— Synthesis —

Final report of the Amur Okhotsk Project 2005-2009

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ABSTRACT

The objective of the project is to elucidate the role of the Amur River in primary productivity in the Sea of Okhotsk and Oyashio region and then evaluate possible human impacts such as land surface disturbances in the Amur River basin on the marine ecosystem of the ocean. In this study, we attempt to answer 1) how dissolved iron is transported from the Amur River basin to the Sea of Okhotsk and Oyashio region, 2) to what extent the supply of dissolved iron regulates the primary production in these open waters, 3) how the land surface disturbances affect the material circulation in the Amur–Okhotsk system, 4) how human activity will impact the system in the future, and 5) how we can conserve this transboundary ecosystem. By answering these five questions, we propose a new global environmental concept, the “giant” fish-breeding forest (GFBF), in which there are physical and humanistic interactions between upstream and downstream, and determine a way of conserving the system in a cooperative effort among China, Russia, Mongolia and Japan.

Iron-bound material and ecological linkages from the Amur River basin to the Oyashio region via the Sea of Okhotsk were finally quantified by 1) observations of the spatiotemporal distribution of dissolved iron in various parts of the Amur River basin, 2) monthly monitoring of dissolved iron concentrations and discharges at Khabarovsk and Bogorodskoe, 3) observations of the temporal distributions of dissolved iron in the lower reach, mouth, and estuarial area of the Amur River, 4) measurements of dissolved iron in the Sea of Okhotsk and Oyashio region, and 5) measurements of the atmospheric iron input to the Oyashio region. It was found that approximately 40% of the dissolved iron necessary to support phytoplankton production in the Oyashio region was transported through the GFBF system. The remaining 60% was microbially recycled iron originally provided by intermediate water and atmospheric input.

It was found that there are two current threats to the GFBF system: global warming and human impacts on land surfaces. The former is most clearly indicated by the decreasing trend of sea ice production in the Sea of Okhotsk in recent decades and its impact on the ocean and material circulation in the northern North Pacific. The latter is illustrated by the decreasing trend of iron discharge from the Amur River basin to the Sea of Okhotsk due mainly to the reclamation of wetland to form paddy fields and dry land.

The Amur Okhotsk Consortium was established in November 8, 2009 as a multinational academic network to discuss the conservation and sustainable use of the GFBF. Japanese, Chinese and Russian members decided to hold a joint meeting every two years and exchange ideas, information and data routinely via the Internet between meetings.

1. INTRODUCTION

Those employed in fisheries in coastal and estuarial areas of Japan have protected the forest of the drainage basins bordering their fishery fields. The forest was called uotsuki-rin (the fish-breeding forest) and the existence of such forest was believed to improve the condition for fish growth in the coastal areas by providing various nutrients to the coast. In the late 1970s, professional fishermen noticed that coastal zones were seriously damaged and the areas were no longer productive. Pioneering fishermen believed that such ecological deterioration in coastal and estuarial areas was caused by rapid changes in the land surface of the adjacent drainage basins through excessive land-development starting during the Japanese economic growth in the 1960s. Some leaders of fishery groups advocated reforestation in the adjacent drainage basins to restore a rich ecological environment in coastal and estuarial areas (*e.g.*, Hatakeyama, 1994; Yaginuma, 1999). The movement is called uotsuki-rin undoh (the fish-breeding forest movement).

Practically, it was totally unknown to what extent the material discharged from rivers affects the marine ecosystem, how much and what kinds of materials are exported under various conditions of land surfaces and how far the terrestrial materials affect the off-shore marine ecosystem. Matsunaga *et al*. (1984, 1998) conducted one of the first studies to indicate a relationship between riverine organic-iron complex and phytoplankton in an estuarial area. Since then, an increasing number of studies have shown that the land–ocean linkage of material transport through rivers plays a key role in the growth of fish populations in estuarial and coastal areas (*e.g.*, Yamashita and Tanaka, 2008). The mechanisms behind the linkage are not yet fully understood; thereby, several international and domestic research organizations have begun tackling these issues with a multidisciplinary approach (*e.g.*, Connected Rings of Forest–Human Habitation–Marine by the Field Science Education and Research Centre of Kyoto University; Land–Ocean Interactions in the Coastal Zone by the International Geosphere Biosphere Program / International Human Dimensions Program).

In contrast to the relationship between the land-surface and the adjacent estuarial and coastal areas, it is widely accepted there is no relationship between the land-surface and open waters. This is because some of the riverine materials flocculate in estuarial areas and then accumulated on the continental shelves without moving to the open waters. Our project focuses on this conventional idea.

The northern North Pacific is known to be high in nutrients and low in chlorophyll (HNLC); dissolved macro nutrients (nitrate, phosphate and silicate) in the surface water cannot fully be utilized by phytoplankton because of the low availability of iron. Iron is usually supplied to estuarial and coastal regions from the land surface and it is difficult for iron to be transported to the remote central area of the northern North Pacific. This idea was proposed by Martin *et al*. (1989) and is called the iron limitation hypothesis. The idea is now being confirmed by a mesoscale *in situ* iron enrichment experiment in the North Pacific (Tsuda *et al*., 2003).

The neighboring Sea of Okhotsk is also characterized by sufficient nutrients supplied by the winter convective mixing of surface and deep waters. The Sea of Okhotsk is, however, not an HNLC region. This is probably because sufficient dissolved iron is transported from the Amur River. The Amur River, including major tributaries like the Shilka, Argun, Zeya, Bureya, Songhua Jiang (Sungari) and Ussuri Rivers, is 4444 km long and has a drainage area of 2,129,700 km^2 (Simonov and Dahmer, 2008). The major part of the drainage area is covered by boreal forest, mixed forest and swamps. The lower part of the drainage area is cultivated land and major cities such as Blagoveshchensk, Harbin, Khabarovsk and Komsomolsk-na-Amure. The relatively less developed Amur River basin enables the river to transport various kinds of terrestrial materials to the Sea of Okhotsk. Of particular importance is dissolved iron, which is considered to originate in an anoxic environment such as swamps.

