) are given in (Tishchenko et al., 2011b). Additional argue is Fig. 22f which demonstrates low DIN:DIP ratios. Actually they are ranged between 6 – 10 for most part of Sub-area **A**. Second reason is that DIP is involved into recycling.

According to Table 7 Sub-area **A** is subjected maximal annual loads of nutrients. Especially, significance difference between Sub-areas reveals via comparison of nutrients loads per square. Annual loads per square into Amursky Bay are higher in 3 – 5 times than ones into Ussuriisky Bay and more than ten times higher in comparison with Sub-area - **C**. Thus, high nutrient enrichment of Amursky Bay results in seasonal hypoxia which recently discovered (Tishchenko et al., 2008; Tishchenko et al., 2011a). **Using hydrochemical data (nutrient concentrations, chlorophyll and DO contents) we can to conclude that Sub-area A (Amursky Bay) has high eutrophication status.** Similar conclusion was made before using phytoplankton data as indicator of assessment of the trophic state of Amursky Bay (Stonik, Selna, 1995).

As mention above, nutrients loads per square into Sub-area **B** are significantly less. We believe that main source of nutrients for sub-area **B** is deep/intermediate waters of the Sea which comes on the shelf during upwelling (type **c** of source). There are different mechanisms of upwelling which are poorly understood and they are extensively discussed somewhere (Zuenko, 2008). At present time we have no approach to quantify type **c** of nutrient source. Nevertheless, using assessment criteria and parameters of category 1 (nutrient concentrations) and 2, 3 (chlorophyll and DO) we obtained results (Table 7 and Figs. 30 - 35) which **permits to make conclusion that eutrophication status of sub-area B can be considered as “Low”.**

Sub-area **C** is highly dynamic area. Again, main nutrient source for this sub-area is deep water of the Sea which quantification is beyond of the report. Our scarce data about Sub-area **C** which summarized in Tables 7 and 8 say that **Sub-area C has low eutrophication status** as well.

Hydrochemical data (Figs. 4, 5), and biological investigations (Silina, Ovsyannoikova, 1995; Levenets, Skriptsova, 2008; Moshchenko, Belan, 2008) strongly suggest that trend of increasing eutrophication is occurred in sub-area **A**. We did not find any data which may clearly suggest about any trend of eutrophication in Sub-areas **B** and **C**.

IV.9.2 Final eutrophication status of PGB. **Final identification of eutrophication status in PGB is summarized in Table 9.** Another words: a) Sub-area **A has High eutrophic status** and **positive trend toward eutrophication**; b) Sub-area **B** has a **Low** eutrophication status due to specific natural conditions (natural eutrophication caused upwelling) with non-detectable trend; c) Sub-area **C** has **low** eutrophication status with non-detectable trend.

Table 9A. Identification of eutrophication status in Peter the Great Bay for Sub-area **A**.

Cate-gory	Assessment parameter	Assessment value	Identification tools				Parameter Identification	Remarks
			Value [*)]S/B	Comp a-rison	Occur-rence	Trend		
I	Riverine input DIN, t/y	Annual mean	1800	H	-	I	HI	
	Riverine input DIP, t/y	Annual mean	120	H	-	I	HI	
	DIN, µM	Annual mean	5.9 12.6	H	-	I	HI	
	DIP, µM	Annual mean	0.3 0.96	H	-	I	HI	
	DISi, µM	Annual mean	16 36	H	-	I	HI	
	N/P	Annual mean	7.4 7.2					
II	Chlorophyll a, µg/l	Annual mean Annual max	1.9 30	L H	- -	I N	LI HN	
III	DO concentration, µM	Annual mean Annual min	310 250 5	H H	- -	D N	HD HN	
IV	Zoo-Phytobentos							
	Kill fishes				L	N	LN	

[*)]S/B means corresponding concentrations of substance in Surface and Bottom horizons less than 50 m.

Table 9B. Identification of eutrophication status in Peter the Great Bay for Sub-area **B**.

Cate-gory	Assessment parameter	Assessment value	Identification tools				Parameter identification	Remarks
			Value *S/B	Comp a-rison	Occur-rence	Trend		
I	Riverine input DIN, t/y	Annual mean	180	L	-	N	LN	
	Riverine input DIP, t/y	Annual mean	25	L	-	N	LN	
	DIN, µM	Annual mean	2.2 10	L	-	N	LN	
	DIP, µM	Annual mean	0.2 0.86	L	-	N	LN	
	DISi, µM	Annual mean	6.3 25	L	-	N	LN	
	N/P	Annual mean	1-15 1-12					
II	Chlorophyll a, µg/l	Annual mean Annual max	1.9 6	L L	-	N N	LN LN	
III	DO concentration, µM	Annual mean Annual min	310 270 70	L H	- -	N N	LN HN	
IV	Zoo-Phytobentos							
	Kill fishes				**N/D			

*) S/B means corresponding concentrations of substance in Surface and Bottom horizons less than 50 m.

