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Diagrammatic Representation of Environmental Monitoring Data

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The marked increase in the number of environmental problems, combined with the increase in their intensity and spatial extent, has resulted in an ever-increasing need for constant monitoring. This is complicated by the occurrence of new and complicated environmental issues that often prevent a thorough understanding of the entire monitoring framework. In the present study, a diagrammatic method was developed to present the entire framework of a monitoring plan. The diagram was separated into three sections-"Problem Section", "Research Process and Data Section" and "Entities Section"-to clearly present the disparate relationships between monitoring objectives and the monitoring procedure. Notation of the diagrams was undertaken using Unified Modeling Language (UML).

A hypothetical monitoring plan for an environmental problem was designed to assess usefulness of the diagrammatic method. The diagram was capable of reviewing and revising the monitoring plan and could be used to select a monitoring procedure according to the monitoring objectives of the plan. The results suggested that this diagrammatic method was effective for designing an appropriate monitoring plan for a given monitoring objective.

Key words : UML, planning of monitoring, data management, interdisciplinary study

INTRODUCTION

The ever-increasing complexity of new and extant environmental problems has resulted in the need for environmental monitoring programs that are sufficiently expansive, yet also sufficiently flexible, for dealing with a wide variety environmental problems (Jørgensen and Vollenweider, 1989). This is important because the volume and variety of data collected, and often the area under observation itself, are constantly increasing in a monitoring program. For example, use of river basin management-a concept that regards an entire river basin as the fundamental unit of management-has been proposed as a means of solving widespread environmental problems such as eutrophication (Mostert *et al.*, 1999). If the concept is applied, great consideration must be given to the choice of appropriate data, the observation period and monitoring interval in the event of marked increases in the spatial extent of the initiative. This increase in the scale of monitoring often hinders an understanding of the entire monitoring framework, complicating both the application of various data and the ability to integrate research relative to the monitoring objective; despite the demand for environmental issues to be considered from various points of view and scientific disciplines. Consequently, a method for developing monitoring plans that can accommodate theses varying needs must be developed.

Some methods and systems have already been

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applied to the management of monitoring data in the limnological field. Geographic Information Systems (GIS) have been applied to the organization of spatial data, not only for scientific research, but also for management of freshwater ecosystems (Michener *et al*., 1994). Ecological informatics combines data accumulation with data analysis using information technologies, and has been applied to the analysis of lake and river ecosystems (Recknagel, 2003). Other techniques, such as an integrated method with which to arrange and distribute monitoring data using metadata and archives, have also been developed (Michener and Brunt, 2000). However, these methods and systems were used for management and the analysis of existing data, and not for planning monitoring initiatives. To resolve the problems related to large−scale monitoring programs, entire frameworks of the monitoring plans, especially the relationships between monitoring objectives and procedures, need to be clearly presented.

Several methods have been developed to manage complicated processes in various fields (industrial engineering (Nayatani *et al*., 1984), marketing (Senge, 1994), software engineering (OMG, 2003) and business modeling (Eriksson and Penker, 2000)). These methods employ diagrams to depict the main focus of a complicated process for management thereof. For example, arrow diagrams that represent the sequence of a focused process used in industrial engineering for quality control (Nayatani *et al*., 1984). When these methods are applied to planning limnological monitoring, and the entire framework of the monitoring plan have been graphically depicted, then the aforementioned problems associated with monitoring can be ameliorated. In the present study, a diagrammatic method was applied to present an entire framework for a hypothetical monitoring plan designed in response to a limnological environmental problem. The usefulness of the diagram as a means of accurately assessing the monitoring plan was then also verified.

METHODS

We used the exploitation of the littoral zone in Lake Biwa reported in Nakanishi and Sekino (1996) as an example to demonstrate the application of our technique to construct monitoring plans for environmental problems. A diagram was constructed to depict the entire framework of the proposed experimental monitoring plan using Unified Modeling Language (UML) notation (Version 1.5; OMG, 2003). An international standard (ISO/IEC 19501) and originally developed for software engineering, UML has been extensively used as a flexible diagrammatic modeling tool for depicting complex processes and relationships among various objects. Various diagram−types can be defined using UML to represent complicated process and subjects from several perspectives. Static structure diagrams were used to represent objects and their relationships to other objects. Objects that had both virtual and real attributes, such as eutrophication, fisheries and lakes, were expressed as classes in the diagram. Activity diagrams are used to express a sequence of actions. Actions in the model were expressed as activities and were connected to each other by arrows according to the sequence in which they occurred. These elements