The Sea of Okhotsk was studied intensively from 1997 to 2002 during the Core Research for Evolutional Science and Technology project led by Prof. Masaaki Wakatsuchi of the Institute of Low Temperature Science, Hokkaido University. It was found that two oceanographic mechanisms transport the water and materials from the mouth of the Amur River to the northern North Pacific. One is the East Sakhalin Current, which is a western boundary current along the east Sakhalin coast. Part of this current flows eastward as far as Bussol Strait to enter the northern North Pacific. The volume transport of this current is estimated to be in the range 3–10 Sv with an increase from summer to winter (Ohshima *et al*., 2002; Mizuta *et al*., 2003). The other mechanism transports water and material from the coastal area near the Amur River to the Sea of Okhotsk and further to the northern North Pacific including the Oyashio region (Nakatsuka *et al*., 2002, 2004). At the bottom of the northwestern continental shelf of the Sea of Okhotsk, very cold dense water due to brine rejection forms in winter. This water is characterized by enormously high turbidity due to tidal mixing and is transported into the intermediate depth by the East Sakhalin Current. By these two mechanisms, the water and material of the Amur River are effectively transported to the southern part of the Sea of Okhotsk and further to the northern North Pacific. Although no measurement of iron concentrations were conducted during Wakatsichi's project, it is highly probable that the riverine iron can be transported by the above mechanism to the northern North Pacific where iron is the key element controlling phytoplankton growth.

2. AIMS OF THE AMUR-OKHOTSK PROJECT (AOP)

If the above-mentioned mechanism is the case, the Amur River basin plays a crucial role in determining the biomass production both in the Sea of Okhotsk and the northern North Pacific including the Oyashio region. This relation reminds us of the Japanese concept of uotsuki-rin (the fish-breeding forest). However, the Amur–Okhotsk–Oyashio linkage is much stronger than that in the conventional concept. More importantly, this is the first attempt to relate the continental-scale terrestrial environment with open waters. Therefore, we refer to the idea as kyodai uotsuki-rin kasetsu (the "giant" fish-breeding forest (GFBF) hypothesis) and the verification of the hypothesis constitutes the first part of the AOP.

The dissolved iron mainly forms as a complex of iron and fulvic acids originating from forests and swamps in the basin (Matsunaga *et al*., 1998). The processes of the formation of the dissolved iron, its transportation to the river, and its delivery to the ocean are still open to question. It is, nevertheless, clear that changes in the land surface and river discharge affect the flux of the dissolved iron significantly, because the land surface and river constitute the source and method of dissolved iron inputs. The change in the dissolved iron flux may affect biomass production in the Sea of Okhotsk and the adjacent Oyashio region in the long run. Verifying the impact of terrestrial anthropogenic disturbances in the Amur River basin on primary production in the Sea of Okhotsk and Oyashio region is the second part of this project.

The Amur River drainage was developed after the end of the 19^{th} century in Russia (Ganzey, 2005). In China, *i.e.* the Songhua Jiang River basin, intensive human activity dates back several hundred years. An accelerated human impact became more obvious from the middle of the 20^{th} century on both sides of the Amur River. The area is disturbed currently by various anthropogenic and natural impacts such as forest fires, deforestation, agricultural and industrial activities, flooding and drought. Land-use changes in the Amur River drainage area, therefore, might have caused or may cause significant changes in the flux of dissolved iron, which might have or may result in biomass production changes in the ocean.

The Sea of Okhotsk and the northern North Pacific are known to be one of the most productive oceanic areas in the world. Approximately 50% of the sea product of Japan is from this area. Therefore, the ecosystem and environment of the Sea of Okhotsk and the adjacent Oyashio region are important not only with respect to the environment but also the economy of Japan.

Moreover, recent climatological analysis showed that sea–air CO_2 exchange in Oyashio and its adjacent areas was a unique centre where the most intensive exchange in pCO_2 occurred (Takahashi *et al*., 2002). This indicates phytoplankton growth in this region is important not only to the sea product but also the global climate.

Therefore, it is very important to clarify a robust relationship between conditions of the Amur River basin and ecosystems in the Sea of Okhotsk and Oyashio region to predict land-use impacts on the future marine primary productivity in the ocean. This information will be helpful not only for people concerned with uotsuki-rin, but also for people consuming sea products. In this context, the Amur River basin and the Sea of Okhotsk and Oyashio region are the most typical and extensive examples in the world.

As mentioned previously, the conservation of uotsuki-rin was begun by fishermen who profited from this system. The idea was then accepted nationwide and there began regional-scale attempts to protect uotsuki-rin by various stakeholders such as fishermen, citizens and municipal officers. The third part of this project therefore presents an idea of how we can conserve the GFBF, which encompasses multiple countries, exclusive economic zones and open waters.

In addition to physical boundaries, the Amur River has been the site of political boundaries between China and Russia since the “Treaty of Aigun” and “Convention of Peking” signed by the two countries in 1858 and 1860, respectively. Since the two agreements were considered to be unequal treaties, the boundary was rather unstable until the two countries finally agreed to define the boundary in 2004. This history has made the Amur River one of the most difficult rivers to monitor for conservation purposes. In practice, there was no formal joint-monitoring program between the two countries until a notorious accident involving a petrochemical company in the Chinese province of Jiling in 2005. This accident significantly polluted the Songhua River, the largest tributary of the Amur River (UNEP, 2006).

The Sea of Okhotsk has been a political hot spot between Russia and Japan. Owing to territorial conflict, it was practically impossible for Japan to monitor environmental problems in the Sea of Okhotsk during the last half of the 20th century. A collaborative effort between Russia and Japan for the environmental conservation of the Sea of Okhotsk is urgently needed owing to increasing activities relating to oil mining and natural gas exploration in the Sea of Okhotsk and its vicinity.

The above background indicates the GFBF is of local as well as worldwide importance and its concept will contribute to the solving of practical problems several countries are facing.

3. PROJECT ORGANIZATION

The physical structure of the GFBF was studied by joint collaborations between groups in the fields of biogeochemistry, geography, hydrology, climatology, glaciology and oceanography. Economic flows, land-use background analyses, and a conservation strategy for the system were studied by scientists in the fields of forest engineering, agronomy, economic geography, international law and politics (see the project members listed in the Appendix).

This project is composed of 10 research groups headed by group leaders. The project leader and 10 group leaders constitute the board of the project. In addition to individual group meetings, at least one project meeting was held each year to discuss cross boundary issues. Daily communications and discussions were carried out through an Internet mailing list.

The themes/tasks of each research group are as follows.

Group 1 (GL: Dr. Kay I Ohshima): Physical oceanographic conditions in the Sea of Okhotsk and the northern North Pacific. This group carried out physical oceanographic observations aiming to quantify the flux of the East Sakhalin Current and water exchange across Bussol Strait, all of which are essential in estimating the iron flux in the Sea of Okhotsk and Oyashio region. Special attention was paid to the role of sea ice in the Sea of Okhotsk, which was supposed to be a driver of thermohaline circulation in the Sea of Okhotsk.