**) N/D means No Data

Table 9C. Identification of eutrophication status in Peter the Great Bay for Sub-area **C**.

Cate-gory	Assessment parameter	Assessment value	Identification tools				Parameter identification	Remarks
			Value *S/B	Compa-rison	Occur-rence	Trend		
I	Riverine input DIN, t/y	Annual mean	250	L		N	LN	
	Riverine input DIP, t/y	Annual mean	11	L		N	LN	
	DIN, µM	Annual mean	1.7 8	L		N	LN	
	DIP, µM	Annual mean	0.3 0.8	L		N	LN	
	DISi concen-tration, µM	Annual mean	7 21	L		N	LN	
	N/P	Annual mean						
II	Chlorophyll a.	Annual mean	0.86	L		N	LN	
		Annual max	11	H		N	HN	
III	DO concentration, µM	Annual mean	312 293	L	-	N	LN	
		Annual min	185	L		N	LN	
IV	Zoo-Phytobentos							
	Kill fishes				**N/D			

*)S/B means corresponding concentrations of substance in Surface and Bottom horizons less than 50 m.

**)N/D means No Data

V. Macroscopic view on eutrophication status of PGB

We include this short chapter because fully agree with S.W. Nixon which states "Seeing eutrophication in the macroscopic view is important for understanding and managing the phenomenon." (Nixon, 2006). Obviously, eutrophic status of ecosystems of Sub-areas **B**, and **C** directly depends from eutrophic status of the open sea area. This area is intensively studied during many decades by many scientists. It was clearly established that this Sea reveals temporal variations in oxygen content in deep waters. T. Gamo with colleagues was first, who found temporal variability (decline oxygen concentration of deep water) (Gamo et al., 1986). Trend of oxygen decreasing of deep water is still continue and some authors supposed that this Sea will become anoxic in 2200 (Chen et al., 1996). Many researches explained the decreasing of oxygen concentration by stagnation of deep waters (no ventilations and renewal) (Gamo et al., 1986; Chen et al, 1996; Kim and Kim, 1996). However stagnation process should be result in vertical redistribution of hydrochemical parameters. Actually, below 100 m oxygen content reduces, nutrients (phosphates, nitrate) and NDIC contents increase with time (Fig, 36, Tishchenko et al., 2002). Tishchenko and coauthors (2002) explained theses temporal variability of observed hydrochemical parameters by eutrophication of this Sea. Main considered causes are eutrophication of East China Sea (Chen, 2000) and existent of system of surface currents.

The driving forces on the global scale include human population growth (mostly around the East China Sea), increased anthropogenic emission of reactive nitrogen species to the atmosphere (mostly through agriculture, the increase in automobile use, oil exploration, and deforestation), increased atmospheric CO_2 (global acidification), and climate change (Duarte, 2009). It is well documented that the exponential increasing of fossil fuel combustion, production of N-fixing crops, and the industrial production of fertilizers corresponds to periods of exponential spreading of coastal eutrophication (Boesch, 2002; Rabalais et al., 2010; Zhang et al., 2010; Kim et al., 2011). There is a period between 1960s–1980s , in which Amursky Bay became hypoxic during the summer, most likely originating in the 1970s (Fig. 19). This could be the result of global processes. Obviously, the natural drivers have been active in the area over many years. However, analysis of available published data and our observations suggests that a negative tendency in DO content of the bottom water of Amursky Bay has started only in the second half of the last century. This could be explained by an increasing role of non-local sources of nutrients over time. This is in agreement with the conclusion of Rabalais et al. (2009), that eutrophication of coastal waters by non-local sources of nutrients is a part of global change. Lack of efficient management of non-local nutrient loading is a global social problem at the present time.

