A Case Study Report

on Assessment of Eutrophication Status

in Peter the Great Bay, Russia

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1. 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.

2. Introduction

Historical development of concept of eutrophication was overviewed in fresh water environments by Hutchinson (Hutchinson, 1969) and Rodhe (Rodhe, 1969). Rodhe gave definition of eutrophication as follows: "Every permanent change toward a higher degree of autotrophy deserves to be called "eutrophication"". Historical overview of the discovery of marine eutrophication, progress in understanding nutrients enrichment role on marine and costal ecosystems, interest of politicians and managers to an eutrophication are given in detail by F. de Jong (De Jong, 2006). He particularly noted that "…several researchers underlined the potential benefits of increased nutrient inputs in terms of increased primary and secondary production, rather than the negative aspects. For these reasons, marine eutrophication was not regarded a large-scale serious international marine pollution issue in the 1970s and the beginning of the 1980s. …In the 1990s, scientific information became available about many other possible causes of the observed changes. These were changes in nutrient ratios, changes in the light regime, polluting substances interfering with the grazing ability of zooplankton and, in particular, climatic changes." 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, 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). 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 et al., 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.

The objective of this report is assessment of eutrophic status of Peter the Great Bay with aiming to improve management and healthy of coastal environment of NOWPAP member states via sharing information about nutrient sources and consequences of eutrophication.

3. Peculiarities of Peter the Great Bay

Peter the Great Bay (PGB) is situated in a northwestern part of NOWPAP region (Fig. 3.1). 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. 3.1). 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) .

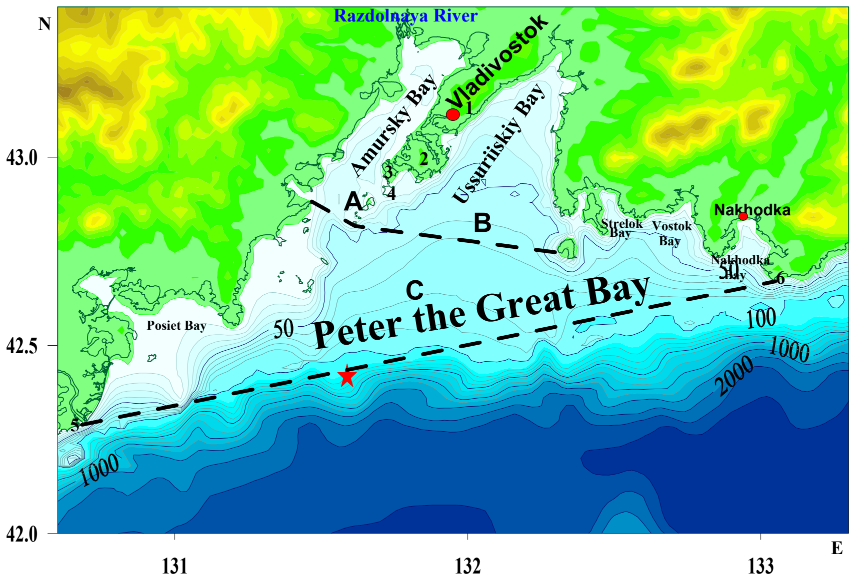

Fig. 3.1　Peter the Great Bay and its sub-areas

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 (Fig.3.2, (Lobanov et al., 2009)).

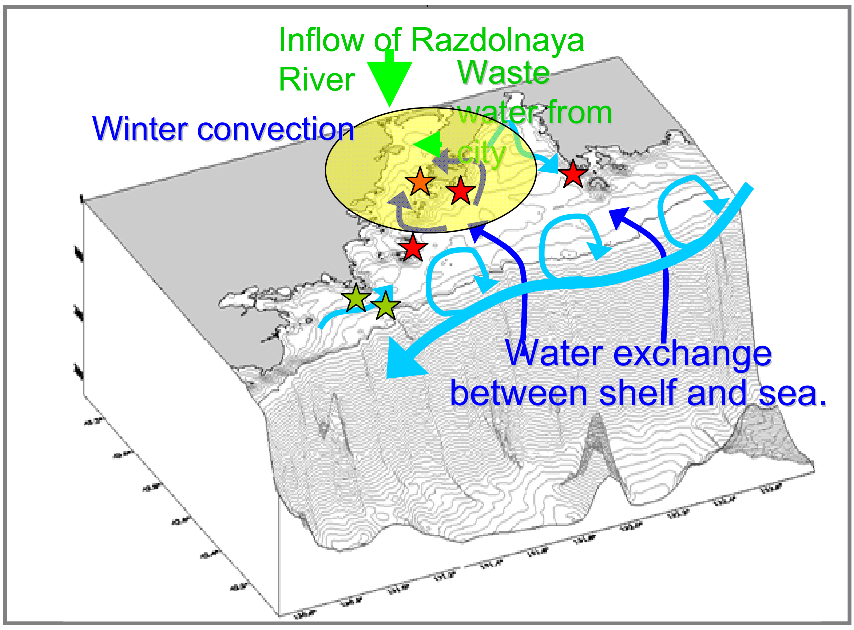

Fig.3.2 Sketch of main peculiarities of Peter the Great Bay:
a) Inputs waters enrichment by nutrients via Razolnaya River inflow and waste waters of Vladivostok-city (yellow ring); b) sea-ice formation and winter convection mostly occur in yellow ring; c) There is water exchange between shelf and NOWPAP area through steep continental slope.

4 Scope of assessment

4.1 Dividing of PGB on sub-areas

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.3.1).

Sub-area A. Amursky Bay is semiclosed basin (Fig. 4.1). 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.

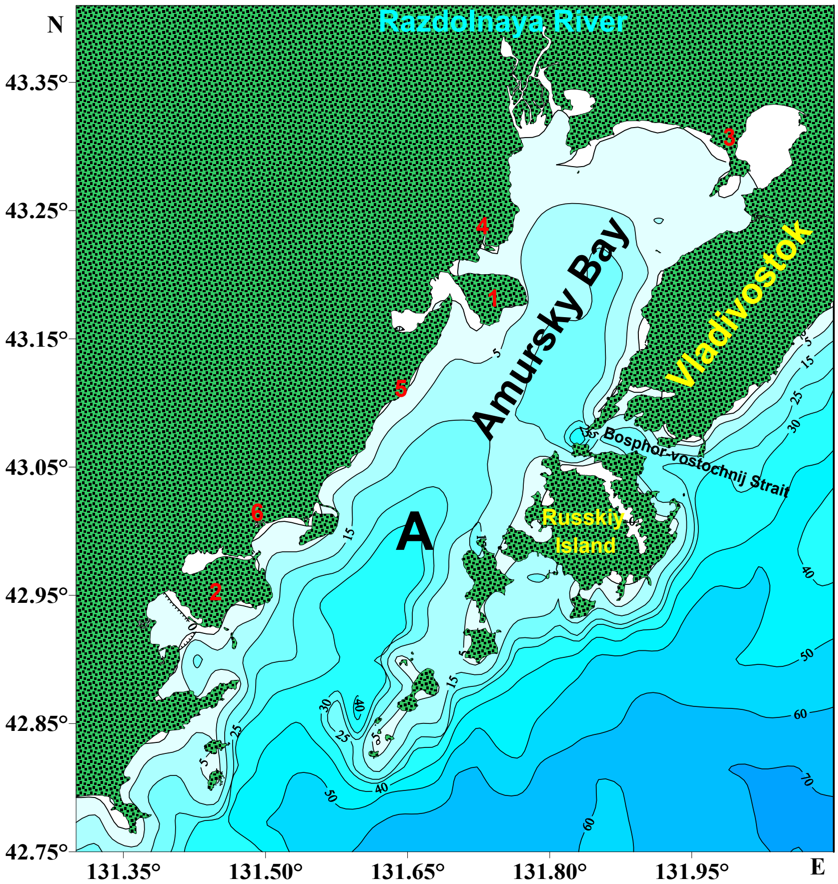

Fig.4.1 . Amursky Bay – Sub-area A.

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. 4.2); 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. 4.3). According to Municipal Data, the total annual volume of waste water inflowing into Amursky Bay is about 40-50*10^6 m^3.

Fig.4.2 Inputs of untreated waste waters into Vtoraya Rechka which inflow into Amursky Bay.

Fig.4.3 Agriculture fields in valley of the Razdolnaya River are considered as main diffusive source of nutrients loaded into Amursky Bay.

Table 4.1 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
Far-Eastern Polytechnic Institute, 1988	54	100-650*	18-45	nd*)	5-8	nd*)	nd*)	100-350
Pacific Oceanological Institute, 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, 1992).

Annual loads of nutrients, suspended solids and COD_{Cr} into Amursky Bay supplied by Razdolnaya River were published somewhere (Mihajlik et al., 2011).

Table 4.2 Annual loads (T/year) of nutrients, COD_{Cr}, SS into Amursky Bay from river runoff and waste waters of Vladivostok

Nutrients, COD, SS	DIN	N-tot	DIP	P-tot	COD_{Cr}	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, 1992); ***)(Gavrilevsky et al. 1998); ****)(POMRAC, 2006).

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 et al., 2008) . Killed fishes event (Fig. 4.4) and recently discovered OMZ (Fig. 4.5, (Tishchenko et al ., 2008)) are consequences of eutrophication of Amursky Bay.

Fig.4.4 Killed fishes on coast of Amursky Bay at 14th September 2008.
Most part of fishes is Smelt. Photo Vladimir Kolesnikov.