Group 2 (GL: Dr. Takeshi Nakatsuka): Geochemical and biological conditions in the Sea of Okhotsk and the northern North Pacific. This group embarked on research cruises in the Sea of Okhotsk and adjacent areas and focused on the spatial distribution of chemical and biological properties to investigate the source and transportation of dissolved iron. *In situ* observations of phytoplankton in the Sea of Okhotsk and Oyashio region were also conducted.

Group 3 (GL: Dr. Seiya Nagao): Transport of biogeochemical materials from the Amur River to the Sea of Okhotsk. This group conducted three different observations: the monthly monitoring of water quality at Khabarovsk, Bogorodtskoe and Nikoraevsk-na-Amure, observations of water samples collected on research cruises along the lower reaches of the

Amur River, and observations of water samples collected on research cruises in the estuarial area of the Amur River. These field samplings and the analyses provided a basic idea of how dissolved iron was transported from the Amur River to the Sea of Okhotsk.

Group 4 (GL: Dr. Hideaki Shibata): Biogeochemical transport from the terrestrial ecosystem to the Amur River. This group continuously monitored water quality on various land surfaces including natural forest, forest damaged by fire, wetlands, paddy fields and upland fields in Russia and China. The Sanjiang plain was of particular interest since this vast plain was largely covered with wetlands but has been most intensively reclaimed during the last 20 years of the 20th century.

Group 5 (GL: Dr. Hiroaki Kakizawa): Background of anthropogenic impacts in the Amur River basin. This group analyzed the background behind forest management, agricultural policy and timber trading both in Russia and China. The group paid special attention to the international driving forces behind these socio-economic situations.

Group 6 (GL: Dr. Shigeko Haruyama): Spatial and historical monitoring of land-use changes in the Amur River basin. This group attempted to visualize spatial changes in land uses in the Amur River basin by means of satellite image interpretation, field work and statistical analyses.

Group 7 (GL: Dr. Sumito Matoba): Estimation of the atmospheric transport of terrestrial material. This group extended a real-time observation network for aerosol deposition around the Sea of Okhotsk. It also conducted ice-core drilling to reconstruct the past atmospheric input of iron to the study area.

Group 8 (GL: Dr. Takeo Onishi): Numerical modelling of basin-scale hydrology and iron transport. This group attempted to develop a numerical hydro-geochemical model with special emphasis on iron dynamics for the Amur River basin.

Group 9 (GLs: Drs. Hiroyuki Matsuda and Fumio Mitsudera): Numerical modelling of iron transport in the Sea of Okhotsk and the northern North Pacific. This group attempted to develop a numerical ocean ecosystem model to simulate the importance of dissolved iron to the phytoplankton in the Sea of Okhotsk and Oyashio region. The model was lately modified by including physical code to describe the North Pacific Intermediate Water (NPIW), which was considered to be the main source of current transporting the dissolved iron to the Oyashio region.

Group 10 (GL: Mr. Yasunori Hanamatsu): Conservation strategy for the GFBF. This group was established just recently and will endeavour to find a framework for conserving the GFBF. The group reviewed all international and domestic laws and institutions that were originally created to address particular aspects of the environment in this region.

3. RESULTS OF THE AMUR OKHOTSK PROJECT

Major achievements of the Amur Okhotsk Project (2005–2009) are described by answering the five essential questions of the project. Detailed results of each topic are described by the group leaders in the group reports in this volume.

1) **How is dissolved iron transported from the Amur River basin to the Sea of Okhotsk and Oyashio region ?**

Average annual fluxes of total and dissolved iron were estimated in various parts of the GFBF and they confirmed the continuity of iron transportation from the land surfaces of the Amur River basin to the surface water of the Oyashio region (Fig. 1). The natural wetlands with gentle slope located at middle and lower part of Amur basin was major source of dissolved iron from terrestrial zone to Amur river.

In the upstream forested basin, dissolved iron in soil was mainly transported with dissolved organic carbon (DOC) rather than as Fe(II) and Fe(III). The riparian zone near the stream channel is an important source of iron owing to its wet and anaerobic condition increasing the DOC concentration and dissolving iron in soil and groundwater.

In the natural wetlands, the dissolved Fe concentration is around 1 mg Fe L^{-1} in the surface water and much higher (sometimes more than 10 mg Fe L^{-1}) in soil interstitial waters, having a seasonal variation with maxima in summer. The dissolved Fe concentration observed for a number of rivers and agricultural drainage waters of the Sanjiang plain when not frozen has an average of approximately 1 mg Fe L^{-1} and varies considerably according to the condition of the watershed. Dissolved Fe is dominantly present as complexed forms in soil water, river water and agricultural drainage water, in which humic substances play an important role in the transportation of iron as a complex ligand.

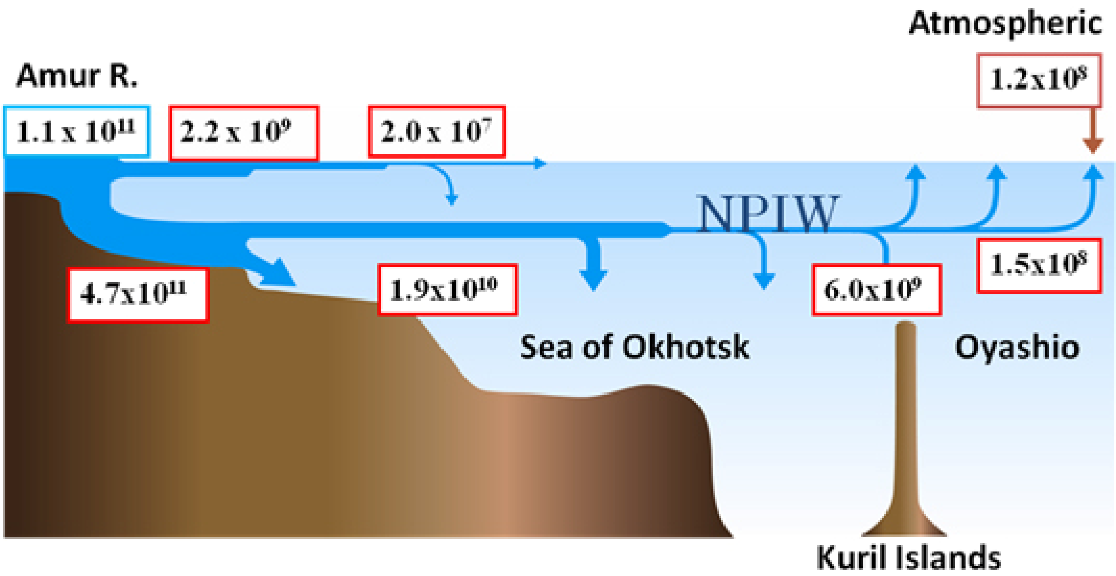

Figure 1 Quantitative evaluation of Fe transport efficiency (g/yr) in the Sea of Okhotsk (modified from Nishioka et al., in press).