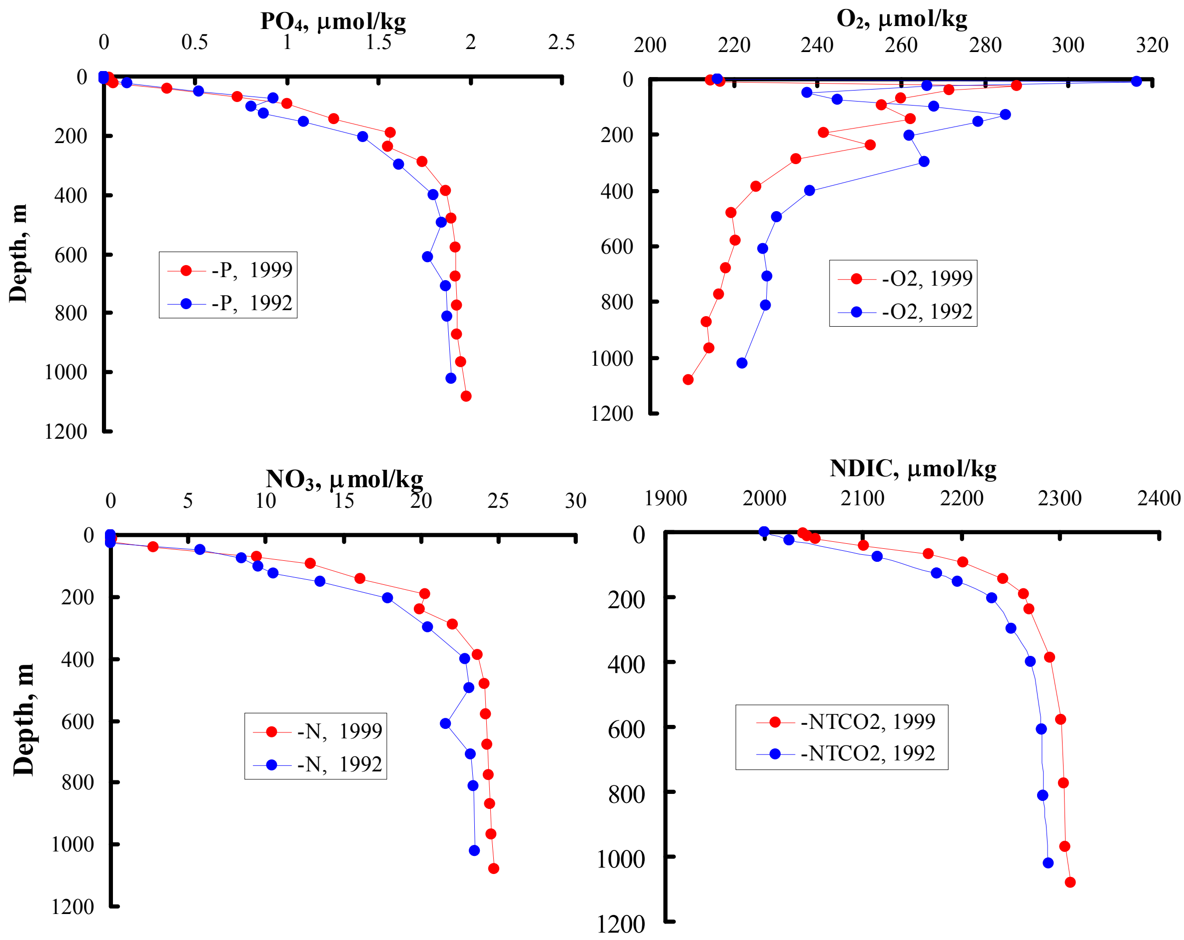


Figure 36. Temporal variability of nutrients (phosphates, nitrate), DO, and normalized dissolved inorganic carbon (NDIC) in NOWPAP Sea from data of station 177 (φ=40.16°N, λ=134.00 °E, 1999) and HS-11j (φ=40.12°N, λ=133.98 °E, 1992) [46].

VI Conclusion and recommendation

Within "narrow view", on the basis of distributions of assessment parameters and literature data about biological changes, we make conclusions as follows:

a. Northwestern part of Peter the Great Bay (Sub-area **A**, Amursky Bay) has current eutrophication status as "**High**" and "**Increase**";

b. Most part of Sub-area B can has eutrophication status as a "Low" with non-detectable trend;

c. At present time, most part of sub-area **C** has a "Low" eutrophication status with non-detectable trend.

2. Within "macroscope view" PGB is undergoing by eutrophication as part NOWPAP Region.

Recommendations

1. To provide monitoring assessment parameters in sites where hypoxia was observed.
2. To provide monitoring assessment parameters estuarine parts of sub-areas **B** and **C** because they are still terra incognito at present time.
3. To build treatment facilities for sewage of the city which are important part of nutrients loads into Sub-area **A**.
4. To form artificial downwelling/upwelling system [48] in hypoxia sites which will increase carrying capacity of ecosystem of Sub-area **A** (Pshenichny, Shevchenko, 1989).

VII. List of Acronyms

BOD	Biological oxygen demand
CEARAC	Coastal Environment Assessment Regional Activity Center
COD	Chemical oxygen demand
DIN	Dissolved inorganic nitrogen (active forms: $NH_4^+ + NO_2^- + NO_3^-$)
DIP	Dissolved inorganic phosphates
DISi	Dissolved inorganic silicates
DO	Dissolved oxygen
LOICZ	Land Ocean Interaction Coastal Zone
NDIC	Normalized Dissolved Inorganic Carbon
NOWPAP	Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Northwest Pacific Region
PGB	Peter the Great Bay
PGI	Pacific Geographical Institute, Russian Federation
POI	Pacific Oceanographic Institute, Russian Federation
POMRAC	Pollution Monitoring Regional Activity Center
SS	Suspended Solids
TN	Total Nitrogen
TP	Total Phosphorou

VIII. References

Andersen J.H., Schlüter L., and Ærtebjerg G. (2006) Coastal eutrophication: recent developments in definitions and implications for monitoring strategies. J. Plankton Research, 28, 621-628.