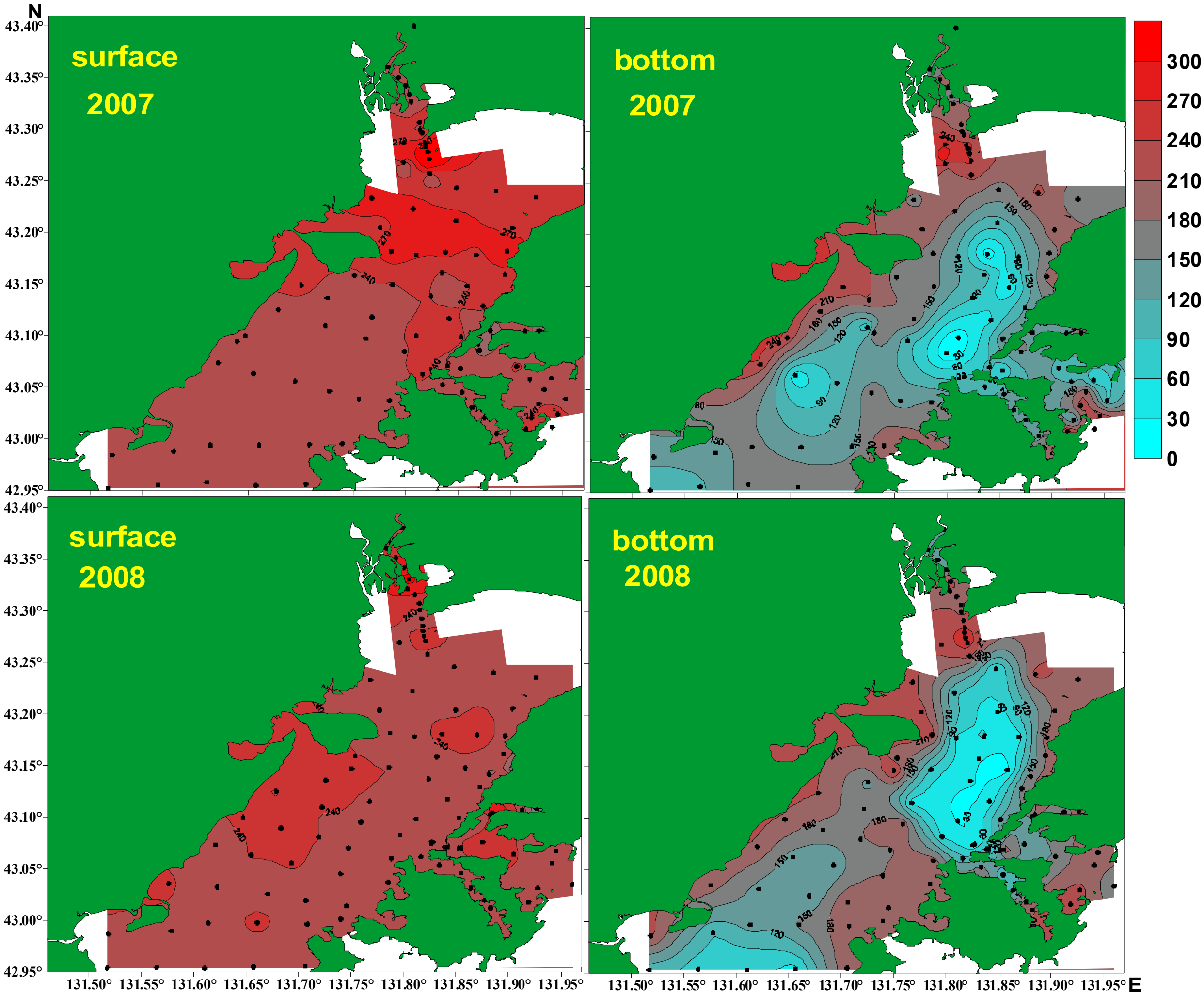

Fig.4.5 Distribution of oxygen concentration (μmol/kg) in Amursky Bay.
August, 2007 (upper panel). August, 2008 (bottom panel).

Sub-area B. Ussuriysky Bay is open basin (Fig. 4.6). 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 4.3.

Table 4.3 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

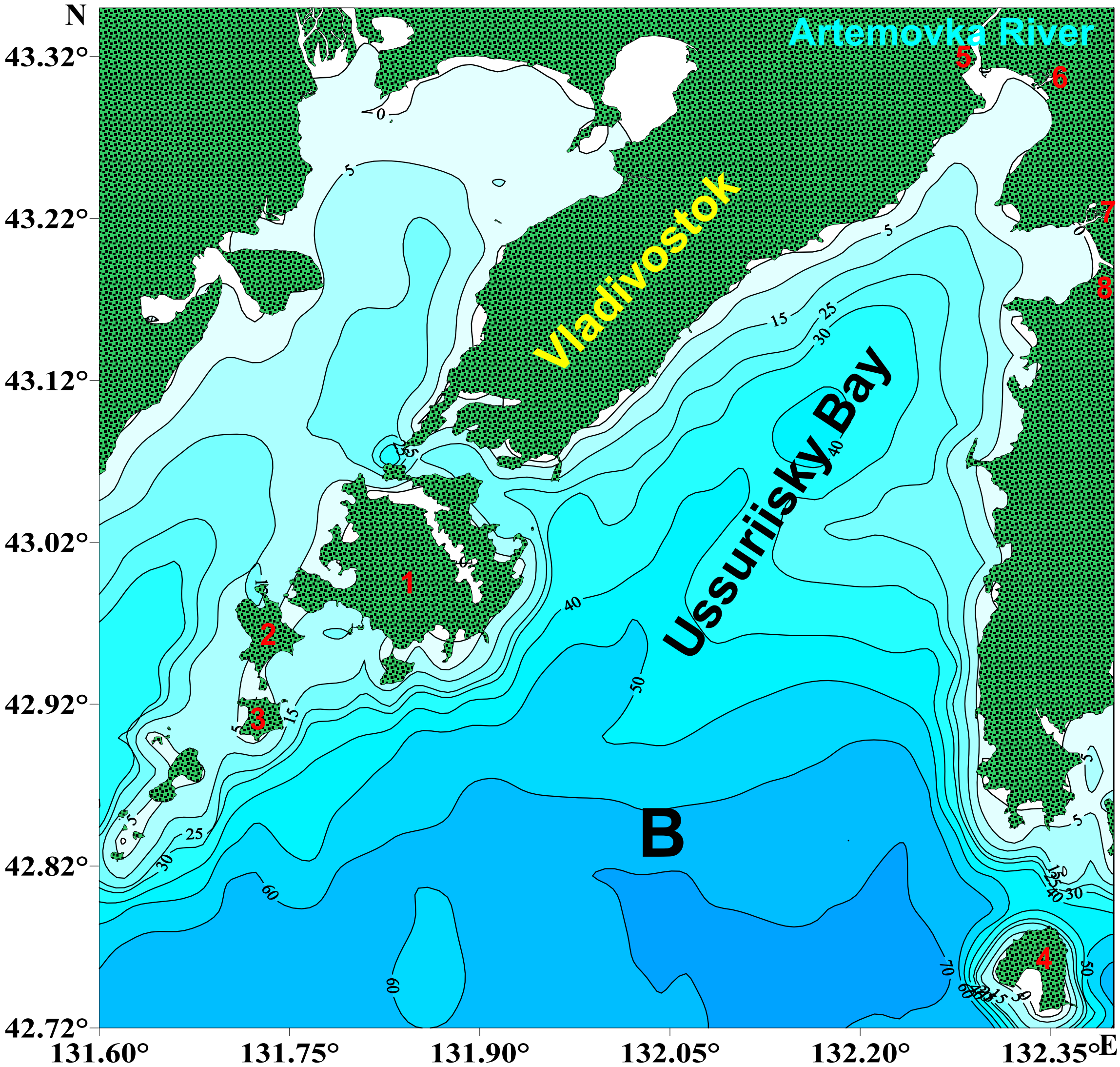

Fig.4.6 Ussurijsky Bay – Sub-area B.

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.

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 a small towns on 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 4.4. 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 4.4.

Table4.4. Annual loads (T/year) of nutrients, COD_{Cr}, 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_{Cr}	DISi	SS
River runoff	178	669	24.3	91	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, 1992) ; ***)(POMRAC , 2009)

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 (Fig. 4.7) 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).

Fig.4.7 Dredging in the Golden Horn Bay.

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. 3.1). 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. According to Coriolis force, Tumannaya River has to away from PGB. Our estimations of nutrient loads into Sub-area C are presented in Table 4.5.

Table 4.5 nnual 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 (Pacific Oceanological Institute, 2000); $^{**)}$(POMRAC, 2009).

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 however they significant effect on assimilation capacity of PGB.

Summation of loads of nutrients into PGB and each of its Sub-area as well are listed in Table 4.6. Thus, according to Table 4.6 we can conclude that anthropogenic pressure is highest for Sub-area A (Amursky Bay) and lowest for sub-area C.

Table 4.6 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	91
Waste waters, t/y	950	1600	130	185
Total, t/y	1130	2000	155	276
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

4.2 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 4.7. 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 4.7 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 (Eds et al.,1999).
Category II parameters used in this case study	
Chlorophyll	Standart oceanological methods (UNESCO, 1966 (UNESCO,1966); Koblenz-Mishke, 1983, (Koblenz-Mishke,1983))
Category III parameters used in this case study	
Dissolved oxygen	Winkler method (Carpenter, 1965, (Carpenter 1965))

4.3 Selection of data.

POI carried out extensive oceanographic surveys of PGB during 1999 to 2010 which include hydrochemical observations. Aim of these surveys was rather establish of hydrochemical status of 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 2600 samples were analyzed (Fig.4.8). However obtained data are quite non-uniform with time and space (Fig. 4.8, 4.9). Sub-area A (Amursky Bay) was studied in detail, especially in 2008, when 738 samples where analyzed.

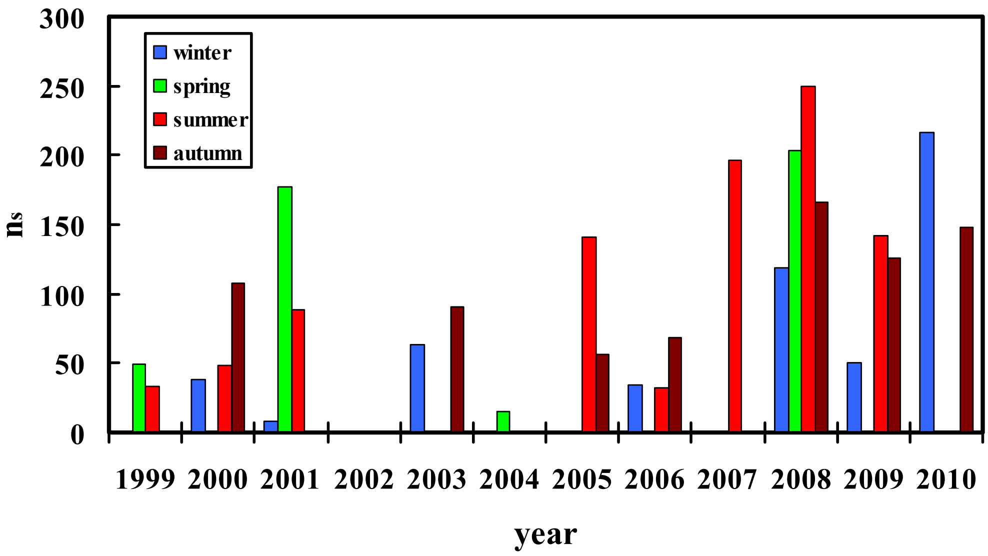

Fig.4.8 A level of study of Peter the Great Bay.
Number of samples used for assessment parameters of eutrophication status of PGB.