As a result, $1.1 \pm 0.7 \times 10^{11}$ g/yr of dissolved iron is transported to the estuarial area from the Amur River annually. Approximately 95% of the dissolved iron coagulates at Amur–Liman (the estuarial area) and Sakhalin Bay. There are two pathways of iron transportation from the estuarial area to the Oyashio region: 1) surface transportation of total iron and 2) transportation with the North Pacific Intermediate Water (NPIW). The former supports primary production in the Sea of Okhotsk while the latter supports primary production in the Oyashio region. It is estimated that approximately $1.2–1.5 \times 10^{8}$ g/yr of total iron is provided by the atmosphere and NPIW in the Oyashio region.

2) To what extent does the supply of dissolved iron regulate primary production in the open waters?

It was found that of the iron used by the spring bloom in the Oyashio region, 40% is provided through the GFBF system and 60% is recycled through microbial processes. We are not yet certain about the relative importance of atmospherically derived iron to primary production in the Oyashio region because of its temporal sporadicity, spatial unevenness and insoluble nature. In spite of this uncertainty, it is reasonably concluded that the iron controls phytoplankton growth in the Oyashio region because phytoplankton growth ceases under iron limitation at all high nitrate concentrations.

It is yet uncertain to what extent the supply of dissolved iron regulates primary production in the open waters. This is due mainly to a lack of sufficient observational data on both annual changes in the dissolved iron flux and the biomass in the Oyashio region. To determine the role of the dissolved iron, we used a three-dimensional coupled ecosystem physical model that includes the effect of iron on the Sea of Okhotsk. We hypothesized that four processes supply iron to sea water: atmospheric loading, input from the Amur River, dissolution from sediments and regeneration by zooplankton and bacteria. We simulated one year, from 1 January 2001 to 31 December 2001. As a result, the model taking iron into account agreed well with the observation. However, we are not yet able to simulate the time series of the iron impact, since the model cannot simulate the NPIW, which we believe is the most important current in the transportation of riverine iron from the Amur River.

3) How do land surface disturbances affect material circulation in the Amur–Okhotsk system?

The impact of land-use change on iron discharge was studied in experimental plots of upland fields and paddy fields on the Sanjiang plain, which were converted from natural wetlands several decades ago (Fig. 2). Soil in the upland fields was found to remain in an oxidized condition throughout the year, implying the absence of iron discharge. In paddy fields, surface water and soil water had dissolved Fe concentrations somewhat lower than

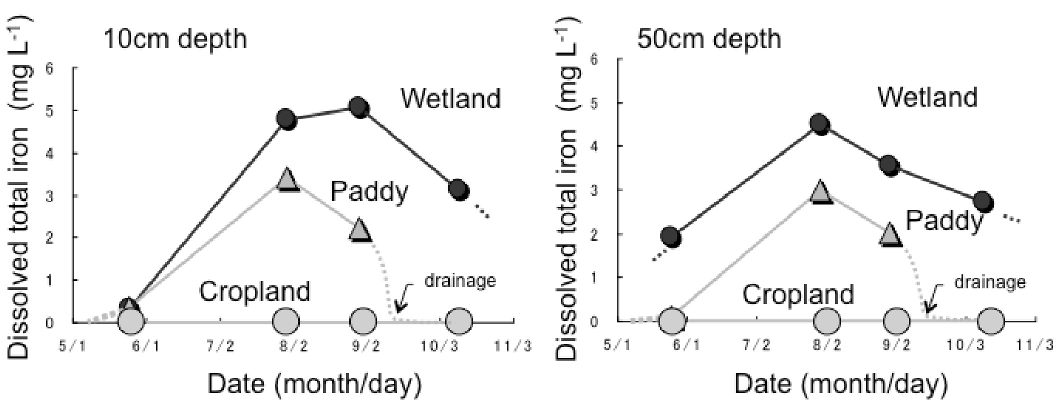

Figure 2 Seasonal changes of dissolved iron concentration in soil solutions of three land-use types in Sanjiang Plain (Yoh et al., in press).

those of natural wetlands, but importantly, the controlled water discharge due to agricultural management is considered to largely lower the iron discharge.

Paddy fields on the Sanjiang plain are irrigated with ground water in most cases. The strikingly high concentration of dissolved iron (largely in the form of Fe^{2+}) might indicate an additional iron source. However, elevated contents of amorphous iron oxides in the upper soil layer in paddy fields were found to adequately account for the calculated total amount of iron supplied by the irrigation of ground water since the rice paddy conversion on the Sanjiang plain, suggesting an almost complete retention of iron added by the ground water. Considering the irrigation and the controlled water discharge described above, it is concluded that iron discharge may be much less for paddy fields than for natural wetlands.

Monitoring data indicate that the concentration of dissolved iron in the Naoli River, which runs across the Sanjiang plain, has been consistently decreasing in recent decades. The observation of a peat layer, except in hilly areas, suggests a predominance of wetlands on the Sanjiang plain in the pristine age. However, a survey of the ground water table demonstrated that the current ground water levels were greatly lowered in most regions owing to reclamation by water drainage. It is likely that the land previously dominated by wetlands has been becoming steadily drier on the Sanjiang plain, which has reduced the Fe discharge as mentioned above.

Land-use and historical changes in the Amur River basin were visualized by various temporal and spatial mappings. We compiled land-use maps for both the 1930s and 2000 for the whole Amur River basin. Changes in the most recent 19 years were analyzed using Pathfinder AVHRR Land datasets and satellite remote-sensing techniques. The results show significant changes on the Sanjiang plain in which approximately 10,000 km^2 of wetland was reclaimed as paddy fields from 1980 to 2000. Aerial changes of Russian forest were not significant but the quality of the forest is considered to be deteriorating mainly owing to frequent forest fires and poor management.