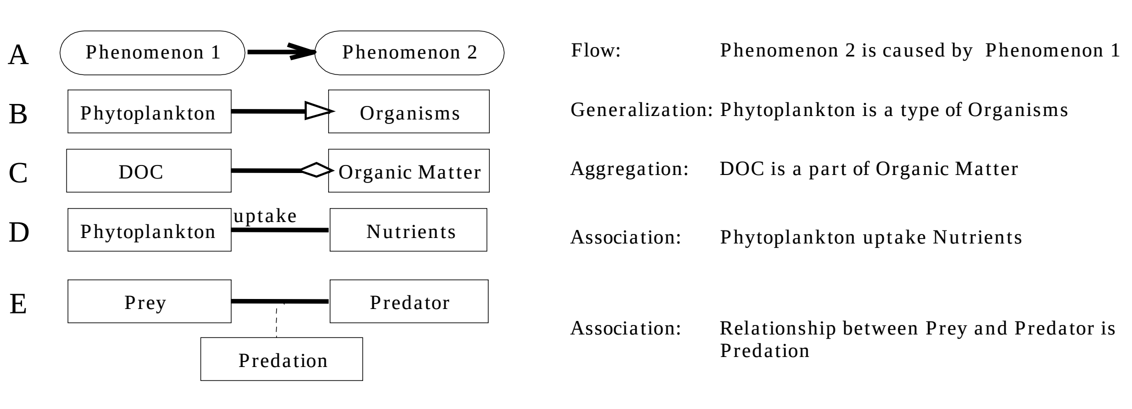

Fig. 1. Examples of UML syntax. These syntaxes were used to express relationships between elements in the diagram constructed in the present study.

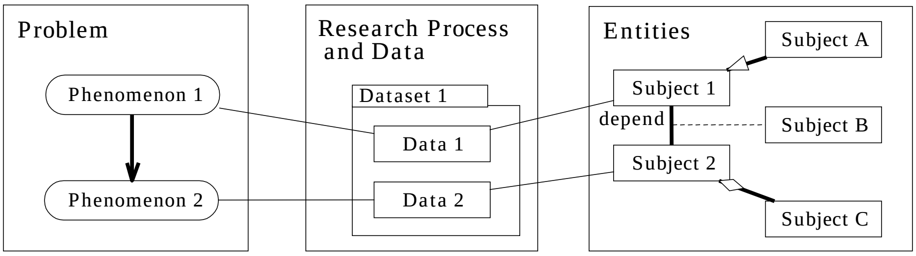

Fig. 2. The major sections of the diagram and an indication of the relationships between these sections.

were represented as having either square or rounded corners (Fig. 1)

The diagram constructed in the present study had to clarify the entire framework of the monitoring plan, especially the relationships between the monitoring objectives and procedures. Therefore, details of problems that were related to the monitoring objectives and monitoring data, such as phytoplankton flora, nutrient concentrations and water temperature, were presented separately in two sections titled, "Problem Section" and the "Research Process and Data Section" (Fig. 2). In the "Problem Section", a sequence of phenomena related to the objective problem was expressed as an UML activity diagram. Causalities between phenomena were expressed as relationships between activities (Syntax A, Fig. 1). In the "Research Process and Data Section", the various monitoring data types were expressed as UML classes, with a dataset expressed as a UML package containing more than one class of monitoring data (Fig. 2). A line that directly connected a class of monitoring data in the "Research Process and Data Section" with an activity of phenomenon in the "Problem Section" indicated that monitoring data could be used to express or prove the existence of a problem with one of the phenomena in the monitoring program. The monitoring plan could be designed based on relationships, not only between the objectives of problem monitoring and the various monitoring data, but also between the entities such as fish and lake water that were observed in the monitoring and monitoring data. Therefore, the observed entities were listed in a section titled, "Entities Section" as a UML static structure diagram. In the "Entities Section", generalization was taken as an expression of the conceptual relationship between entities, aggregation as the relationship between parts, and association as a specific relationship between entities (Syntax B−E, Fig 1). A line between a class of entity in the "Entities Section" and a class of monitoring data in the "Research Process and Data Section" indicated that the monitoring data had been obtained from observations of the entity.