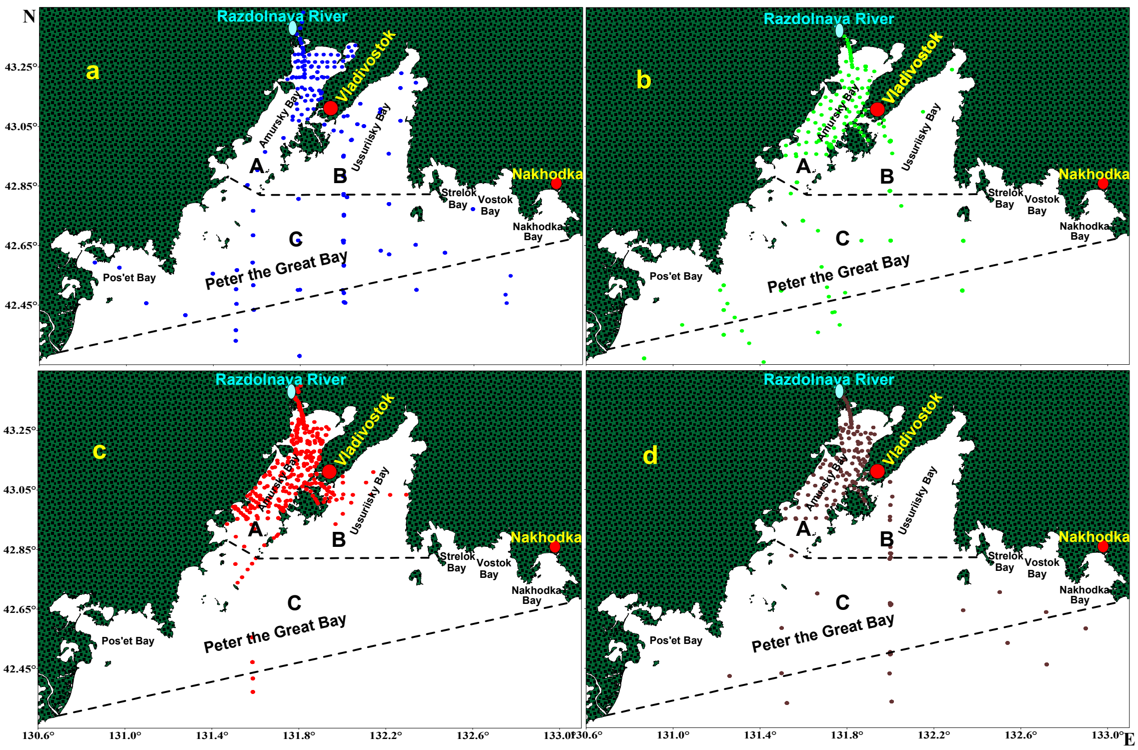

Fig.4.9 Distribution of hydrochemical stations which were implemented during 1999 – 2010 in Peter the Great Bay.
a – Winter; b – Spring; c – Summer; d – Autumn. Points are locations of stations.

5 Data processing

Values of each assessment parameters have been measured using commonly accepted methods (Eds. K. Grasshoff et al., 1999; UNESCO, 1966; Koblenz-Mishke,1983). Data set includes values of NH_4, NO_2, NO_3, PO_4, H_2SiO_3, Chlorophyll *a*, and oxygen concentrations 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.

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 (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 Anderson'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. 6.1). According to Fig. 6.1a, 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 are 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. (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). We use actual properties of body water as "reference" in site which is noted by star (Fig. 3.1). Vertical profiles of some properties are shown on Fig. 6.2 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. 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 in (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 et al., 2009), so that no single definition of hypoxia fits all organisms. Often the threshold level of dissolved oxygen defined as hypoxia is between 2 mg/L (63 μM) (Diaz, 2001) and 2 ml/L (89 μM) (Diaz et al., 2008). We accept average one of these two threshold values of DO, this is 76 μM. 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).

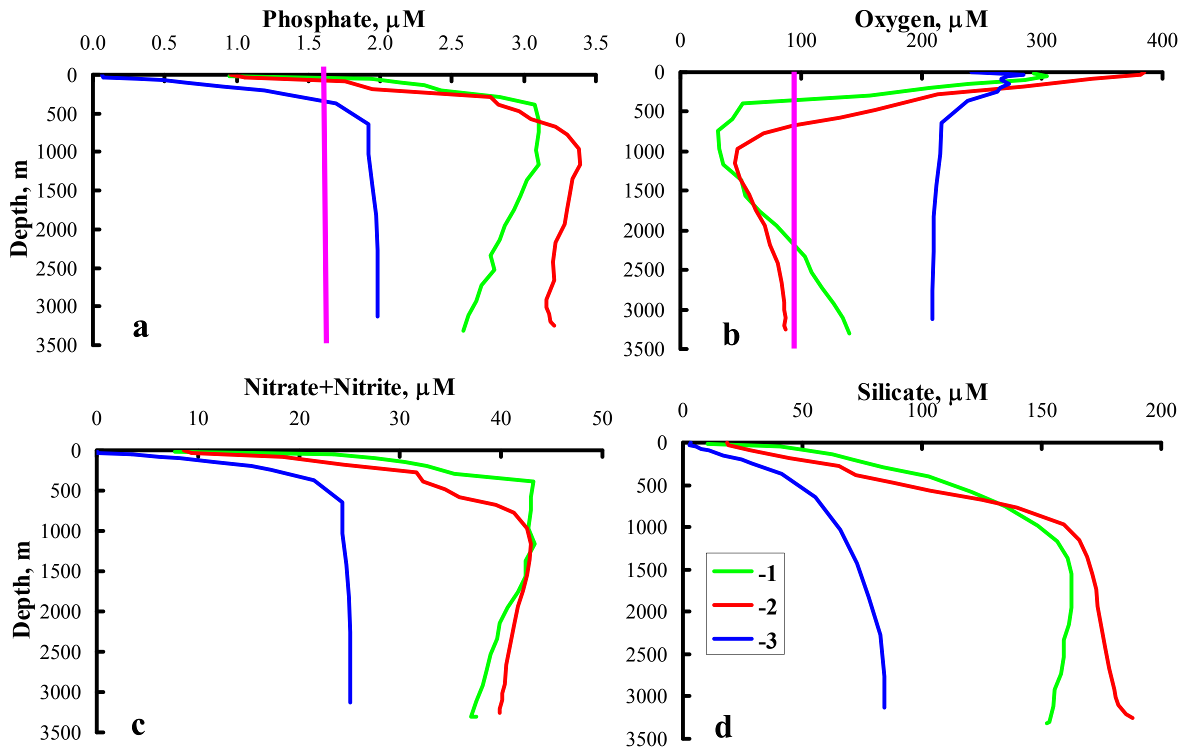

Fig.6.1 Vertical variations of assessment parameters (DIP -a, DO -b, DIN-c, DINSi-d) in NW-Pacific -1 j=44.49oN, l= 153.20oE; Sea of Okhotsk -2 j=47.49oN, l=147.91oE, NOWPAP Sea -3 j=43.54oN, l=139.20o E. Purple vertical lines correspond "maximum permissible concentration" accepted in Russia.

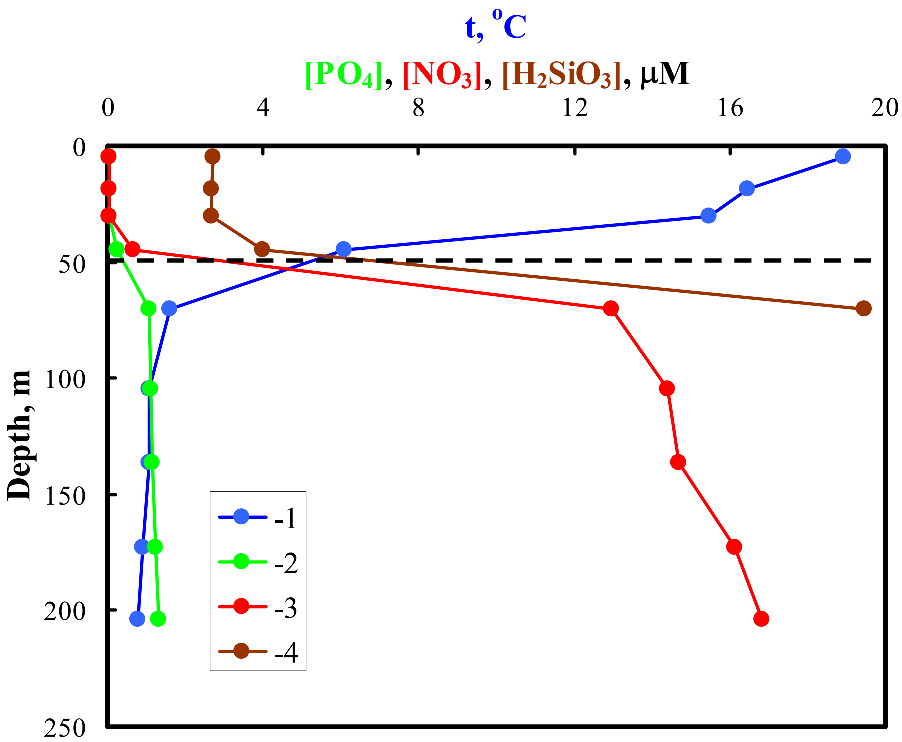

Fig.6.2 Vertical distribution of 1 - temperature (oC), 2 - PO4 (μM), 3 - NO3 (μM), and 4 - H2SiO3 (μM) on the station which is accepted as "standard" (42.417o N; 131.588o E, it is noted by star on Fig.1). Data obtained at August 1999 on R/V "Professor Khromov "-36.

Table 6.1. Threshold values of nutrient concentrations calculated at different temperature and salinity correspond those in near bottom waters of Amursky Bay. These values can be use for assessment of eutrophic status of PGB.

Season	Winter	Spring, Autumn	Summer
t, °C	0	10	20
S, ‰	33	33	33
DIN_{th}, μM	33.4	24.3	18.3
DIP_{th}, μM	2.1	1.5	1.1
DIS_{th}, μM	35.5	25.8	19.4

Thresholds values of nutrients were calculated by equations (1)-(3) and presented in Table 6.1. 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 8 μg/L as threshold value of chlorophyll concentration (OECD, 1982).

7 Assessment process and results

7.1 Sub-area **A** (Amursky Bay)

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 Fig. 7.1 and 7.2. Red color means that nutrients concentrations exceed threshold values and dissolved oxygen concentrations less threshold value. We have to emphasize that nutrient inputs 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 this is grazed by zooplankton and "excessive" biomass settles on the bottom. We suggested (Podorvanova et al.,1989) that phytoplankton bloom might be caused by enhanced supply of nutrients into the upper layer by increased discharge of the river on short-time scale (Fig. 7.3). A high water phase of Razdolnaya River discharge approaching 1000 m^3/c was occurred 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. 7.4). Just after settling of suspended matter perfect conditions for phytoplankton bloom are formed 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. 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. 7.2. Direct observations on concentration cells of phytoplankton support that maximum number of bloom events corresponds to July and August months (Fig. 7.5). Seasonal distributions of DIN, DIP, DISi, DO, Chlorophyll are demonstrated by Fig. 7.6 – 7.10. 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.