Such land-use changes were caused by various factors. According to analyses of the underlying causes of the degradation of forest resources in Khabarovsk Krai and the current state of forest management policy, forest fire and poor management systems are identified as the major causes of forest degradation. The rapid increase in timber exports to China and poor forest policy are considered to accelerate forest degradation. On the Sanjiang plain, there was rapid development of paddy fields in accordance with governmental policy. Farm management has improved, but a lack of water has become a serious issue and the excessive pumping of ground water has caused the rapid lowering of the ground water table on the Sanjiang plain.

4) How will human activity impact the system in the future?

We attempted to develop a numerical hydro-geochemical model with special emphasis on iron dynamics for the Amur River basin. The accuracy of the calculated discharge and dissolved iron concentration are sufficient at a time resolution of one month during the period from 1980 to 1990. Using the model, the effect of land cover change on dissolved iron productivity was evaluated. The results of numerical experiments suggest that 50% conversion of remaining wetlands to agricultural lands might decrease the dissolved iron flux by more than 10% (Fig. 3).

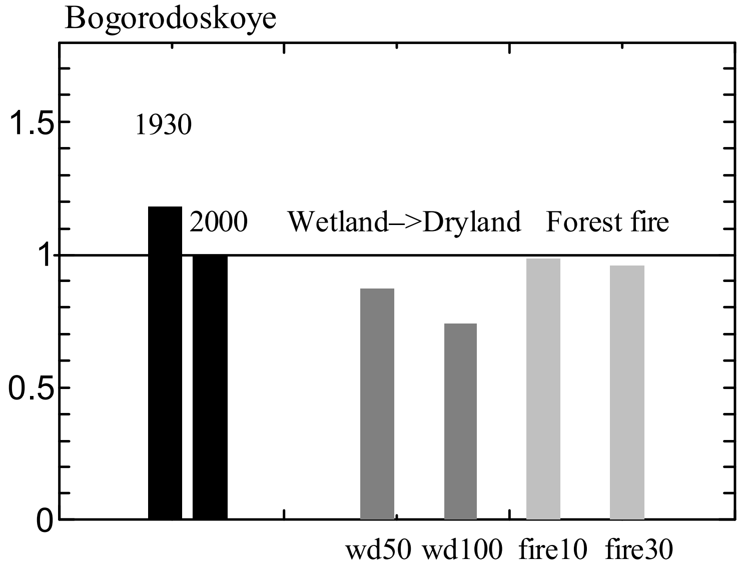

Figure 3 Simulated results of land cover conversion (wd50: 50% converted, wd100: 100% converted, fire10: forest fire area is 10%, fire20: forest fire area is 20%) effect on dissolved iron productivity of the basin (Ohnishi, in press).

5) How can we conserve this transboundary system ?

The key problem in conservation is how to establish a multilateral cooperative framework for the GFBF system. There have already been some bilateral frameworks, including the formal joint-monitoring program between China and Russia after the Songhua River accident involving a petrochemical company in the Chinese province of Jiling in 2005, and the cooperative program on the research, conservation and sustainable use of the ecosystems in the Sea of Okhotsk signed by Russia and Japan in 2009. However, there has been no multilateral governmental framework concerning the GFBF system. At this stage, joint-monitoring, data exchange and mutual communication at an academic level are necessary as a starting point for the protection of the GFBF system. For this purpose, we established the Amur Okhotsk Consortium as a multinational academic network to discuss the conservation and sustainable use of the GFBF (Fig. 4). The network can be thought of as comprising "epistemic communities"; Peter Haas proposed that such networks of knowledge-based experts could help states identify their interests, frame issues for collective debate, propose specific policies, and identify salient points for negotiations. Our attempt is motivated by the history of the environmental protection of the Baltic Sea from marine pollution for over 30 years.

Figure 4 The Amur Okhotsk Consortium was established in November 8, 2009 on the occasion of the International Symposium on "Environmental Conservation of the Sea of Okhotsk: Cooperation between Japan, China and Russia".

On the other hand, we have analysed existing international and domestic laws and policies that seem to be applicable for the conservation of the GFBF system. A future conservation framework would incorporate them as useful components. The results show that while environmental factors in GFBF have already been partially regulated by international and national laws and policies, these management regimes have been established and implemented independently, and they sometimes overlap or conflict; therefore, they are not adequate for the conservation of the whole GFBF system. We conclude that it is important to coordinate and strengthen existing laws and policies in an integrated manner to manage this system consistently and effectively (Fig. 5).

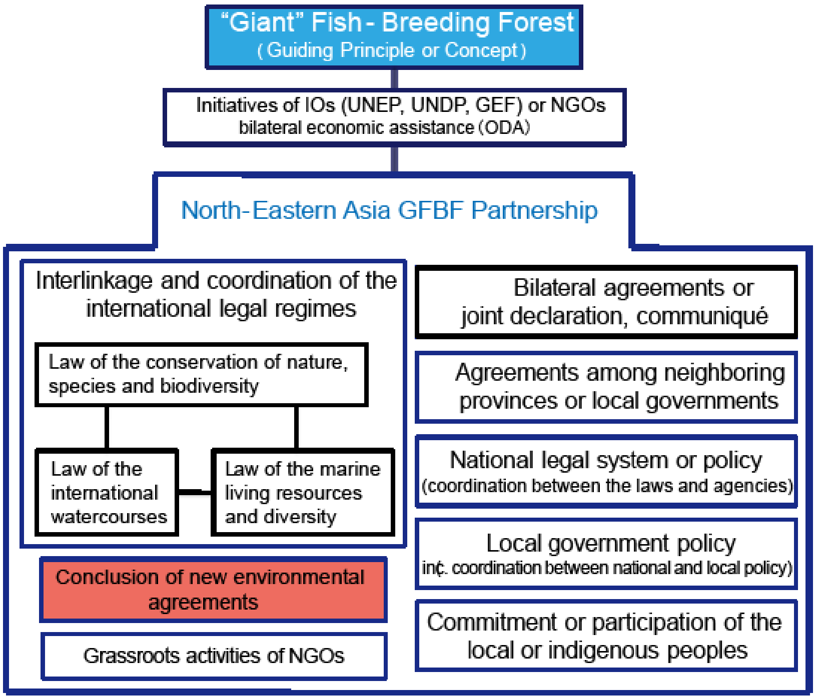

Figure 5 Structure of the Northeastern Asia GFBF Partnership (Hanamatsu, 2009).