Anikiev V.V. (1987) Short-scale of geochemical processes and pollution of ocean. Moscow. Nauka. 192 p.

Belan T.A. (2003) Benthos abundance pattern and species composition in conditions of pollution in Amursky Bay (Peter the Great Bay, Sea of Japan). Marine Pollution Bulletin, 46, 1111–1119.

Belan, T.A., Tkalin A.V., Lishavskaya T.S. (2003) The present status of bottom ecosystems of Peter the Great Bay (the Sea of Japan). Pacific Oceanography, 1, 158–167.

Belan T.A., Moshchenko A.V. (2005) Polychaete taxocenes variability associated with sediment pollutionloading in the Peter the Great Bay (East Sea/Japan Sea). Ocean Science Journal, 40, 1-10.

Belan T.A., Belan L.S. (2006) Composition and Quantitative Distribution of Macrozoobenthos in Amursky Bay. Okeanology, 46, 685-694. (Rus.).

Boesch, D. Challenges and opportunities for science in reducing nutrient over-enrichment of coastal ecosystems // Estuaries, 2002. V. 25, 886-900.

Boyarova M.D., Lukyanova O.N. (2012) Persistent organochlorine pesticides in bivalve mollusks and fish from Peter the Great Bay, pp 334-345. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).

Breitburg, D.L., D.W. Hondorp, L.A. Davias, R.J. Diaz. Hypoxia, nitrogen, and fisheries: Integrating effects across local and global landscapes // Annual Review of Marine Science, 2009, V. 1, p.329 – 349.

Brzezinski M. The Si:C:N ratio of marine diatoms: Interspecific variability and the effect of some environmental variables // J. Phycol., 1985, V.21, p. 347-357.

Carpenter J.H. The Chesapeake Bay Institute technique for the Winkler dissolved oxygen method// Limnol.Oceanogr., 1965, V.10, p.141-143.

CEARAC 2011. Integrated report on eutrophication assessment in selected sea area in the NOWPAP region: evaluation of the NOWPAP Common Procedure. 28, 2011, pp 111. ISBN 978-4-9902809-5-6.

De Jong F. Marine eutrophication in perspective. On the relevance of ecology for environmental policy. Berlin, Heidelberg, New York: Springer, 2006. 335 p.

Diaz R.J. Overview of hypoxia around the World // J. Environ. Qual., 2001, V. 30, p. 275-281.

Diaz R.J., Rosenberg R. Spreading Dead Zones and Consequences for Marine Ecosystems // Science, 2008, V.321, p.926-929.

Duarte C. M. Coastal eutrophication research: a new awareness // Hydrobiologia, 2009. V.629, p.263-269.

Duarte C.M., Conley D.J., Carstensen J., Sanchez-Camacho M. Return to Neverland: Shifting baselines affect eutrophication restoration targets // Estuaries and Coasts, 2009, V.32, p.29-36.

Chen, C.T.A. The Three Gorges Dam: Reducing the Upwelling and Thus Productivity in the East China Sea // Geophys. Res. Lett., 2000, V. 27, p. 381–383.

Chen C.T.A., Bychkov A.S., Wang S.L., Pavlova G.Yu. An anoxic Sea of Japan by the year 2200? // Marine Chem., 1999, V. 67, p. 249–265.

Dolganova N.T. (2005) Plankton researches in TINRO: history, directions, results. Izv. TINRO, 141, 209–228.

Ecological normalization and management of coastal aquatic area of Primorye (2000). Report of Pacific Oceanological Institute (POI FEB RAS), No 01.20.00 06073. Vladivostok, pp 28.

Henze M. (2006) Wastwater, Volumes and Composition. pp. 25-59. Wastewater Treatment. Biological and Chemical Processes. Ed. Mogens Henze. Politeknisk Forlag. (Rus. Moscow, "Mir").

Hutchinson G.E. Eutrophication, past and present // Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences. Washington DC, 1969, P.17-26.

Galysheva Yu. A. (2009) Biological Consequences of Organic Pollution of Nearshore Marine Ecosystems in the Russian Waters of the Sea of Japan. Russian Journal of Marine Biology, 35, 521–534.

Gavrilevsky A. V., Gavrilova T. A., Kochergin I. E. (1998) Complex Quantitative Assessment of the Sources Polluting the Sea Adjacent to Vladivostok. pp 102-113. FERHRI Proceedings, Special Issue (Rus.).

Gamo, T., Nozaki, Y., Sakai, H., *et al.*, Spatial and Temporal Variations of Water Characteristics in the Japan Sea Bottom Layer, J. Mar. Res., 1986, vol. 44, p. 781–793.

Gomoyunov K.A. (1927) Hydrological essay of Amursky Bay and Suyphun River. I conference: Production power of Far East. Vladivostok: 2, 73-91. (Rus.).