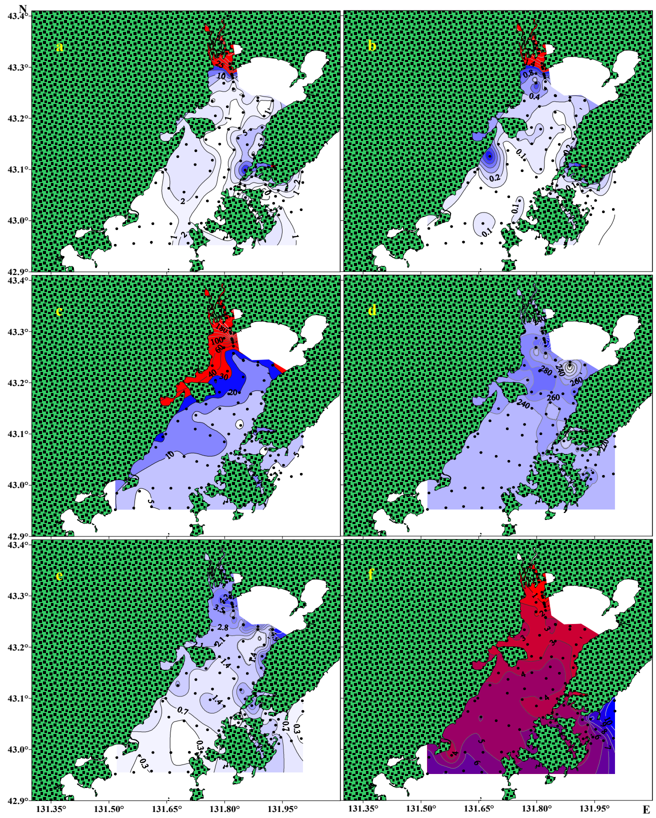

Fig.7.1 Distribution of a - DIN (μM), b – DIP (μM), c – DISi (μM), d – DO (μmol/kg), and e – chlorophyll a (μg/L) in surface layer of Amursky Bay. f – Depth of disk Secci (m). Data obtained at August 2007 on R/V "Malakhit". Red color means that nutrients concentrations exceed threshold values.

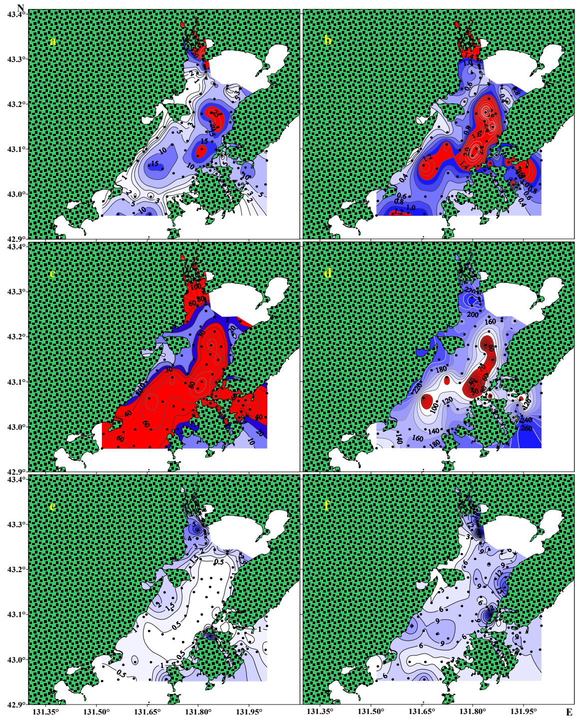

Fig.7.2 Distribution of a - DIN (μM), b – DIP (μM), c – DISi (μM), d – DO (μmol/kg), e – chlorophyll a (μg/L), f – atomic ratios of DIN/DIP in near bottom layer of Amursky Bay. Data obtained at August 2007 on R/V "Malakhit".
Red color means that nutrients concentrations exceed threshold values and oxygen concentrations less threshold value.

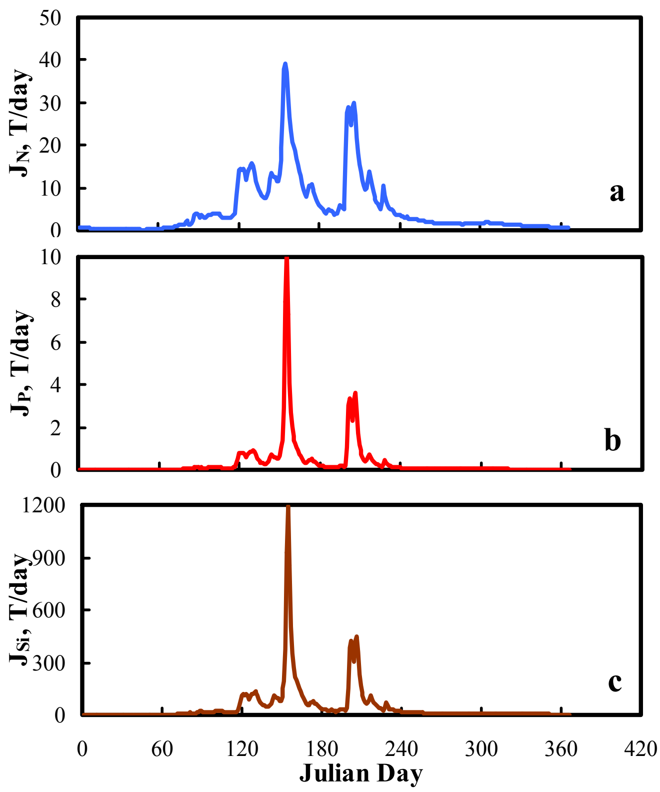

Fig.7.3 Fluxes of nutrients (a – DIN; b – DIP; c – DISi) loaded into Amursky Bay by Razdolnaya River as function of Julian Days [14].

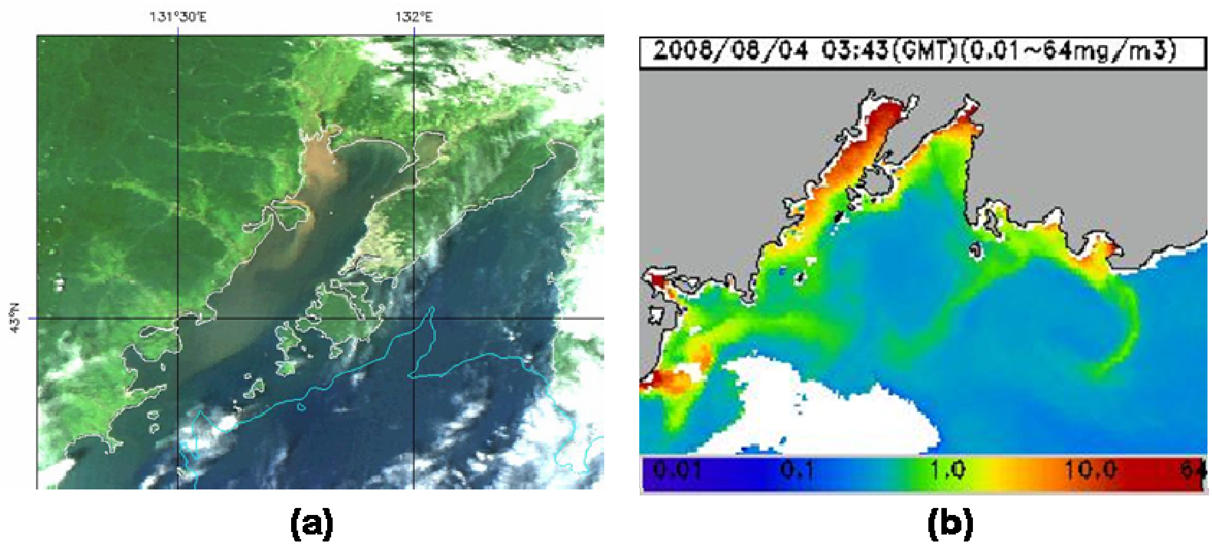

Fig.7.4 Ocean color satellite images from MODIS showing high content of suspended material from Razdolnaya River (a) and then high Chl-a concentration (b) in the Amursky Bay in Summer period.

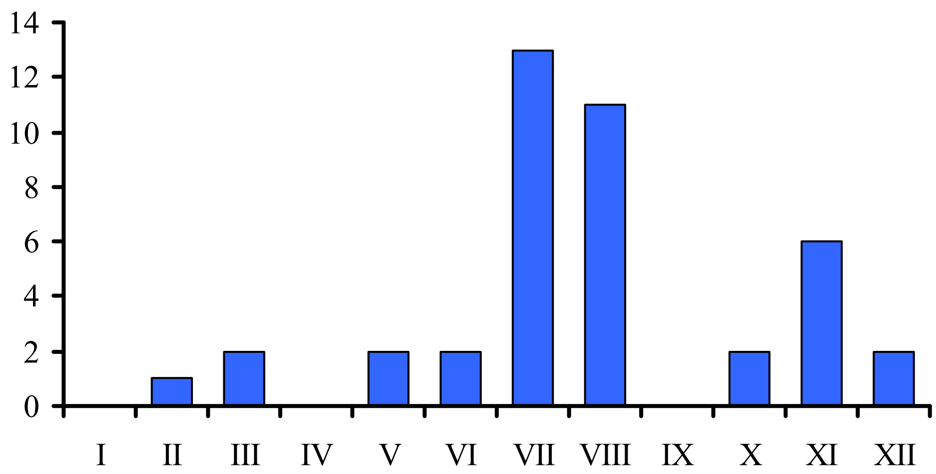

Fig.7.5 Number of bloom events by month in Amurskyi Bay (1991–2007).

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).