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Appendix: Project members

Name	Affiliation	Specialised Fields	Project Working Group	Roles in the Project
SHIRAIWA, Takayuki	Research Institute for Humanity and Nature	Physical geography	Project leader	organization of the project
OHSHIMA, Keiichiro	Institute of Low Temperature Science, Hokkaido Univ.	Physical Oceanography	Group 1	physical oceanographic analysis on the North Pacific intermediate water
FUKAMACHI, Yasushi	Institute of Low Temperature Science, Hokkaido Univ.	Physical Oceanography	Group 1	physical oceanographic analysis on the North Pacific intermediate water
YASUDA, Ichiro	Graduate School of Frontier Science, Univ. of Tokyo	Physical Oceanography	Group 1	tidal mixing of water in the Bussol strait
WAKATSUCHI, Masaaki	Institute of Low Temperature Science, Hokkaido Univ.	Physical Oceanography	Group 1	physical oceanographic analysis on the North Pacific intermediate water
NAKATSUKA, Takeshi	Graduate School of Environmental Studies, Nagoya Univ.	geochemistry	Group 2	transport of materials by dense shelf water and North Pacific intermediate water
KUMA, Kenshi	Graduate School of Fisheries Science, Hokkaido Univ.	geochemistry	Group 2	analysis of iron of open waters
NISHIOKA, Jun	Institute of Low Temperature Science, Hokkaido Univ.	geochemistry	Group 2	transport of iron in the Sea of Okhotsk and Oyashio region
SUZUKI, Koji	Graduate School of Environmental Earth Sciences, Hokkaido Univ.	Ocean biogeochemistry	Group 2	phytoplankton dynamics in the Sea of Okhotsk and Oyashio region
SEKI, Osamu	Institute of Low Temperature Science, Hokkaido Univ.	Geochemistry	Group 2	analysis on bottom sediment in the Sea of Okhotsk
SOURIN, Rumi	Faculty of Science, Shizuoka Univ.	Ocean biology	Group 2	microbial process in the open waters
TUDA, Atsushi	Graduate School of Frontier Science, Univ. of Tokyo	Ocean biology	Group 2	zooplankton dynamics in the Sea of Okhotsk and Oyashio region
MATSUNAGA, Katsuhiko	Yokkaichi Univ.	Geochemistry	Group 2	fuluvic acids and iron complex in the sea water
YOSHIMURA, Takeshi	Environmental Science Research Laboratory, Central research Institute of Electric Power Industry	Geochemistry	Group 2	transport of iron in the Sea of Okhotsk and Oyashio region
SUGIE, Kouji	Central Research Institute of Electric Power Industry	Geochemistry	Group 2	iron analysis in the sea water
NAGAO, Seiya	Low Level Radio activity Laboratory, Institute of Nature and Environmental Technology, Kanazawa Uni.	Geochemistry	Group 3	biogeochemical analyses on Amur-river water
KODAMA, Hiroki	Analytical Research Center for Experimental Sciences, Saga University	Geochemistry	Group 3	analysis on organic matter in the river water
TERASHIMA, Motoki	Japan Atomic Energy Research Institute	Geochemistry	Group 3	experimental study on dynamics of organic matter and iron
SHIBATA, Hideaki	Field Science Center for Northern Biosphere, Hokkaido Univ.	Biogeochemistry	Group 4	biogeochemical characteristics of river waters from different land surfaces

YOH, MUNEOKI	ENVIRONMENTAL CONSERVATION, TOKYO UNIV. OF AGRICULTURE & TECHNOLOGY	BIOGEOCHEMISTRY	GROUP 4	BIOGEOCHEMICAL CHARACTERISTICS OF RIVER WATERS FROM DIFFERENT LAND SURFACES
KAWAHIGASHI, MASAYUKI	NIHON UNIVERSITY COLLEGE OF BIORESOURCE SCIENCES	GEOCHEMISTRY	GROUP 4	ANALYSES ON ORGANIC-IRON COMPLEX IN THE AMUR RIVER BASIN
KAKIZAWA, HIROAKI	GRADUATE SCHOOL OF AGRICULTURE, HOKKAIDO UNIV.	FOREST MANAGEMENT	GROUP 5	BACKGROUND ANALYSIS ON RUSSIAN FOREST MANAGEMENT
IWASHITA, AKIHIRO	SLAVIC RESEARCH CENTER, HOKKAIDO UNIV.	POLITICAL SCIENCE	GROUP 5	POLITICS BETWEEN RUSSIA AND CHINA
PAKU, KOU	GRADUATE SCHOOL OF AGRICULTURE, HOKKAIDO UNIV.	AGRICULTURAL ECONOMICS	GROUP 5	BACKGROUND ANALYSIS ON CHINESE AGRICULTURAL SOCIOLOGY
SAKASHITA, AKIHIKO	FIELD SCIENCE CENTER FOR NORTHERN BIOSPHERE, HOKAKIDO UNI.	AGRICULTURAL ECONOMICS	GROUP 5	BACKGROUND ANALYSIS ON CHINESE AGRICULTURAL SOCIOLOGY
YAMANE, MASANOBU	KANAGAWA PREFECTURAL NATURE CONSERVATION CENTER	FOREST ECONOMICS	GROUP 5	BACKGROUND ANALYSIS ON TIMBER TRADES AMONG RUSSIA, CHINA AND JAPAN
HARUYAMA, SHIGEKO	GRADUATE SCHOOL/FACULTY OF BIORESOURCES, MIE UNIV.	PHYSICAL GEOGRAPHY	GROUP 6	LANDFORM CLASSIFICATION IN THE AMUR RIVER BASIN
KONDO, AKIHIKO	CHIBA UNIV. ENVIRONMENTALREMOTE SENSING CENTER	PHYSICAL GEOGRAPHY	GROUP 6	REMOTE SENSING ON LAND COVER CHANGES IN THE AMUR RIVER BASIN
MUROOKA, MIZUE	HOKKAIDO ABASHIRI FISHERIES EXPERIMENTAL STATION	PHYSICAL GEOGRAPHY	GROUP 6	REMOTE SENSING ON LAND USE CHANGES IN THE AMUR RIVER BASIN
YAMAGATA KOTARO	JOETSU UNIV. OF EDUCATION	PHYSICAL GEOGRAPHY	GROUP 6	GEOMORPHOLOGICAL ANALYSIS ON FLOOD PLAIN LANDFORMS IN THE AMUR RIVER BASIN
HIMIYAMA, YUKIO	HOKKAIDO UNIV. OF EDUCATION	HUMAN GEOGRAPHY	GROUP 6	LAND-USE CHANGES AND ITS BACKGROUND ANALYSIS
UEMATSU, MITSUO	OCEAN RESEARCH INSTITUTE, UNIV. OF TOKYO	GEOCHEMISTRY	GROUP 7	DEPOSITION OF VARIOUS MATERIALS FROM ATMOSPHERE
MATOBA, SUMITO	INSTITUTE OF LOW TEMPERATURE SCIENCE, HOKKAIDO UNIV.	GEOCHEMISTRY	GROUP 7	HISTORICAL CHANGES OF IRON DEPOSITION BY MEANS OF ICE CORE ANALYSIS
NARITA, HIDEKI	INSTITUTE OF LOW TEMPERATURE SCIENCE, HOKKAIDO UNIV.	GEOCHEMISTRY	GROUP 7	REAL-TIME MONITORING OF ATMOSPHERIC DEPOSITION OF VARIOUS MATERIALS
NAKAWO, MASAYOSHI	NATIONAL INSTITUTES FOR THE HUMANITIES	GLACIOLOGY	GROUP 7	ICE CORE ANALYSIS
MINAMI, HIDEKI	SCHOOL OF BIOLOGICAL SCIENCE AND ENGINEERING, TOKAI UNIV. HOKKAIDO SAPPORO CAMPUS	GEOCHEMISTRY	GROUP 7	CHEMICAL ANALYSIS ON AEROSOL AND OCEAN SEDIMENTS
YASUNARI, TEPPEI	NASA GODDARD SPACE FLIGHT CENTER (GEST/UMBC)	ATMOSPHERIC SCIENCE	GROUP 7	RECONSTRUCTION OF DUST DEPOSITION BY MEANS OF ICE CORE ANALYSIS
SASAKI, HIROTAKA	GRADUATE SCHOOL OF ENVIRONMENTAL EARTH SCIENCES, HOKKAIDO UNIV.	GEOCHEMISTRY	GROUP 7	RECONSTRUCTION OF IRON FLUX FROM ATMOSPHERE BY MEANS OF ICE CORE ANALYSIS
ONISHI, TAKEO	RIVER BASIN RESEARCH CENTRE, GIFU UNI.	HYDROLOGY	GROUP 8	NUMERICAL MODELLING OF HYDROLOGICAL / GEOCHEMICAL TRANSPORTS IN THE AMUR RIVER BASIN
TACHIBANA, YOSHIHIRO	GRADUATE SCHOOL/FACULTY OF BIORESOURCES, MIE UNIV.	CLIMATOLOGY	GROUP 8	CLIMATE CHANGES AND ITS IMPACT ON AMUR RIVER AND THE SEA OF OKHOTSK