Karydis M. Eutrophication assessment of coastal waters based on indicators: A literature review // Global NEST J. 2009, V. 11, N.4, p.373-390.

Khen G.V., Moroz I.F. (2005) Oceanographic studies in TINRO-Center. Izv. TINRO, 141, 297-324.

Khristoforova N.K., Shulkin V.M.,Kavun V.I. and Chernova F.M. (1993) Heavy metals in commercial and cultured mollusks of Peter the Great Bay. Vladivostok: Dalnauka, pp 296. (Rus.).

Khristoforova N.K. (2012) Peter the Great Bay: natural environment and biodiversity, 12-30. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).

Kim T.-W., Lee K, Najjar R.G., Jeong H.-D., Jeong H.-J. Increasing N Abundance in the Northwestern Pacific Ocean Due to Atmospheric Nitrogen Deposition // Science, 2011. V. 334, 505-509.

Kim, K.-R. and Kim, K. What Is Happening in the East Sea (Japan Sea)?: Recent Chemical Observations during CREAMS'93–96 // J. Kor. Soc. Oceanogr., 1996, V. 31, p. 164–172.

Klimova V.L. (1971) Quantitative distribution of benthos in Peter the Great Bay (Sea of Japan) in summer of 1970. Proceedings VNIRO, 87, 97-103.

Klimova V.L. (1976) Variation of distribution of benthic trophic zones in Peter the Great Bay from 1930s to the 1970s. Oceanology, 16, 343-345.

Koblenz-Mishke O.I. Extraction and non-extraction methods in determination of photosynthetic pigments // Modern methods of quantify marine phytoplankton. Nauka: Moscow, 1983, p. 114 – 125.

Konovalova G.V., Orlova T.Yu., Pautova L.A. (1989) Atlas of phytoplankton of the Japan Sea. Leningrad: Nauka, pp 160. (Rus.).

Korshenko A., Matveichuk I., Plotnikova T., Udovenko A.V., Luchkov V.P. (2008a) Marine Water Pollution. Annual Report, 2005. Moscow. PC "Meteoagency ROSHYDROMET", pp 160.

Korshenko A., Matveichuk I., Plotnikova T., Udovenko A.V. (2008b) Marine Water Pollution. Annual Report, 2006. Obninsk. PC "Artifex", pp 146.

Korshenko A., Matveichuk I., Plotnikova T., Panova A., Ivanov D., Kirianov V. (2009a) Marine Water Pollution. Annual Report, 2007. Obninsk. PC "FOP", pp 199.

Korshenko A., Matveichuk I., Plotnikova T., Panova A., Ivanov D., Kirianov V., Krutov A., Kochetkov V. (2009 b) Marine Water Pollution. Annual Report, 2008. Obninsk. PC "FOP", pp 192.

Kovekovdova L.T., Kiku D.P., Blokhin M.G. (2012) Metals in bottom sediments of Peter the Great Bay, pp 312-333. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).

Lastovetsky E.I, Veshcheva V.M. (1964) Hydrometeorological essay of Amurskiy and Ussuriiskiy Bays. Ed. Zaokopnaya L.N. Vladivostok: Regional Hydrometeorological agency, pp 264. (Rus.).

Levenets I.R., Skriptsova A.V. (2008) Benthic flora of the inner part of Amursky Bay (Sea of Japan), pp 284 – 301. Ecological Studies and the State of the Ecosystem of Amursky Bay and the Estuarine Zone of the Razdolnaya River (Sea of Japan), 1.

Levin L.A., Ekau W., Gooday A.J., et al. Effects of natural and human-induced hypoxia on coastal benthos // Biogeosciences, 2009, V. 6, p. 2063-2098.

Lishavskaya T.S., Sevastyanov A.V., Chernova A.C., Chatkina T.V. (2010) Monitoring of pollutions of Peter the Great Bay coastal area. Proceedings. FERHRI – 60 year. Vladivostok, 97-112.

Lobanov V.B., Tishcheno P.Ya., Sergeev A.F., et al. Seasonal hypoxia and ventilation waters in Amursky Bay // Nature Without Borders, Vladivostok, 2009, p.171-172.

Luchin V.A., Tikhomirova E.A., Kruts A.A. (2005) Oceanographic regime of Peter the Great Bay (Japan Sea). Izvestiya TINRO, 140, 130-169. (Rus.).

Luchin V.A., Kislova S.I., Kruts A.A. (2007). Tendencies of long-term changes of temperature in the waters of Peter the Great Bay, pp 33-50. Dynamics of Marine Ecosystems and Modern Problems of Conservation of Biological Resources of the Russian Seas. Vladivostok: Dalnauka. (Rus.).

Lukyanova O.N., Cherkashin S.A., Nigmatulina L.V., Chernyaev A.P., Veideman E.L., Ireykina S.A., Pryazhevskaya T.S. (2009) Integral chemical-ecological assessment of the state of Ussuriysky Bay (the Sea of Japan) 36 (5), 615-622. (Rus.).