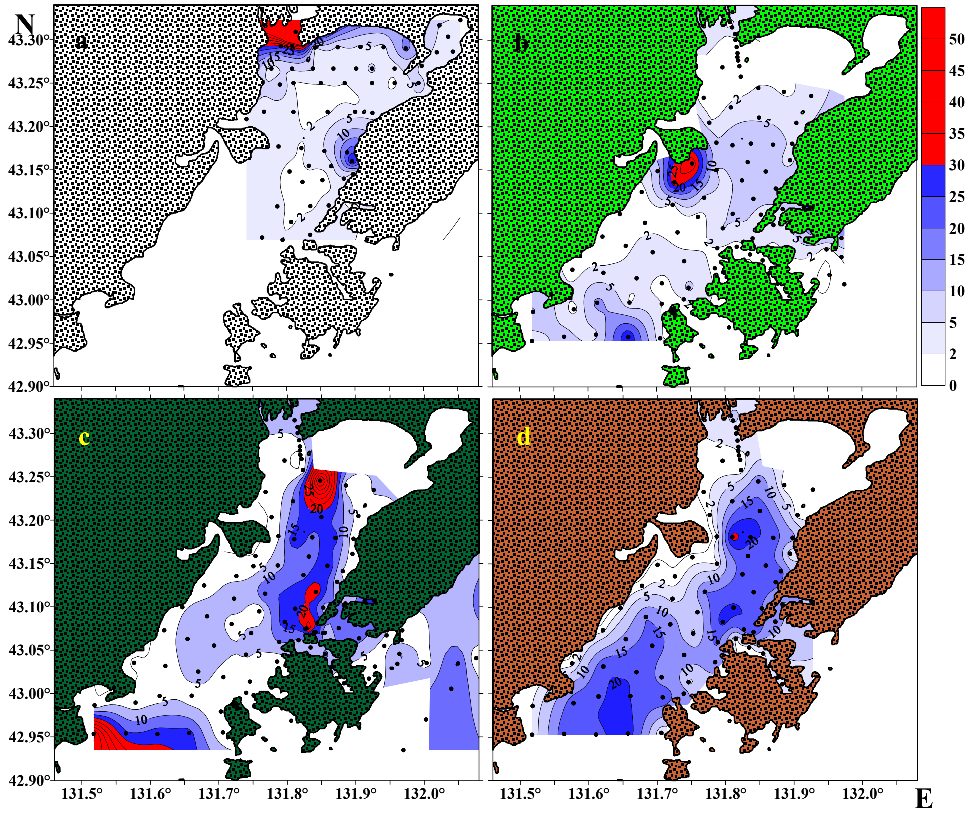

Fig.7.6 Seasonal distribution of DIN concentration (μM) in bottom waters of Amursky Bay. a – Winter, b – Spring, c – Summer, d – Autumn 2008. Red color means concentrations of DIN higher than threshold value.

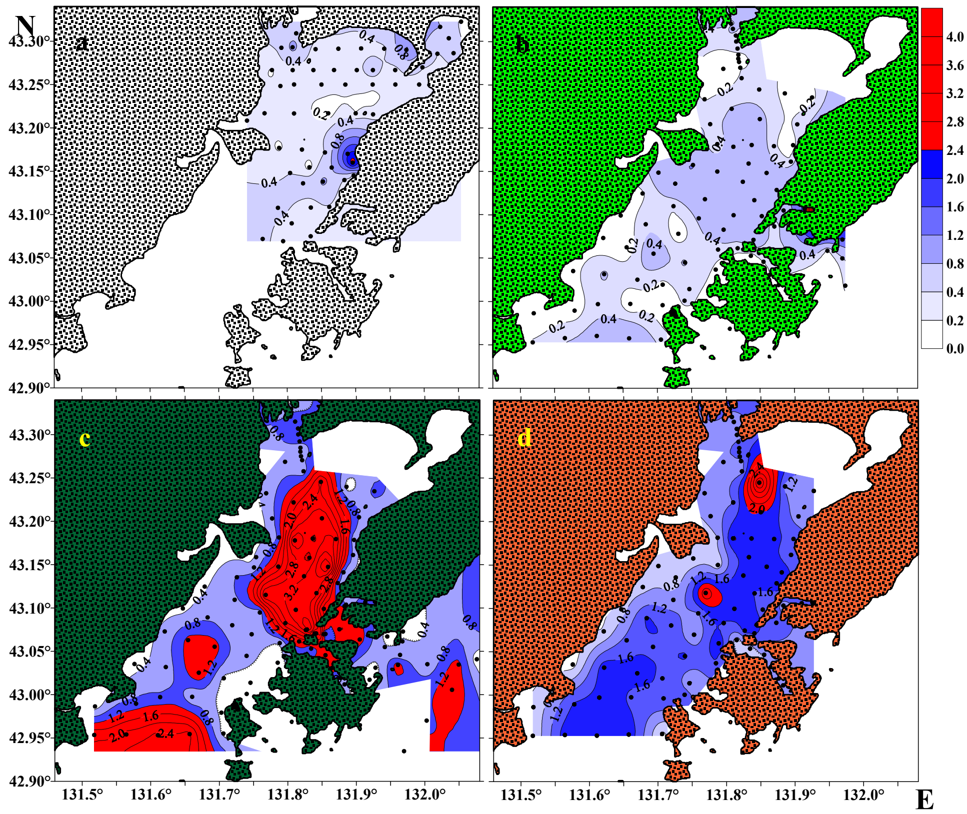

Fig.7.7 Seasonal distribution of DIP concentration (μM) in bottom waters of Amursky Bay. a – Winter, b – Spring, c – Summer, d – Autumn 2008. Red color means concentrations of DIP higher than threshold value.

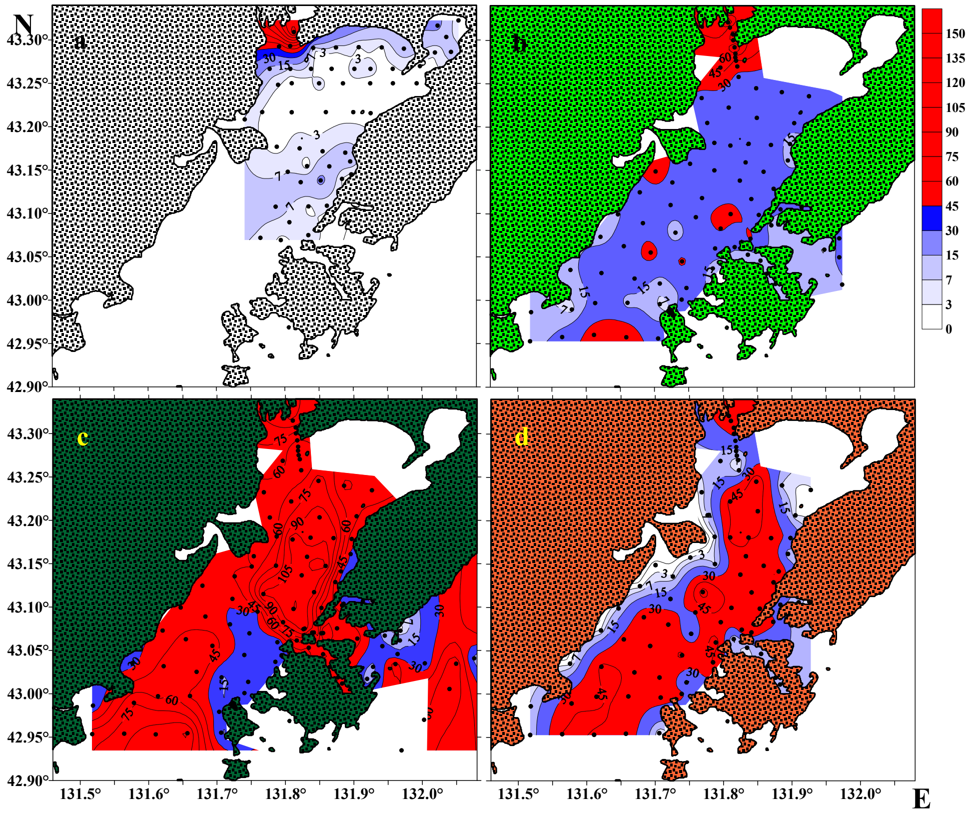

Fig.7.8 Seasonal distribution of DISi concentration (μM) in bottom waters of Amursky Bay. a – Winter, b – Spring, c – Summer, d – Autumn, 2008. Red color means concentrations of DISi higher than threshold value.

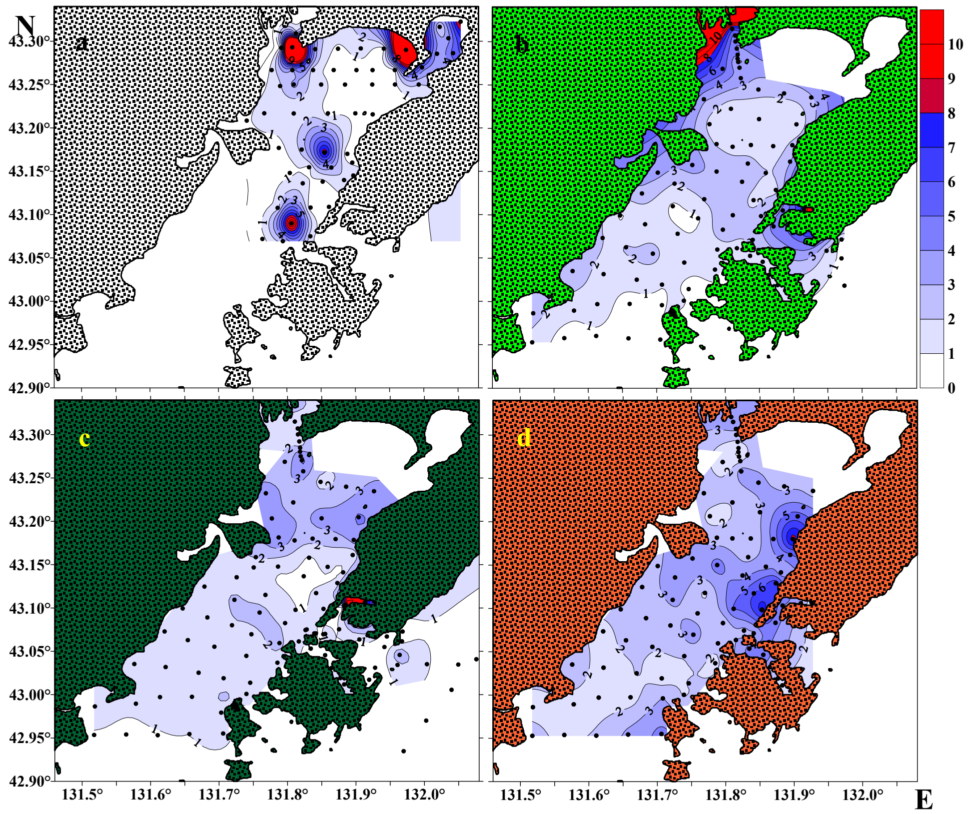

Fig.7.9 Seasonal distribution of Chlorophyl concentration (μg/L) in bottom waters of Amursky Bay. a – Winter, b – Spring, c – Summer, d – Autumn, 2008. Red color means concentrations of DISi higher than threshold value.