KUBOTA, JUMPEI	RESEARCH INSTITUTE FOR HUMANITY AND NATURE	HYDROLOGY	GROUP 8	HYDROLOGICAL ANALYSES
TAKAHARA HIKARU	KYOTO PREFECTURAL UNIV.	FOREST ECOLOGY	GROUP 8	RECONSTRUCTION OF PALEOENVIRONMENT IN THE AMUR RIVER BASIN BY POLLEN ANALYSIS
MATSUDA, HIROYUKI	GRADUATE SCHOOL OF ENVIRONMENT AND INFORMATION SCIENCES, YOKOHAMA NATIONAL UNIV.	THEORETICAL ECOLOGY	GROUP 9	THEORETICAL CONSIDERATION ON MANAGEMENT OF "GIANT" FISH-BREEDING FOREST
KISHI, MICHIO	GRADUATE SCHOOL OF FISHERIES SCIENCE, HOKKAIDO UNIV.	OCEAN BIOLOGY	GROUP 9	NUMERICAL MODELLING OF PHYTOPLANKTON PRODUCTION IN THE SEA OF OKHOTSK AND OYASHIO REGION
MITSUDERA, FUMIO	INSTITUTE OF LOW TEMPERATURE SCIENCE, HOKKAIDO UNIV.	PHYSICAL OCEANOGRAPHY	GROUP 9	NUMERICAL MODELLING OF NORTH PACIFIC INTERMEDIATE WATER
ARAI, NOBUO	SLAVIC RESEARCH CENTER, HOKKAIDO UNIV.	ECONOMICS	GROUP 9	ASSESSMENT OF SEA PRODUCT IN THE SEA OF OKHOTSK
SAITO, SEIICHI	GRADUATE SCHOOL OF FISHERIES SCIENCE, HOKKAIDO UNIV.	OCEAN BIOLOGY	GROUP 9	SATELLITE OBSERVATION ON PRIMARY PRODUCTION
SUGIMOTO, TAKASHIGE	SCHOOL OF MARINE SCIENCE AND TECHNOLOGY, TOKAI UNIV.	OCEAN BIOLOGY	GROUP 9	ASSESSMENT OF TERRESTRIAL IMPACT ON ESTUARY ECOSYSTEM
HANAMATSU, YASUNORI	RESEARCH INSTITUTE FOR HUMANITY AND NATURE	INTERNATIONAL LAW	GROUP 10	INTERNATIONAL LAW ON AMUR-OKHOTSK SYSTEM
HORIGUCHI, TAKEO	HOKKAIDO UNIV. PUBLIC POLICY SCHOOL	INTERNATIONAL LAW	GROUP 10	INTERNATIONAL LAW ON AMUR-OKHOTSK SYSTEM
ENDOU, TAKAHIRO	RESEARCH INSTITUTE FOR HUMANITY AND NATURE	INTERNATIONAL RELATIONS	GROUP 10	REGIONAL AND INTERNATIONAL WATER MANAGEMENTS
SERGIRNKO, VALENTINE.	RUSSIAN ACADEMY OF SCIENCES, FAR EASTERN BRANCH	GEOCHEMISTRY	RUSSIAN COLLABORATION	ORGANIZATION OF RUSSIAN SCIENTISTS
SHCHEKA, OLEG	INTERNATIONAL COOPERATION AND TOURISM DEPARTMENT OF PRIMORSKY TERRITORY GOVERNMENT	GEOCHEMISTRY	RUSSIAN COLLABORATIONS	ANALYSES ON FOREIGN TRADES AMONG THE FAR EASTERN COUNTRIES
VORONOV, BORIS A.	INSTITUTE OF WATER AND ECOLOGICAL PROBLEMS, FEBRAS	BIOLOGY	RUSSIAN COLLABORATIONS	CONSERVATION OF AMUR RIVER
MAKHINOV, ALEXEY N.	INSTITUTE OF WATER AND ECOLOGICAL PROBLEMS, FEBRAS	HYDROLOGY	RUSSIAN COLLABORATIONS	HYDROLOGICAL ANALYSIS ON AMUR RIVER
KONDRATJEVA, LUBOV M	INSTITUTE OF WATER AND ECOLOGICAL PROBLEMS, FEBRAS	CHEMISTRY	RUSSIAN COLLABORATIONS	POLLUTION OF AMUR RIVER
SHAMOV, VLADIMIR V.	INSTITUTE OF WATER AND ECOLOGICAL PROBLEMS, FEBRAS	HYDROLOGY	RUSSIAN COLLABORATIONS	GROUND WATER MONITORING IN THE AMUR RIVER BASIN
SHESTERKIN, VLADIMIR P.	INSTITUTE OF WATER AND ECOLOGICAL PROBLEMS, FEBRAS	GEOCHEMISTRY	RUSSIAN COLLABORATIONS	GEOCHEMICAL ANALYSIS ON WATERS FROM AMUR RIVER
KIM, VLADIMIR.	INSTITUTE OF WATER AND ECOLOGICAL PROBLEMS, FEBRAS	GEOCHEMISTRY	RUSSIAN COLLABORATIONS	GEOCHEMICAL ANALYSIS ON WATERS FROM AMUR RIVER
BAKLANOV, PETER YA.	PACIFIC INSTITUTE OF GEOGRAPHY, EBRAS	ECONOMIC GEOGRAPHY	RUSSIAN COLLABORATIONS	ECONOMIC GEOGRAPHICAL ANALYSIS ON AMUR RIVER BASIN
GANZEI, SERGRY S.	PACIFIC INSTITUTE OF GEOGRAPHY, EBRAS	HUMAN GEOGRAPHY	RUSSIAN COLLABORATIONS	LAND-USE CHANGES IN THE AMUR RIVER BASIN AND ITS TRANSBOUDARY PROBLEMS