RESULTS

A hypothetical monitoring plan designed in the present study to examine the processes associated with the environmental problem reported by Nakanishi and Sekino (1996). A diagram representing the entire framework of the monitoring plan was constructed (Fig. 3) and used to review and revise the monitoring plan. A diagram of the revised monitoring plan that includes additionally required monitoring data is shown in Fig. 4. The details of diagram construction, as well as the review and revision of the monitoring plan using the diagram, are as follows:

Diagram Construction

Phenomena contributing to the exploitation of the littoral zone of Lake Biwa were listed in the "Problem Section" based on a diagram presented in Nakanishi and Sekino (1996) that represents the process of the problem using similar notation of that employed for the "Problem Section" (Fig. 3). We attempted to enumerate monitoring data to identify or characterize each phenomenon listed in the "Problem Section" in the following step of diagram construction, listing the title of this monitoring data (e.g. "Nutrient concentration" or "Algal flora") in the "Research Process Section and Data", each time. Records of construction in the littoral zone held by the national and prefectural governments could be used to indicate

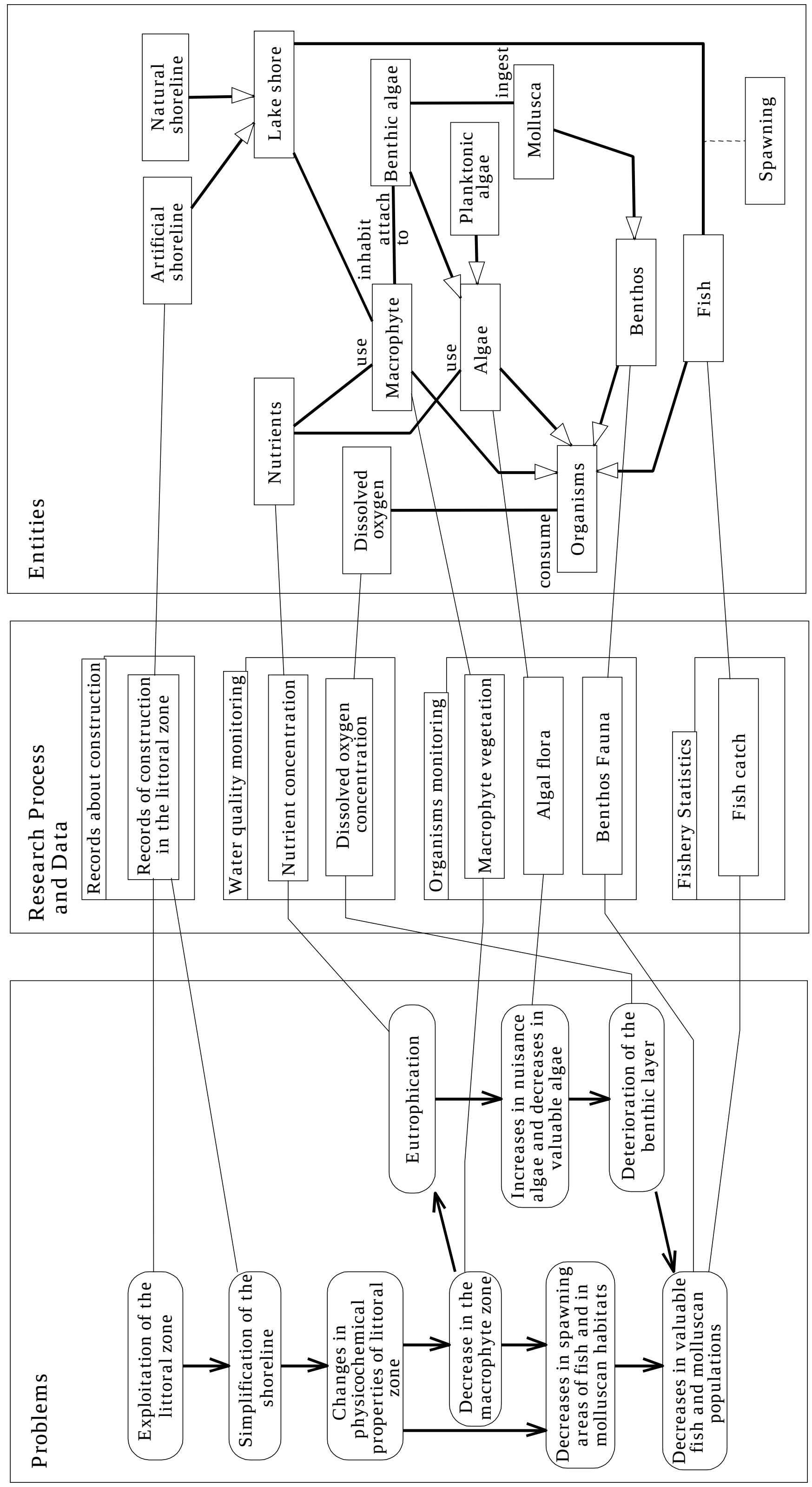

Fig. 3. Hypothetical monitoring plan depicting the exploitation of the littoral zone of a lake. Narrow lines between sections indicate a relationship between the problem, monitoring data and entities observed in the monitoring.