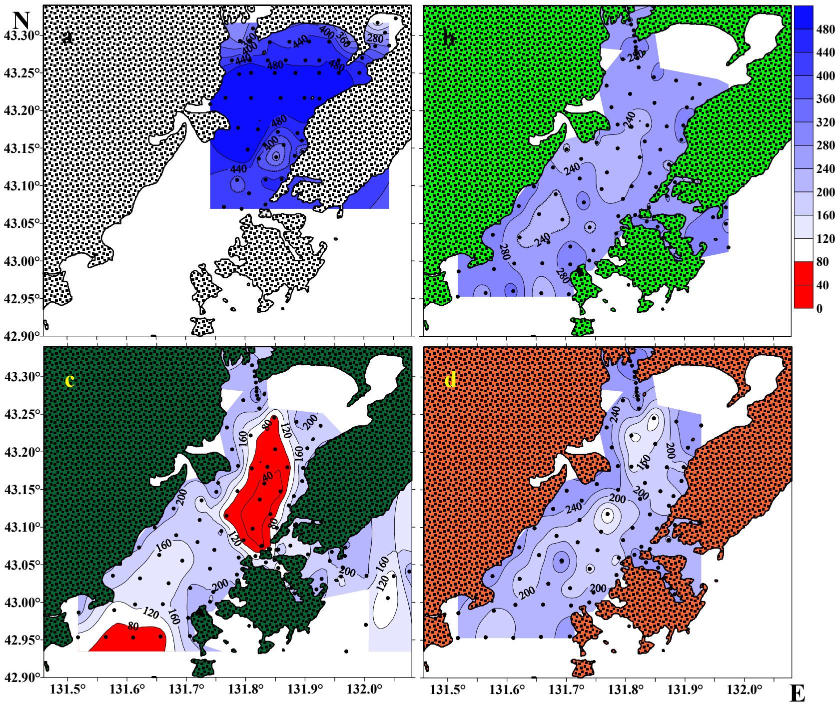

Fig.7.10 Seasonal distribution of dissolved oxygen concentration (μM) in bottom waters of Amursky Bay. a – Winter, b – Spring, c – Summer, d – Autumn, 2008. Red color means concentrations of DO less than threshold value.

7.2 Sub-area **B** (Ussurijsky Bay)

Sub-area B (Ussurijsky Bay) was significantly less studied in comparison with sub-areas A. 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. However, situation is quite different for both sub-areas at September in 2010 (Fig. 7.11 – 7.12). In contrast with Sub-area A, practically there is not any hypoxic region in Ussuriisky Bay, and region where concentrations of DIN and DIP exceed threshold values. However historical data (Podorvanova et al.,1989) documents that in summer time there are local sites in Ussuriisky Bay with low oxygen concentration near bottom which is less than threshold value. We carried out observations of hydrochemical parameters at August 31 in 2008, 2009. These results are presented on Fig. 7.13. 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 80 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 NOWPAP area. Upwelling is mechanism which supplies nutrients on the shelf of Sub-area B and Sub-area A as well at autumn season.

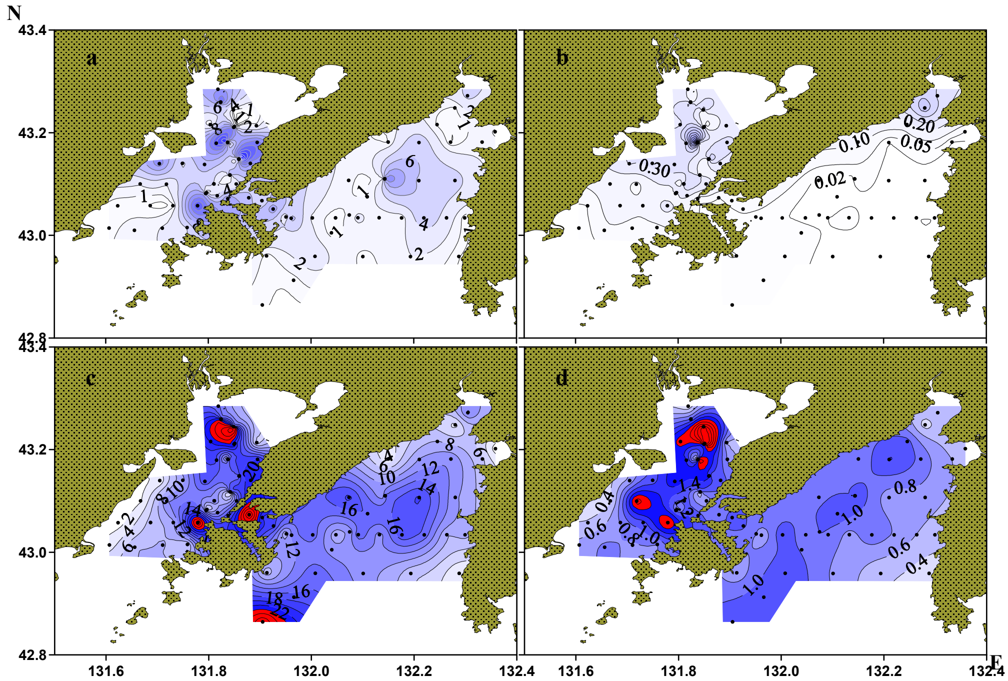

Fig.7.11 Distribution of a, c – DIN (μM), b, d – DIP (μM), in surface layer (upper panel) and in bottom layer (bottom panel) of sub-areas I, II.

Data obtained at September 2010 on R/V "Malakhit". Red color means that nutrients concentrations exceed threshold values.

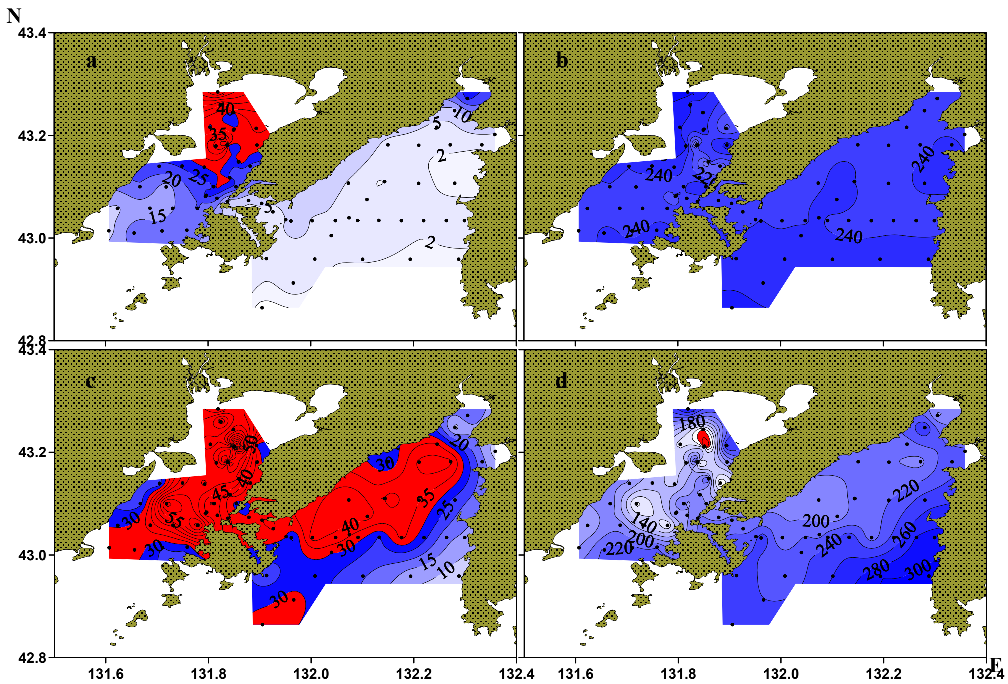

Fig.7.12 Distribution of a, c – DISi (μM), b, d – DO (μM), in surface layer (upper panel) and in bottom layer (bottom panel) of sub-areas I, and II.

Data obtained at September 2010 on R/V "Malakhit". Red color means that DISi concentrations exceed threshold value and DO concentration were less than threshold value.

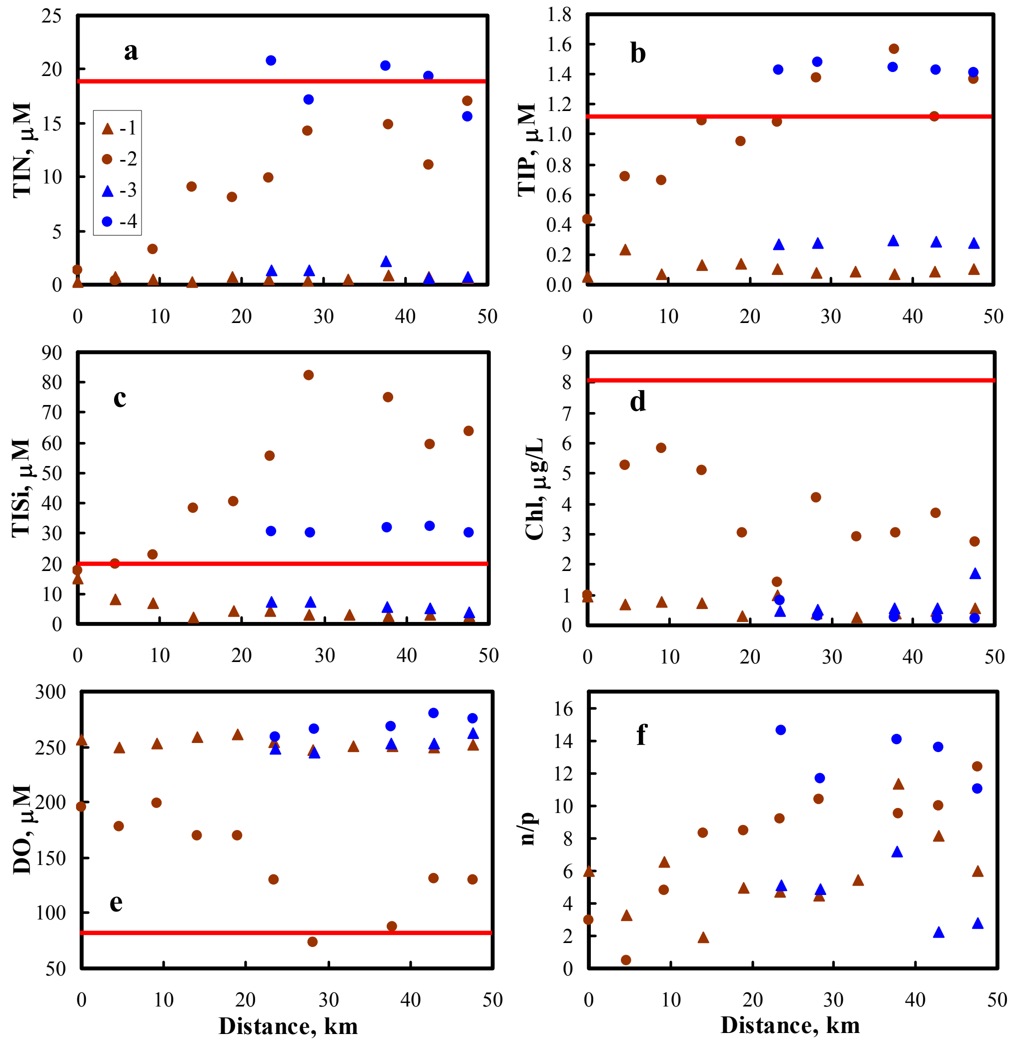

Fig.7.13 Distributions of a – DIN, b – DIP, c – DISi, d – Chlorophyll a content, e – DO, f – N:P ratios along longitudinal section. 1, 3 – surface horizon, 2, 4 – bottom horizon.
Ussurijsky Bay. Red liens correspond threshold values of assessment parameters. 1, 2 – 31 August 2008; 3, 4 – 31 August 2009.