EMORSHIN, VICTOR V.	PACIFIC INSTITUTE OF GEOGRAPHY, EBRAS	GEOGRAPHICAL INFORMATION SYSTEM	RUSSIAN COLLABOR ATIONS	GIS COMPILATION OF LAND-USES IN THE AMUR RIVER BASIN
MISHINA, NATALIA.	PACIFIC INSTITUTE OF GEOGRAPHY, EBRAS	HUMAN GEOGRAPHY	RUSSIAN COLLABOR ATIONS	LAND-USE CHANGES AND THE ANALYSIS ON MATERIAL FLOWS IN THE FAR EAST
ISHONIN, MIKHAIL.	ROSHYDROMET	METEOROLOGY	RUSSIAN COLLABOR ATIONS	AEROSOL MONITORING IN KAMCHATKA
GAVRILOV, ALEXANDR V.	ROSHYDROMET	HYDROMETEOROL OGY	RUSSIAN COLLABOR ATIONS	HYDRO-GEOCHEMICAL MONITORING IN THE AMUR RIVER
VOLKOV, YURI N.	FAR EASTERN HYDROMETEOROGICAL RESEARCH INSTITUTE	PHYSICAL OCEANOGRAPHY	RUSSIAN COLLABOR ATIONS	OCEANOGRAPHIC OBSERVATIONS IN THE SEA OF OKHOTSK
YAROSLAV, D. MURAVYEV.	INSTITUTE OF VOLCANOLOGY SEISMOLOGY	GLACIOLOGY	RUSSIAN COLLABOR ATIONS	ICE CORE DRILLING IN KAMCHATKA
ZHANG, BAI	NORTHEAST INSTITUTE OF GEOGRAPHY AND AGRICULTURE ECOLOGY, CAS	GEOGRAPHY	CHINESE COLLABOR ATIONS	LAND-USE CHANGES IN SANJIYANG PLAIN
YAN, BAIXING	NORTHEAST INSTITUTE OF GEOGRAPHY AND AGRICULTURE ECOLOGY, CAS	GEOCHEMISTRY	CHINESE COLLABOR ATIONS	GEOCHEMICAL ANALYSES OF WATERS IN SANJIANG PLAIN
WANG, DEXUAN	NORTHEAST INSTITUTE OF GEOGRAPHY AND AGRICULTURE ECOLOGY, CAS	GEOCHEMISTRY	CHINESE COLLABOR ATIONS	GEOCHEMICAL ANALYSIS OF INTERNATIONAL WATERS IN SANJIANG PLAIN
WANG, ZONGMING	NORTHEAST INSTITUTE OF GEOGRAPHY AND AGRICULTURE ECOLOGY, CAS	GEOGRAPHICAL INFORMATION SYSTEM	CHINESE COLLABOR ATIONS	GIS-BASED ANALYSIS ON LAND-USE CHANGES IN HELONGJYIANG PROVINCE
CHEN, XIN	INSTITUTE OF APPLIED ECOLOGY, CHINESE ACADEMY OF SCIENCES	GEOCHEMISTRY	CHINESE COLLABOR ATIONS	GEOCHEMICAL ANALYSIS OF SOILS AT SANJIANG PLAIN
CHEN, LIJUN	INSTITUTE OF APPLIED ECOLOGY, CHINESE ACADEMY OF SCIENCES	GEOCHEMISTRY	CHINESE COLLABOR ATIONS	GEOCHEMICAL ANALYSIS OF SOILS AT IN HEILONGJIYANG PROVINCE
CAI TIJIU	NORTHEAST FOREST UNIV.	HYDROLOGY	CHINESE COLLABOR ATIONS	HYDROGEOCHEMICAL ANLYSIS ON WATERS FROM CHINESE FORESTS
GUO QINGXI	NORTHEAST FOREST UNIV.	HYDROLOGY	CHINESE COLLABOR ATIONS	HYDROGEOCHEMICAL ANLYSIS ON WATERS FROM CHINESE FORESTS
HU HAIQING	NORTHEAST FOREST UNIV.	FORESTRY	CHINESE COLLABOR ATIONS	RECONSTRUCTION OF FOREST FIRE IN THE NORTHEAST OF CHINA
GU JINFENG	NORTHEAST FOREST UNIV.	FORESTRY	CHINESE COLLABOR ATIONS	RECONSTRUCTION OF FOREST FIRE IN THE NORTHEAST OF CHINA
SHI, FUCHEN	NANKAI UNIV.	PLANT ECOLOGY	CHINESE COLLABOR ATIONS	FOREST ECOLOGY IN THE NORTHEAST OF CHINA
XU, XIAONIU	ANHUI AGRICULTURAL UNIVERSITY	GEOCHEMISTRY	CHINESE COLLABOR ATIONS	GEOCHEMICAL ANALYSIS ON WATERS FROM CHINESE FOREST