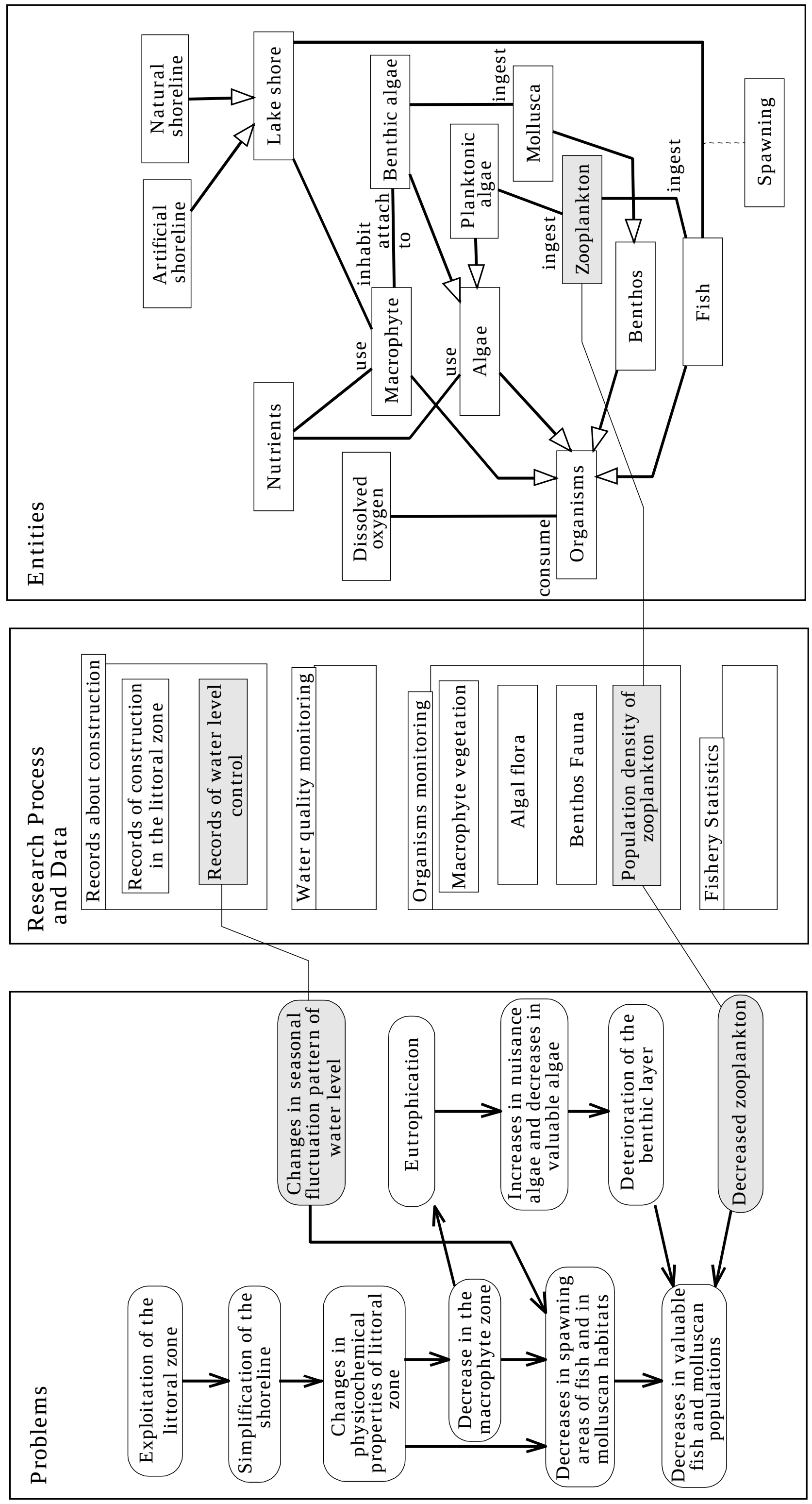

Fig. 4. Revised monitoring plan that includes additional monitoring data (shaded elements) found after reviewing the monitoring plan depicted in Figure 3. The new monitoring data are presented as they relate to existing processes associated with the problem. Monitoring data and lines between sections were omitted except where elements were related to the new monitoring data.

the frequency and details of the phenomena, “Exploitation of the littoral zone” and “Simplification of the shoreline”, and therefore, “Records of construction in the littoral zone” was presented as a monitoring data in the diagram (Fig. 3). Similarly, the magnitude of the phenomena of “Eutrophication” and “Deterioration of the benthic layer” could be deduced by monitoring nutrient and dissolved oxygen concentrations, respectively. The phenomenon of “Increased nuisance algae and decreased valuable algae” could be ascertained by monitoring algal flora, while, “A decrease in valuable fish and molluscan populations” could be ascertained from harvest data and fishery statistics published by the national and prefectural government and monitoring of benthic fauna.

Entities observed for monitoring data were subsequently listed as UML classes in the “Entities Section” in the next step of the diagram−constructing process. The class “Organisms” was then added to the “Entities Section” to represent the relationship between organisms (Macrophytes, Algae, Benthic fauna and Fish) and oxygen even though it was not monitored directly. The classes “Planktonic algae” and “Benthic algae” were also added to the “Entities Section” to more accurately represent the role of the entity, “Algae”.

Review and revision of the monitoring plan using the diagram

Although the diagram (Fig. 3) was made based on the study presented in Nakanishi and Sekino (1996), the possibility exists that phenomena that were not presented in their study and other new and potentially useful monitoring data could have been included to improve the monitoring plan. Furthermore, the possibility exists that omission or simplification of monitoring observations may sometimes be required because of cost and working efficiency considerations. Therefore, the monitoring plan developed here was reviewed and revised to ensure that it was capable of dealing with the various possibilities.