7.3 Sub-area **C**

Sub-area C is open part of PGB. This Sub-area is less studied. Nevertheless, Tables 4.5, 4.6 suggest that this Sub-area has minimal anthropogenic pressure in comparison with sub-areas A and B.

Table 7.1 summarizes spans of variations of assessment parameters. 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.

Table 7.1. Minimal and maximal assessment parameters for Sub-areas A, B, C.

Sub-area **A** Amursky Bay						
Parameters	DIN µM	DIP µM	DISi µM	Chl µg/l	O_2 µM	Depth of Secci disk m
Minimum	0.2	0.01	0.7	0.02	4.7	0.5
Maximum	56	4.7	124	26	615	8
Sub-area **B** Ussuriisky Bay						
Parameters	DIN µM	DIP µM	DISi µM	Chl µg/l	O_2 µM	Secci disk m
Minimum	0.25	0.01	2	0.2	74	3.5
Maximum	21	1.6	82	6	452	13
Sub-area **C** South Part of Peter the Great Bay						
Parameters	DIN µM	DIP µM	DISi µM	Chl µg/l	O_2 µM	Secci disk m
Minimum	0.3	0.16	2.0	0.05	240	10
Maximum	12	0.9	17	11	450	20

8 Review of results

8.1 Eutrophycation status of PGB.

There are three types of nutrient sources into 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 and coastal runoff. Fluxes of these sources have distinct seasonal variability due to seasonal atmospheric precipitation. c) Deep water of NOWPAP area which contains high concentration of nutrients is natural source of nutrients. Fluxes from this source are determined by frequency and intensity of upwelling of deep water on the shelf of 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 (Fig. 7.2, 7.6, 7.7, 7.8, 7.11). 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., 2011). 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:

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

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

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

and

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

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., 2011). Additional argue is Fig. 7.2f 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 4.6 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., 2011). Using raw 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 et al., 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 water of NOWPAP area which comes on the shelf during upwelling (type c of source). There are different mechanisms of upwelling which are poorly understood and extensively discuss 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 4.6 and Fig. 7.11, 7.13) 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 4.6 and 7.1 say that Sub-area C has low eutrophication status as well.

8.2 Trend of eutrophication status of PGB.

Coastal waters are a very dynamic environment since they are influenced by both terrestrial inputs, natural and anthropogenic, as well as from inshore – offshore water exchanges, weather conditions and wind – driven water movements. All these physical mechanisms and the fact that nutrient transformations, nutrient uptake and phytoplankton growth proceed at a high rate, suggest that the trophic status of coastal area should not be considered as an almost static state. Otherwise, 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 impossible to establish any trends of these parameters on long-term scale. Nevertheless, we will 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.4.1).

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.8.1). 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.8.1. 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.8.2. Graphs on Fig.8.2 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.

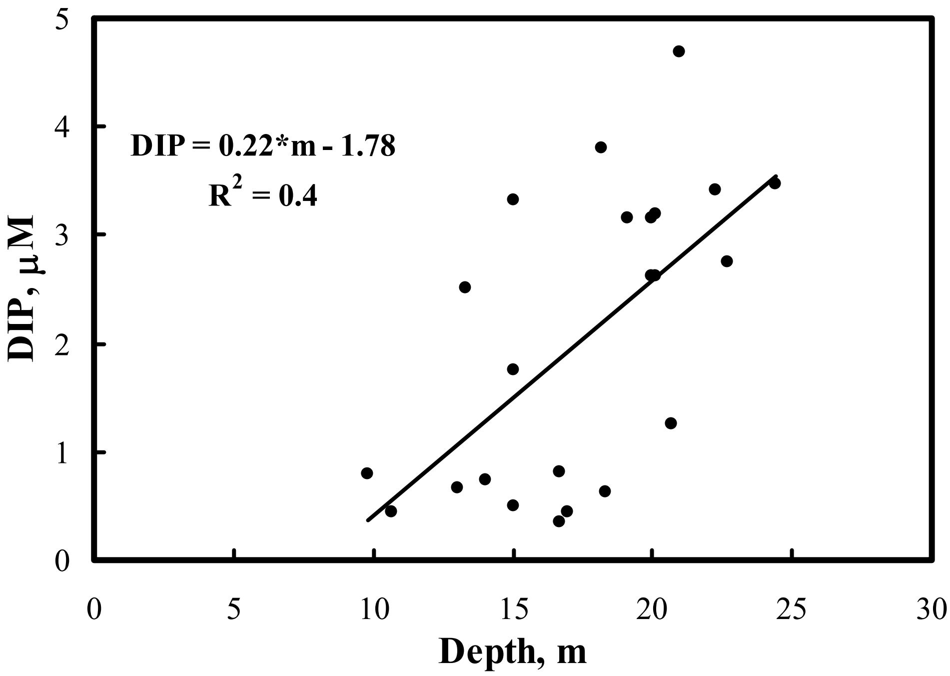

Fig.8.1 DIP concentrations in bottom layers as function of depth in chosen local area of central part of Amursky Bay which is situated on contrary of Peschanij Peninsula. Data obtained at August, 2008.

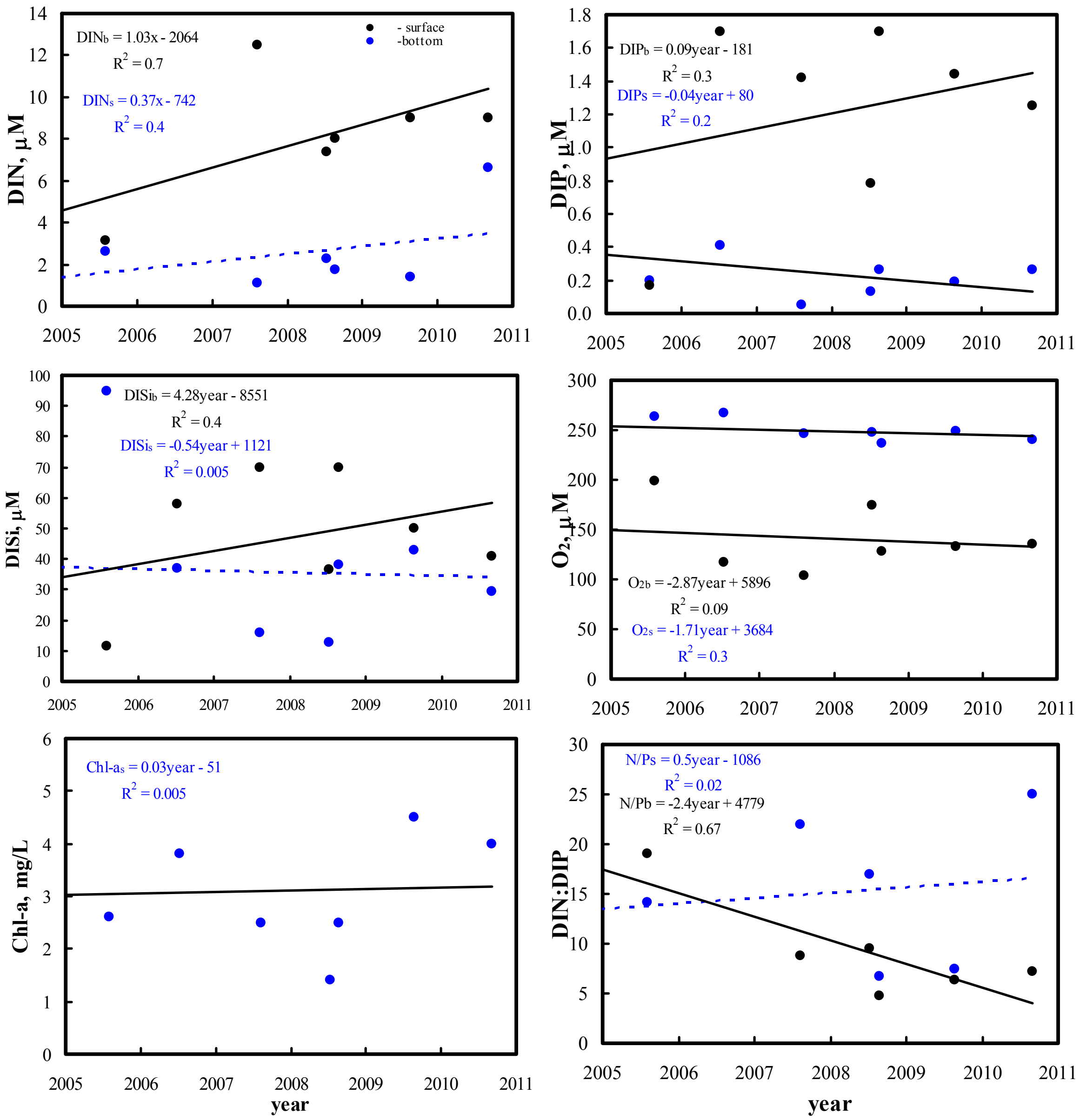

Fig.8.2 The variation of parameters in The Peter the Great Bay.

There are available data of water quality trends of Razdolnaya River (Fig. 8.3, (POMRAC, 2009)). Fig. 8.3 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 et al., 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 et al., 1995). Dramatically changes of bentic flora in Amursky Bay were found (Levenets et al., 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 et al., 2008). The investigations of long-term changes of macrozoobenthos in Amursky Bay suggest negative tendency in ecosystem of the bay (Moshchenko et al., 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 et al., 2008). Hydrochemical data (Fig. 8.1), and biological investigations (Silina et al., 1995; Levenets et al., 2008; Moshchenko et al., 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.