Lukyanova O.N**.,** Cherkashin M.V., Simokon M.V. (2012) The review of modern ecological state of Peter the Great Bay (2000-2010). Vestnik FEB RAS, 2, 55-63. (Rus.).

Lutaenko K.A., Vaschenko M.A. (2008) Amursky Bay – an ecosystem under stress, pp 7-29. Ecological studies and the state of ecosystems of Amursky Bay and estuarine zone of Razdolnaya River, 1. Vladivostok: Dalnauka. (Rus.).

Methods of Sea Water **Analysis** // Eds. K.Grasshoff, K. Kremling, M. Ehrhardt. Viley-VCH: Weinheim, New York, 1999.

Mihailik T.A., Tishchenko P.Ya., Koltunov A.M., et al. (2011) Impact of Razdolnaya River on ecological status of the Amursky Bay (Japan Sea). Water Resources, 38, 474-484. (Rus.).

Moshchenko A.V, Belan T.A. (2008) Ecological state and long–term changes of macrozoobenthos in the northern part of Amursky Bay (Sea of Japan), pp 61-91. Ecological studies and the state of ecosysytems of Amursky Bay and estuarine zone of Razdolnaya River, 1. Vladivostok: Dalnauka. (Rus.).

Nadtochy V.V. (2012) Seasonal dynamics of plankton in the Amursky Bay (Japan Sea). Izv. TINRO, 169, 147-161. (Rus.).

Nadtochy V.A., Budnikova L.L., Besrukov R.G. (2005a) Macrozoobenthos of Peter the Great Bay (Japan Sea): composition, distribution, stocks. Izvestiya TINRO, 140, 170-195. (Rus.).

Nadtochy V.A., Koblikov V.N. (2005b) Studies of benthos of the Far Eastern Seas of Russia in TINRO-Center. Izv. TINRO, 141, 229–236. (Rus.)

Nadtochy V.A., Galysheva Yu.A. (2012) Modern condition of macrobenthos in Peter the Great Bay pp 129-174. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).

Nigmatulina L.V. (2005) Impacts of waste waters imputes on ecological state of Amursky Bay. Thesis on Ph.D. on biological sciences. Vladivostok: TINRO-Center, pp 19.

Nixon S.F. (1995) Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia, 41, 199-219.

Nixon S.F. (2009) Eutrophication and the macroscope. Hydrobiologia, 629, 5-19.

Orlova T.Yu. (2012) Toxic microalgae in Peter the Great Bay of the sea of Japan, pp 227-238. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).

Orlova T.Yu., Zhukova N.V., Stonik I.V. (1996) Bloom–forming diatom *Pseudonitzschia pungens* in Amyrskii Bay (the Sea of Japan): morphology, ecology and biochemistry, pp 147-150. Harmful and toxic algal blooms. UNESCO.

Orlova T.Yu., I.V. Stonik, O.G. Shevchenko (2009) Flora of planktonic microalgal of Amursky Bay, Sea of Japan. Biologia Morya, 35, 48-61. (Rus.).

Petrenko V.S. (2003) The main features of technogenesis on Primorye coasts. Thematic Edition of DVNIGMI, 4, 175-184. (Rus.).

Podorvanova N.F., Ivashinnikova T.S., Petrenko V.S., Khomichuk L.S. (1989) Main features of hydrochemistry of Peter the Great Bay (Japan Sea). Vladivostok: FEB AS USSR, pp 206. (Rus.).

Polyakov D.M., Botsul A.I. (2004) Geochemistry of some metals in the sediments of the marginal filter of the Razdolnaya River, Amur Bay, Sea of Japan. Geochemistry International, 42(4), 383-388.

POMRAC Technical Report No 4 (2006). Regional overview on river and direct inputs of contaminants into the marine and coastal environment in NOWPAP region. POMRAC, Vladivostok, Russian Federation, pp 64.

POMRAC Technical Report No 7 (2009). Regional overview on river and direct inputs of contaminants into the marine and coastal environment in NOWPAP region. With Special Focus on the Land Based Sources of Pollution. POMRAC, Vladivostok, Russian Federation, pp 104.

Pshenichny B.P., Shevchenko V.V. Perspectives of increasing of biological productivity by artificial upwelling // Voprosi Ichthyology, 1989. V.99, No2, p. 333-335.

Qualifying of territory around Vladivostok and adjacent areas on bases damped wastewaters // Report, No 01870066599, of Far-Eastern Polytechnic Institute. Vladivostok, 1988, 65 p.

Rabalais, N.N., R.E. Turner, R.J. Diaz, and J. Dubravko Global change and eutrophication of coastal waters // ICES Journal of Marine Science, 2009. V. 66, 1528-1537.