In the “Problem Section”, the two processes of spawning and eutrophication contributed to the final phenomenon of “Decreases in valuable fish and molluscan populations” (Fig. 3). When the importance of the processes of spawning and eutrophication were found to differ, this difference was incorporated into the monitoring plan. For instance, if the processes related to spawning were found to be more important than those related to eutrophication, monitoring of eutrophication (Nutrient concentration, Algal flora and Dissolved oxygen concentration) could be reduced or omitted to mitigate costs or improve working efficiency.

When records of water level control was included in the “Records of construction events” dataset then this data was incorporated into the monitoring plan because seasonal fluctuations in water level affects fish spawning and the growth of juvenile fish (Yamamoto, 2002). Given that fluctuations in water level affect the phenomenon, “Decrease in spawning areas of fish and molluscan habitat”, a new phenomenon called “Artificial water level control” could be added to the “Problem Section” as a phenomenon that affects “Decrease in spawning areas of fish and in molluscan habitat” (Fig. 4).

In the “Entities Section”, the need for the inclusion of zooplankton connecting planktonic algae and fishes in the food chain is obvious. This is due to the very direct link that exists between changes in fish population density and food resources. Consequently, a category of monitoring data called “Population density of zooplankton” should also be incorporated into the monitoring plan. Influence of zooplankton population density could also be listed in the “Problem Section” as a relationship between the phenomena of “Decreased zooplankton” and “Decrease in valuable fish and molluscan populations” exists (Fig. 4).

DISCUSSION

In the present study, a hypothetical monitoring plan was designed and presented as a diagram in which a “Problem Section”, “Research Process and Data Section” and “Entities Section” were all represented separately (Fig. 3). The structure of the monitoring plan was reviewed and additional monitoring data, included to improve the monitoring plan, were identified. Furthermore, the difference in importance of the various processes associated with the objective problem could be incorporated into the monitoring plan using the diagram. These revisions of the monitoring plan were represented as they related to the objective problem (Fig. 4). It was found that the diagrammatic method described here could be used for representing the entire monitoring framework and also for flexibility in dealing with the necessary revisions to the monitoring plan caused by cost and working efficiency constraints, as well as other factors.