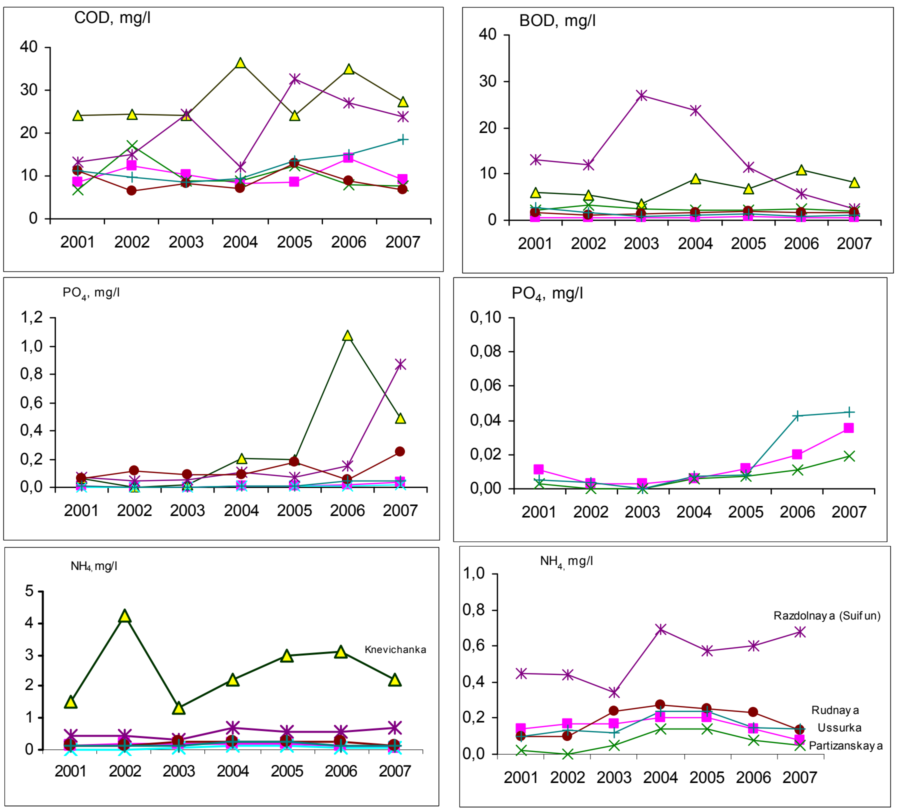

Fig.8.3 Trends of the water quality chemical parameters for some Russian rivers within NOWPAP area

Final identification of eutrophication status in PGB is summarized in Table 8.1. 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 8.1 Identification of eutrophication status in Peter the Great Bay for Sub-area A.

Category	Assessment parameter	Assessment value	Identification tools				Parameter Identification	Remarks
			Value	Comparison	Occurrence	Trend		
I	Riverine input DIN, t/y	Annual mean	1800	-	-	I	I	
	Riverine input DIP, t/y	Annual mean	120	-	-	I	I	
	DIN, μM	Raw data	Fig.7.1, 7.2, 7.6	H	-	I	HI	
	DIP, μM	Raw data	Fig.7.1, 7.2, 7.7	H	-	I	HI	
	DISi, μM	Raw data	Fig.7.1, 7.2, 7.8	H	-	I	HI	
	N/P	Annual mean	7.3					
II	Chlorophyll a, μg/l	Raw data	Fig.7.1, 7.2, 7.9	H	-	N	HN	
III	DO concentration, μM	Raw data	Fig.7.1, 7.2, 7.10	H	-	D	HD	
IV	Zoo-Phytobentos	*N/D						
	Kill fishes				L	N	LN	

*) N/D means No Data

Table 8.2 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	Compa-rison	Occur-rence	Trend		
I	Riverine input DIN, t/y	Annual mean	180	-	-	N	N	
	Riverine input DIP, t/y	Annual mean	25	-	-	N	N	
	DIN, µM	Raw data	Fig.7.11	L	-	N	LN	
	DIP, µM	Raw data	Fig.7.11	L	-	N	LN	
	DISi, µM	Raw data	Fig.7.12	H	-	N	HN	
	N/P	Annual mean	7.5					
II	Chlorophyll a, µg/l	Annual mean Annual max	1.9 6	L L	-	N N	LN LN	
III	DO concentration, µM	Raw data	Fig.7.12	L	-	N	LN	
IV	Zoo-Phytobentos	*N/D						
	Kill fishes				*N/D			

*)N/D means No Data

Table 8.3 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	Compa-rison	Occur-rence	Trend		
I	Riverine input DIN, t/y	Annual mean	250	-		N	N	
	Riverine input DIP, t/y	Annual mean	11	-		N	N	
	DIN, μM	Raw data	Table 7.1	L		N	LN	
	DIP, μM	Raw data	Table 7.1	L		N	LN	
	DISi concen-tration, μM	Raw data	Table 7.1	L		N	LN	
	N/P	Annual mean	10.5					
II	Chlorophyll a.	Raw data Raw value max	Table 7.1 11	L H		N N	LN HN	
III	DO concentration, μM	Raw data	Table 7.1	L	-	N	LN	
IV	Zoo-Phytobentos	*N/D						
	Kill fishes				*N/D			

*)N/D means No Data

9 Macroscopic View

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, 2009). 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., 1999). Many researches explained the decreasing of oxygen concentration by stagnation of deep waters (no ventilations and renewal) (Chen et al., 1999; Gamo et al., 1986; Kim et al.,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, 9.1, (Tishchenko et al., 2002)). Authors of paper (Tishchenko et al., 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. Now, we have to include additional important source of nutrients, it is N-enriched atmospheric deposition became widespread and caused unambiguous impacts in many areas that were not urban (Nixon, 2009). Because even open sea area between Japan, Russia and Korea is undergoing by eutrophication, then Sub-areas B and C of PGB are undergoing by eutrophication as well. Most important, a look through the global macroscope readily reveals that eutrophication of PGB is not a process affecting individual ecosystem, but is a global phenomenon both in its global spread and in the relative synchrony of this spread. Driven forces on the global scale include human population growth (mostly around East China Sea), increased anthropogenic emission of reactive nitrogen species to the atmosphere (mostly through using cars growth), increased atmospheric CO_2 (global acidification), climate change (Duarte., 2009).

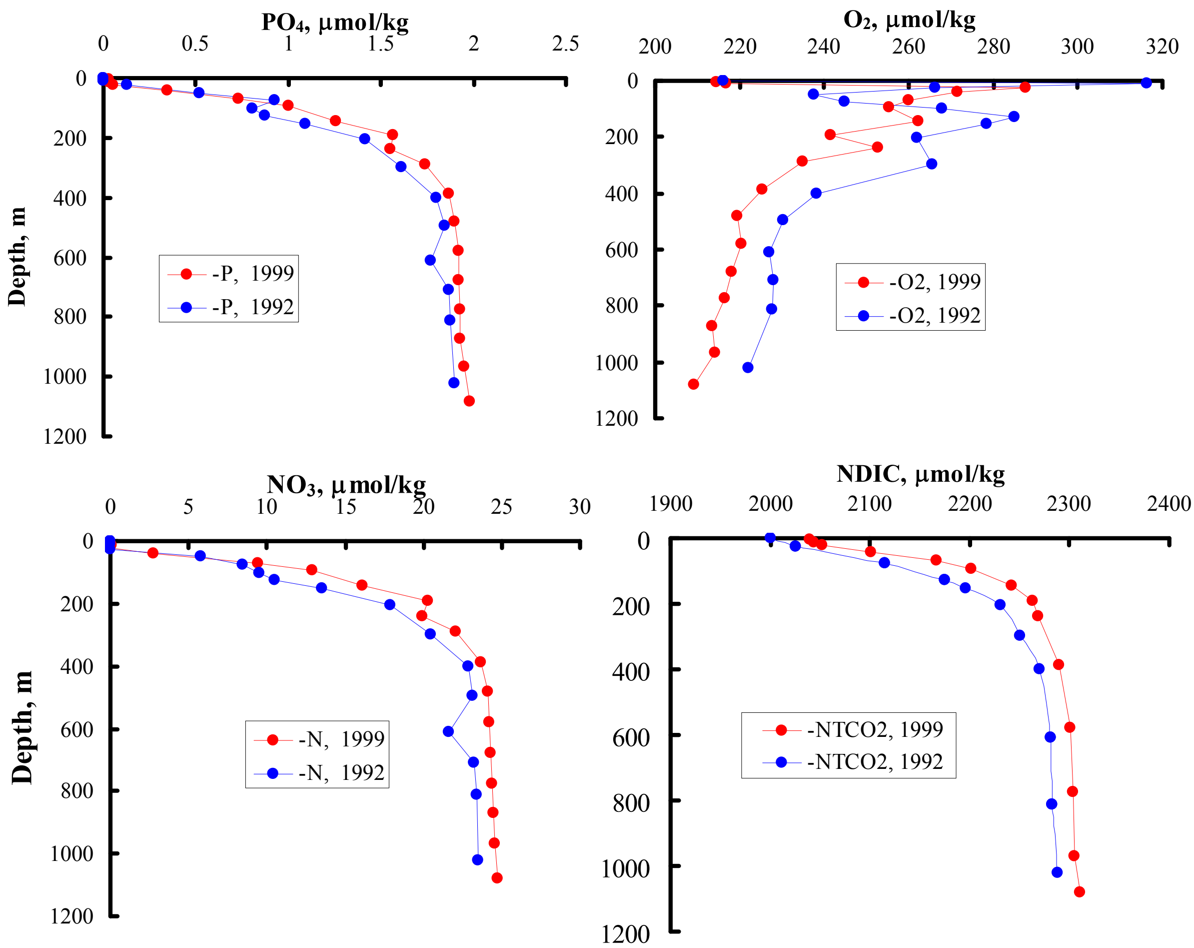

Fig.9.1 Temporal variability of nutrients (phosphates, nitrate), DO, and normalized dissolved inorganic carbon (NDIC) in NOWPAP Sea from data of station 177 (・=40.16oN, □=134.00 oE, 1999) and HS-11j (・=40.12oN, □=133.98 oE, 1992) [46].

10 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:

1. Northwestern part of Peter the Great Bay (Sub-area **A**, Amursky Bay) has current eutrophication status as "**High**" and "**Increase**";
2. Most part of Sub-area B can has eutrophication status as a "Low" with non-detectable trend;
3. At present time, most part of sub-area **C** has a "Low" eutrophication status with non-detectable trend.
4. 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 (Pshenichny et al., 1989) in hypoxia sites which will increase carrying capacity of ecosystem of Sub-area **A**.

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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 Phosphorous