Rabalais, N.N., R.J. Diaz, L.A. Levin, R.E. Turner, D. Gilbert, and J. Zhang. Dynamics and distribution of natural and human-caused hypoxia // Biogeosciences, 2010, V. **7**, 585-619.

Rachkov V.I. (2002) Characteristics of hydrochemical conditions of waters of Amursky Bay in warm period // Izv. TINRO, 131, 65-77.

Rachkov V.I. (2006) Hydrochemical conditions in the inner part of the Ussuri Bay for the period of Anadara mollusk spawning. Izv. TINRO, 146, 264-275.

Rodhe W. Crystallization of eutrophication concepts in northern Europe // Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences. Washington DC, 1969, P.50-64.

Redkovskaya Z.P. (1980) Influence of chemical pollutants on oxygen regime of Peter the Great Bay pp. 94-103. Estimations of pollutant migrations and their impact on environment / Ed. V.S. Belen'ky. FERHRI Report, no 73.

Rodionov N.P. (1984) Prediction of pollutions of seas of the USSR, pp 118-150. Leningrad: GIMIZ. (Rus.).

Redfield A.C., Ketchum B.H., Richards F.A. The influence of organisms on the composition of seawater // The Sea / Ed. Hill. M.N. New York: Interscience, 1963. V. 2. p. 26-77

Qualifying of territory around Vladivostok and adjacent areas on bases damped wastewaters (1988) Report, No 01870066599, of Far-Eastern Polytechnic Institute. Vladivostok, 65 pp.

Semkin. P.Ju., Tishchenko P.Ya., Lobanov V.B., Sergeev A.F., Tishchenko P.P., Koltunov A.M., Sagalaev S.G.,Chichkin R.V., Shvetsova M.G., Pavlova G.Yu. (2012) Features of chemical parameters distribution in the Ussuri Bay (Japan Sea) in summer season. Izv. TINRO, 168, 152-168.

Semkin. P. Ju., Tishchenko P. Ya., Lobanov V.B., Sergeev A.F., Chichkin R.V., Pavlova G.Yu., Sagalaev S.G., Shkirnikova E.M., Shvetsova M.G., Tishchenko P.P., Volkova T.I., Zvalinsky V.I. Seasonal and spatial variability of hydrochemical parameters of the Ussuriiskiy bay (Japan/East sea). // Report on Annual PICES Meeting, Khabarovsk, 2011. P.234.

Shulkin V.M., Kavun V.I. (1995) The use of marine bivalves in heavy metal monitoring near Vladivostok, Russia. Mar. Poll. Bull., 31, 330-333.

Shulkin V.M., Presley B.J., Kavun V.I. (2003) Metal concentrations in mussel *Crenomytilus grayanus* and oyster *Crassostrea gigas* in relation to contamination of ambient sediments. Environment International, 29, 493-502.

Shulkin V.M., G. I. Semykina. (2004) Seasonal and Annual Variability of the Concentration and Output of Nutrients by the Razdolnaya River (Primorskii Krai). Water Resources, 32(4), 1-9. (Rus.).

Shulkin V.M., Semykina G.I. (2012) Input of pollutants in Peter the Great Bay and assessment of their role in forming of ecological problems, pp 252-287. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).

Silina A.V., Ovsyannikova I.I. (1995) Long-term changes in the community of Japanese scallop and its epibionts in the polluted area of Amursky Bay, Sea of Japan. Biologiya Morya, 21, 59-66. (Rus.).

Some of regional consequences of anthropogenic impacts on marine environment (1990). Ed. A.V. Tkalin. Leningrad. Hydrometeoizdat, pp 107. (Rus.).

Stonik, I.V., and T.Yu. Orlova (2002) Phytoplankton of the coastal waters off Vladivostok (the North-western part of the East Sea) under Eutrophic conditions. Ocean and Polar Res., 24, 359-365.

Stonik, I.V., and T.Yu. Orlova (1998) Summer-autumn phytoplankton in Amursky Bay, the Sea of Japan. Biologia Morya, 24, 205-211. (Rus.).

Stonik I.V., Selina M.S. (1995) Phytoplankton as indicator of trophic state in Peter the Great Bay. Biologia Morya, 21, 403-406. (Rus.).

Talley L.D., Lobanov V., Ponomarev V. et al. Deep convection and brine rejection in the Japan Sea // Geophys. Res. Letters, 2003. V. 30. No. 4, 1159, doi:10.1029/2002GL016451

Tishchenko P.Ya., Sergeev A.F., Lobanov V.B., et al. (2008) Hypoxia in near-bottom waters of the Amursky Bay. Bulletin Far Eastern Branch Rus. Acad. Sci., 6, 115-125 (Rus.).

Tishchenko P. Ya., Lobanov V.B., Zvalinsky V. I., Sergeev A.F., T.I.Volkova, Koltunov A.M., Mikhajlik T.A., Sagalaev S.G., Tishchenko P.P., Shvetsova M.G. (2011a) Seasonal hypoxia of Amursky Bay (Japan Sea). Izv. TINRO, 165, 108-129. (Rus.).