In the present study, the “Problem Section” was developed in response to a process presented in Nakanishi and Sekino (1996). In the same way that the present study developed the “Problem Section” by employing data derived from another study, so too can other papers, proceedings of conferences and discussion among persons be employed to design a monitoring plan. Since monitoring programs for specific environmental problems often require a hypothetical process, such as the process presented by Nakanishi and Sekino (1996) to solve a problem, the “Problem Section” can be easily be adapted to accommodate hypothetical processes. However, monitoring programs are often designed to collect baseline or background data and not to monitor a particular environmental problem. Therefore, it is difficult to develop a “Problem Section” when a monitoring plan is designed for these programs. In such an instance, it may be easier to construct the diagram in the opposite direction of the approach adopted in the present study i.e. the “Entities Section” would be written before the other two sections (“Problem Section” and “Research Process and Data Section”). The procedure required for adopting this diagrammatic method for the development of a monitoring program to collect baseline or background data such as Long Term Ecological Research (see web page URL−http://lternet.edu) will be the subject of future study.

The diagram in the present study contained many elements and lines, and was complicated even though we did not present all monitoring data relating with phenomenon in the “Problem Section” due to space limitations. Therefore, a method for arranging elements in the diagram is required. Emphasis on focused elements and omission of non−focused elements are one solution for arranging such a complicated diagram (Fig. 4). However, the omission or simplification of the elements in the diagram increases the risk of misunderstanding arising. Another solution for simplifying the layout of the diagram is by employing pattern language (Alexander *et al*., 1977). Pattern language is a method in which subjects and procedures that are often closely associated with each other are put together to form a particular pattern. Any subsequent treatments applied to either of these components will henceforth be applied to the level of the pattern and thus to both components simultaneously. For instance, eutrophication is common in many lakes and is often associated with parameters that are monitored commonly (transparency, nutrient concentrations, and chlorophyll concentrations and dissolved oxygen concentrations). The processes and procedures required for monitoring the progress of eutrophication can be grouped together and regarded as a single pattern. Although the idea of the pattern origi-nated in architecture (Alexander *et al*., 1977), it has recently been applied to various fields (software development (Gamma *et al*., 1995) and organization management (Kim and Anderson, 1998)). When the idea of pattern is applied to the diagrammatic method in the present study, a series of relationships between the problems and their solutions are expressed as a pattern, and the diagram can then be simplified systematically. Such use of pattern and the notation thereof will also be examined in the following study.

The diagram can be used to depict the entire framework of the monitoring plan, not only for the benefit of the designers of the monitoring plan, but for also parties not directly involved with the execution of the monitoring plan. Many interdisciplinary projects that aim at studying interactions between the natural environment and human activities have been started in recent years. ESSP (Earth System Science Partnership), an international project directed at studying environmental issues, consists of four research programs: IGBP (International Geosphere−Biosphere Programme), WRCP (World Climate Research Programme), IHDP (International Human Dimensions Programme on Global Environmental Change) and DIVERISTAS (an integrated programme of biodiversity science) (see URL at http://www.ess−p.org). In these projects communication between researchers, often from disparate scientific fields, is essential. The diagrammatic method described here could be applied to such interdisciplinary projects to enhance the understanding of the monitoring plan by researchers from different scientific fields and to promote application of data between scientific fields.

Limnological monitoring is highly dependent upon the tacit knowledge, experience and expertise of limnologists (Polanyi, 1966). Consequently, new methods are required to explain and convey this tacit knowledge to others. Knowledge management system applied to the dissemination of tacit knowledge is a fine example of such a method (Awad and Ghaziri, 2003). The diagrammatic method proposed in the present study can also be regarded as a method through which the tacit knowledge of limnologists can be accessed. Environmental issues related to limnology become complicated and require prompt action. Consequently, limnologists should share their tacit knowledge and improve the efficiency with which they apply their knowledge to such issues. The development of methods to manage tacit knowledge in limnology, like the diagrammatic method in the present study, should thus be advocated.

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