Tishchenko P.P., Tishchenko P.Ya., Zvalinsky V.I., Sergeev A.F. (2011b) Carbonate system of Amursky Bay (Sea of Japan) under conditions of hypoxia. Oceanologiya, 51, 246-257. (Rus.).

Tishchenko P. Ya., Talley L. D., Nedashkovsky A. P., Sagalaev S. G. and Zvalinsky V. I. Temporal Variability of the Hydrochemical Properties of the Waters of the Sea of Japan // Oceanologiya, 2002, V.42, p.838-847.

Tkalin A.V., Belan T.A. and Shapovalov E.N. (1993) The state of marine environment near Vladivostok, Russia. Marine Pollution Bulletin, 26, 418-422.

Tkalin A.V. (1995) Investigation of marine environment radioactivity in the dumping areas and coastal zone of the Sea of Japan. Arctic Res. of the United States, 9, 88-89.

Tkalin A.V. (1996) Chlorinated hydrocarbonsin coastal bottom sediments of the Japan Sea. Environ. Poll., 91, 183-185.

Tkalin A.V., Presley B.J., Boothe P.N. (1996) Spatial and temporal variations of trace metals in bottom sediments of Peter the Great Bay, the Sea of Japan. Environ. Poll., 92, 73-78.

Tkalin A.V., Lishavskaya T.S. and Hills J.V. (1997) Organochlorine pesticides in mussels and bottom sediments from Peter the Great Bay near Vladivostok. Ocean Res., 19, 115-119.

Tkalin A.V. (1998) Assessment of state marine environment near Vladivostok on pollutant content in mussels and sediments, pp 114-124. Hydrometeorological processes on shelve: assessment of impact on marine environment. Proceedings of FERHRI. Vladivostok: Dalnauka. (Rus.).

Tkalin A.V., Lishavskaya T.S. and Shulkin V.M. (1998) Radionuclides and trace metals in mussels and bottom sediments around Vladivostok, Russia. Marine Pollution Bulletin, 36, 551-554.

Tkalin A.V., Samsonov D.P., Lishavskaya T.S. and Chernik G.V. (2000) New Data on Organochlorine Distributions in the Marine Environment near Vladivostok. Marine Pollution Bulletin, 40(10), 879–881.

UNESCO. Determination of photosynthetic pigments in seawater // Monogr. on Oceanogr. Metodol. Paris. 1966. V. 1. 70p.

Vaquer-Sunyer R., and C.M. Duarte. Thresholds of hypoxia for marine biodiversity // Proceedings National Academy of Sciences, 2008, V. 105, p.15452-15457.

Vaschenko M.A. (2000) Contamination of Peter the Great Bay (Sea of Japan) and its biological consequences. Biologiya morya, 26(3), 149-159 (Rus.).

Voronkov P.P. (1941a) Hydrochemical regime of Peter the Great Bay, Sea of Japan, pp 42-102. The Problems of sea chemistry. Hydrometeoizdat. (Rus.).

Voronkov P.P. (1941b) Daily variations of hydrochemical parameters in coastal waters of Peter the Great Bay, Sea of Japan, pp. 137-149. The Problems of sea chemistry. Hydrometeoizdat. (Rus.).

Zhabin, I.A., Gramm-Osipova, O.L., Yurasov, G.Ya. Upwelling along north-western coast of the Japan Sea induced by wind. Meteorology Hydrology, 1993. V.10. p. 82-86. (in Russian).

Zhadan P.M., Vaschenko M.A., Almyashova T.N., Slinko E.N. (2005) Monitoring of ecological state of the coastal ecosystems of Amursky Bay (Peter the Great Bay, Sea of Japan) based on biological and biogeochemical parameters, pp 201-227. State of Marine Ecosystems Influenced by River Runoff. Vladivostok: Dalnauka. (Rus.).

Zhang, J., D. Gilbert, A.J. Gooday, L. Levin, S.W.A. Naqvi, J.J. Middelburg, M. Scranton, et al. Natural and human hypoxia and consequences for coastal areas: synthesis and future development // Biogeosciences, 2010, V. 7, 1443-1467.

Zuenko Yu.I. (2008) Fisheries of Oceanography of the Japan Sea. Vladivostok: TINRO-center, pp 227. (Rus.).

Zvalinskiy V.I., Tischenko P.P., Mikhailik T.A., Tischenko P.Ya. (2012) Eutrophication of the Amursky Bay. pp 76-113. Current Ecological State of Peter the Great Bay, Sea of Japan. Ed. N.K. Khristoforova. Vladivostok: Far Eastern Federal Univ. Press. (Rus.).

Table of contents of the regional overview of eutrophication assessment in the NOWPAP region (Draft as of August, 2013)

Table of contents